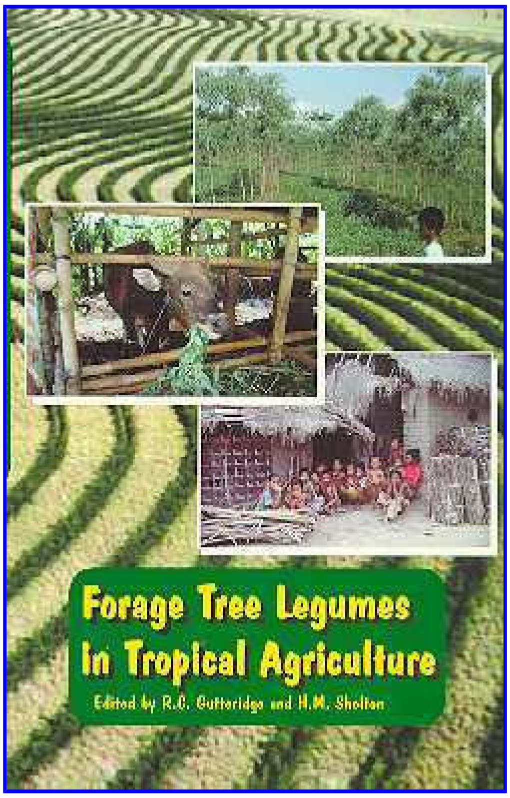
Forage Tree Legumes in Tropical Agriculture



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Cover photographs:
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Top: Sesbania grandiflora growing on bunds in irrigated terraces on Lombok, Indonesia for timber and cattle feed, by Ross Gutteridge.
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Forage tree legumes in tropical agriculture

Preface

Over the past 10-15 years, interest and research activity in the use of tree legumes in tropical agriculture has grown exponentially. Multipurpose tree legumes are increasingly recognised for their capacity to enhance the productivity and sustainability of tropical agricultural systems, both in developed and less developed countries of the world.

Tree legumes can provide fuelwood, nutrient-rich mulch, erosion control and land stabilisation, as well as other products such as food and fencing materials for farmers. However, one of their major uses is as a source of high quality forage for ruminants. In developing countries, forage tree legumes contribute high protein herbage to supplement crop residues and other low quality feeds. In developed countries, tree legumes can provide the basis for highly productive intensive grazing systems.

In recognition of this interest, The University of Queensland conducted international training courses in 1990 and 1992 entitled *Fodder Tree Legumes-Multipurpose Species for Agriculture.* Scientists from The University of Queensland, Queensland Department of Primary Industries, CSIRO and the Queensland Forest Service contributed to the course. Participants were agronomists, animal nutritionists, agroforesters and extension personnel from over 20 countries.

The course comprised a series of lectures, practical demonstrations and field visits to familiarise participants with the production and use of tree legumes. The text of this book is a compilation and expansion of the material presented at the course together with contributions from leading scientists in the field working in other regions of the world. The book therefore provides a comprehensive coverage of the latest information on the major tropical forage tree legume species, and their evaluation and utilisation in sustainable agricultural production systems.

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Abbreviations

ACIAR	Australian Centre for International Agricultural Research
ADF	acid detergent fibre
CATIE	Centro Agronomico Tropical De Investigacion y Enseñanza
CGIAR	Consultative Group for International Agricultural Research
CIAT	Centro Internacional de Agricultura Tropical
CPI	Commonwealth Plant Introduction Number
CSIRO	Commonwealth Scientific and Industrial Research Organization
DENR	Department of Environment and Natural Resources (The Philippines)
DHP	3-hydroxy-4(1H)-pyridone
FAO	Food and Agriculture Organization
ICRAF	International Centre for Research in Agroforestry
IDRC	International Development Research Centre
IITA	International Institute for Tropical Agriculture
ILCA	International Livestock Centre for Africa
K	Hawaiian Plant Introduction Designation e.g. K8, K636
LSD	least significant difference
MBRLC	Mindanao Baptist Rural Life Center
NAS	National Academy of Sciences
NDF	neutral detergent fibre
NFT	Nitrogen Fixing Tree
NFTA	Nitrogen Fixing Tree Association
ODA	Overseas Development Administration
OFI	Oxford Forestry Institute
PEG	polyethylene glycol
QDPI	Queensland Department of Primary Industries
SALT	Sloping Agricultural Land Technology
UNDP	United Nations Development Programme
VAM	vesicular arbuscular mycorrhizae

1.1 The Role of Forage Tree Legumes in Cropping and Grazing Systems

R.C. Gutteridge and H.M. Shelton

Introduction

Legumes have been used in agriculture since ancient times. Legume seeds or pulses were among the first sources of human food and their domestication and cultivation in many areas occurred at the same time as that of the major cereals. Nutritionally they are 2-3 times richer in protein than cereal grains and many also contain oil. Leguminous mulches have always been used as a source of nutrient-rich organic matter and nitrogen for crops. In more recent times, legumes have become important as high quality forages for livestock both in cultivated pastures and in naturally occurring associations.

Of all plants used by man, only the grasses are more important than the legumes but it is the legumes that show the most promise for future exploitation and development.

The legumes are the third largest group of flowering plants comprising over 18,000 species in 650 genera which are well distributed in most environments throughout the world. Taxonomists have divided the legumes into three families:

- The **Caesalpiniaceae** contains about 2,800 species, most of which are trees of tropical savannahs and forests of Africa, South America and Asia (Williams 1983).

- **Mimosaceae** also contains about 2,800 species. These are predominantly small trees and shrubs of semiarid tropical regions of Africa, the Americas and Australia. *Acacia* species are the best known examples of this family.

- **Fabaceae** contains over 12,000 species, mainly herbs and small shrubs distributed worldwide, and includes the well-known grain legumes such as beans and peas.

Legumes in agriculture

Nitrogen is the most limiting element in agricultural production, and deficiency reduces the productivity of crops, pastures and animals. There are several potential sources of nitrogen to overcome this shortfall, namely:

- N from the mineralisation of soil organic matter,
- N from artificial fertilisers,
- N from biological nitrogen fixation in legumes, and
- N from organisms associated with tropical grasses.

Of these, N from soil is often insufficient for plant growth especially in most tropical soils which are low in organic matter. N from organisms associated with grasses is a minor source. Fertiliser N and N fixed by legumes are the largest potential sources with the latter being the cheapest source. Biologically fixed N is transformed into leguminous protein and this may be consumed directly by animals to meet their protein requirements and the excess returned to the soil via animal wastes. Alternatively, N may be returned directly to the soil as organic mulch.

Since few other plant families include species with a nitrogen fixing ability, legumes produce most biologically fixed nitrogen and are therefore crucial to maintaining the N-balance in nature. In Australia, Steele and Vallis (1988) estimated annual use of 35,000 t of artificial fertiliser N on pastures compared with 1.2 Mt of N derived from biological nitrogen fixation. Very high yielding leguminous crops can add up to 500 kg of nitrogen to the soil per hectare per year (NAS 1979) although inputs of 100-300 kg N/ha/year from good quality legume-based pasture would be a more realistic expectation (Steele and Vallis 1988). Legume associations are therefore vital to sustaining soil nitrogen fertility over long periods. The practice of shifting cultivation, traditional in many countries, is heavily dependent on the leguminous component of the primary and secondary forest cover for fertility restoration.

Another advantage of legumes is their high quality for animal production. The nutritive value of legumes is measured in terms of the potential intake of digestible dry herbage and, in general, legumes have both higher digestibility and higher intake than grasses and their nutritive value tends to remain higher as plants mature.

Tree legumes

Until recently, tree legumes were largely neglected by researchers because their utilisation and management fell between the disciplines of forestry and pasture agronomy. They are now receiving increased research attention because of their multipurpose value and some distinctive features which set them apart from herbaceous legumes. Their special characteristics may be summarised as follows:

Tree legumes

- are usually long-lived and low maintenance, and therefore enhance the sustainability of farming systems,

- provide high quality forage for feeding of livestock,

- stabilise sloping lands against erosion because of their deep-rooted habit,

- supply N-rich mulch for cropping systems,

- can be used to colonise and rehabilitate adverse environments, e.g. saline or arid locations,

- provide a source of timber and firewood for either domestic or industrial use,

- are used in farming systems as living fences, as shade trees for plantation crops, and as living trellises for climbing crops, and

- are a source of fruit and vegetables for human consumption (Figure 1.1.1).

Tree legumes can therefore be regarded as truly multipurpose trees for agriculture. These features of tree legumes will now be discussed separately.

Fig. 1.1.1. Pods of tree legume sold for human consumption in Indonesia.

Tree Legumes as Forage for Animals

The role of browse in natural grazing systems

Trees and shrubs have provided valuable forage to man's herbivorous animals probably since the time of their domestication (Robinson 1985). At least 75% of the shrubs and trees of Africa serve as browse plants and many of these are leguminous (Skerman 1977).

The overall importance of browse was summarised in the Commonwealth Agricultural Bureaux statement (1947) 'more animals feed on shrubs and trees or on associations in which shrubs and trees play an important role than on true grasslands'. McKell (1980) pointed out that shrubs and trees are the most visible plant forms in many landscapes, yet have been neglected in most scientific research. Much research effort has concentrated on methods for their eradication. In some arid and semiarid climates, livestock would not exist without browse species to supply feed.

Browse has been defined as the leaves, shoots and sprouts including tender twigs and stems of woody plants which are cropped to a varying extent by domestic and wild animals. It should be extended to include the fruit, pods and seeds which provide valuable feed, especially if the tree is deciduous.

Many tree legume species have evolved in semiarid regions alongside herbivorous animals and therefore have developed means of protection against browsing or grazing. Among the protective devices are thorns, toxins, fibrous foliage and height of tree crowns (Brewbaker 1986). Thorns characterise many woody legumes and are particularly prevalent on juvenile plants. Toxins are of two general types, those which deter feeding and those which poison the animal.

The nutritional quality of tree legumes varies from excellent (*Leucaena leucocephala*) *to* quite poor (most Australian *Acacia* species). Poor quality can be due to tannins which reduce the digestibility of both herbage and protein. The presence of tannins is often evident as brownish, reddish tinges in juvenile growth. Another reason for poor quality is that some species have phyllodes (expanded and flattened leaf petioles) instead of compound pinnate or bipinnate leaves which are very high in fibre and therefore of low digestibility, e.g. the Australian acacias.

Forage from tree legumes is often used as a buffer to overcome feed gaps that arise from seasonal fluctuations in the productivity of other feed sources. For example, grasses and other herbs may die when upper soil layers lose their moisture but the deep-rooted trees exploit moisture at depth and continue to grow. During the dry season or in times of drought, trees provide green forage rich in protein, minerals and vitamins while the herbaceous cover provides only poor quality straw.

The use of naturally occurring browse species is a vital component of livestock production systems in many regions of the world. In the Sahelian savannahs in Africa from Senegal to the Sudan, *Faidherbia albida* is a native leguminous species which is extremely important both in providing forage for livestock and in enhancing soil fertility for crops. *Prosopis* species provide forage for the sheep and cattle industries of the arid subtropical plains of Brazil, Argentina, Uruguay and Northern Chile. *Prosopis chilensis* contributes regular cattle feed in northwest Argentina and central Chile while *P. tamarugo,* a native of Chile's northern plateau, is the only tree that survives on the arid salt flats producing the only available forage, timber and fuelwood in that region. In southwestern Queensland and northern New South Wales, mulga (*Acacia aneura*) occurs naturally often in monospecific stands and is used as a drought reserve for grazing sheep (see Section 7.1).

Under natural conditions, a large proportion of the foliage of tree species will be out of reach of grazing animals so utilisation can be manipulated by cutting or lopping to make it available when needed. Sometimes natural leaf fall through senescence is an important day-to-day component of the diet of some grazing animals. In Africa, goats thrive on the leaf fall of *Acacia melliflora* (Dougall and Bogden 1958).

Tree legumes as planted forage in cropping and grazing systems

As well as naturally occurring stands, tree legumes are often planted specifically for forage both in extensive grazing systems and in association with crops.

In many of the more intensive agricultural areas of Asia and Africa, where livestock are raised in small numbers by smallholder farmers, tree legumes are planted as 'forage banks' on unused land along field borders or fence lines, on rice paddy bunds or in home gardens. These areas are usually harvested under a 'cut-and-carry' system and are a principal source of high quality forage used to supplement low quality roughages such as crop residues. Productivity from these areas can be quite high. In the Batangas region of the Philippines, a 2 ha area of *Leucaena leucocephala* grown in association with the fruit tree *Anona squamosa* was able to supply the forage requirements of 20 growing cattle over a 6 month period (Moog 1985). At Ibadan in Nigeria, Reynolds and Atta-Krah (1986) suggested that the surplus foliage produced over a year from 1 ha of *Leucaena leucocephala* and *Gliricidia sepium* planted at 4 m intervals in an alley cropping system could be used as a supplement to provide half the daily forage requirements for 29 goats.

In many of these intensive cropping areas, tree legumes are planted not only for their forage but also for firewood, green manure and other uses.

In the more extensive grazing areas of Australia, southern Africa and South America, tree legumes are increasingly being planted in association with improved grasses to increase carrying capacity and productivity of grazing cattle. In central Queensland, over 20,000 ha have been sown to *Leucaena leucocephala* in the past 10 years. The leucaena is sown in wide spaced rows 4-10 m apart and an improved grass such as green panic (*Panicum maximum* var. *trichoglume*)*,* Rhodes grass (*Chloris gayana*)*,* buffer grass (*Cenchrus ciliaris*) or signal grass (*Brachiaria decumbens*) sown between the leucaena rows. A high stocking rate (up to 3-4 animals/ha) and liveweight gain (up to 1 kg/head/day) can be achieved with this system. A record liveweight gain of 1,442 kg/ha for cattle grazing a grass/legume pasture was achieved on an irrigated leucaena/pangola grass mixture in the Ord River District of north Western Australia (Jones 1986).

Other tree legume species that are being investigated for use in extensive grazing systems include *Calliandra calothyrsus* (Section 2.4), *Albizia chinensis, Cajanus cajan, Gliricidia sepium* (Section 2.2) and *Sesbania sesban* (Section 2.3).

Tree Legumes and the Environment

Degradation of natural systems

Unfortunately, due in large part to over-exploitation by both people and livestock, valuable tree and shrub resources over vast areas in arid and semiarid regions have been destroyed in the last few decades. In these areas, it is important that management practices are adopted which foster the wise use of diminishing tree and shrub resources. Livestock access should be restricted, and pruning and harvesting of products performed on a rotational basis, to ensure time for regeneration.

In some cases, the presence of tree legumes has contributed to the degradation of the landscape. Animals can be maintained long after the loss of palatable perennial grass species due to drought or overgrazing, by feeding the foliage of hardy tree species. Vast areas of southwestern Queensland and East Africa have been degraded in this way.

Soil reclamation and erosion control

The restoration and maintenance of soil fertility is a basic and critical environmental problem. It is especially serious in tropical and subtropical regions where many soils lack plant nutrients and organic matter and intense rainfall erodes vulnerable top soil.

The nitrogen fixing ability of tree legumes allows them to grow on difficult sites subject to erosion, low fertility or other adverse soil conditions. Once established, they can create conditions favourable for the growth of other species leading to a balanced plant ecosystem. Tree legumes are a good source of organic matter for green manure. Their dry foliage contains 2.5-5.5% N and leaf material incorporated into the soil improves fertility, moisture and nutrient retention and general filth. At the same time, by improving soil structure, erosion can be retarded.

The extensive root systems of tree legumes enable them to adapt to steeply sloping sites unsuited to conventional cropping or grazing thus stabilising the sites from erosion and providing a measure of production which would not otherwise exist. The Sloping Agricultural Land Technology (SALT) developed in the Philippines (Tacio *et al.* 1987) is a prime example of the use of tree legumes in substantially reducing soil erosion and restoring moderately degraded hilly lands to a profitable farming system (see Section 7.5).

Tree Legumes for Fuelwood

It has been estimated (Eckholm 1975) that at least half the timber cut in the world is used as a fuel for cooking and heating. Approximately 2 billion people derive at least 90% of their energy requirements from wood and charcoal while a further 1.5 billion meet at least 50% of their requirements this way.

This essential resource, however, is seriously threatened. If the pace of tree planting around the world is not greatly accelerated, at least 500 million people will be without fuelwood for their minimum cooking and heating needs by the end of the century.

Tree legumes offer a partial solution to the fuelwood crisis. Of the 88 species recommended for fuelwood production by the National Academy of Sciences (1980, 1983), almost half were tree legumes. Tree legumes also meet many of the characteristics which are considered desirable in fuelwood species which include:

- rapid growth,
- nitrogen fixing ability,
- ease of establishment,
- ability to coppice,
- wood of high calorific value,
- wood which burns without sparks or toxic smoke,
- ability to grow well in a wide range of environments including difficult sites,
- multipurpose nature.

Tree legumes have been used successfully in sustained fuelwood production systems. In the early 1920s, in the Paliparan area of the Philippines, *Leucaena leucocephala* was planted over a large area of unproductive *Imperata cylindrica* grassland. Since then it has yielded on average 20 m^3 of fuelwood per hectare per year and is still the main source of fuel for the city of Laguna (NAS 1980) although recent damage by the leucaena psyllid (Section 6.1) has reduced the production of wood.

Other tree legumes that are highly regarded as fuelwood species include *Acacia auriculiformis, A. saligna, A. senegal, A. tortilis, Calliandra calothyrsus, Cassia siamea, Pithocellobium dulce* and *Prosopis* spp.

Conclusions

Tree legumes have an important role in many agricultural production systems throughout the world. They can be used in a multitude of ways including providing high quality forage to animals, contributing rich organic mulches to improve cropping land, stabilisation, of sloping landscapes from erosion, rehabilitation of degraded or saline lands, providing firewood or poles for construction, or as living plants for shade or fence lines.

Most of these topics are covered in greater detail in the following chapters of this book

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2.1 Leucaena leucocephala - the Most Widely Used Forage Tree Legume

H.M. Shelton and J.L. Brewbaker

Introduction

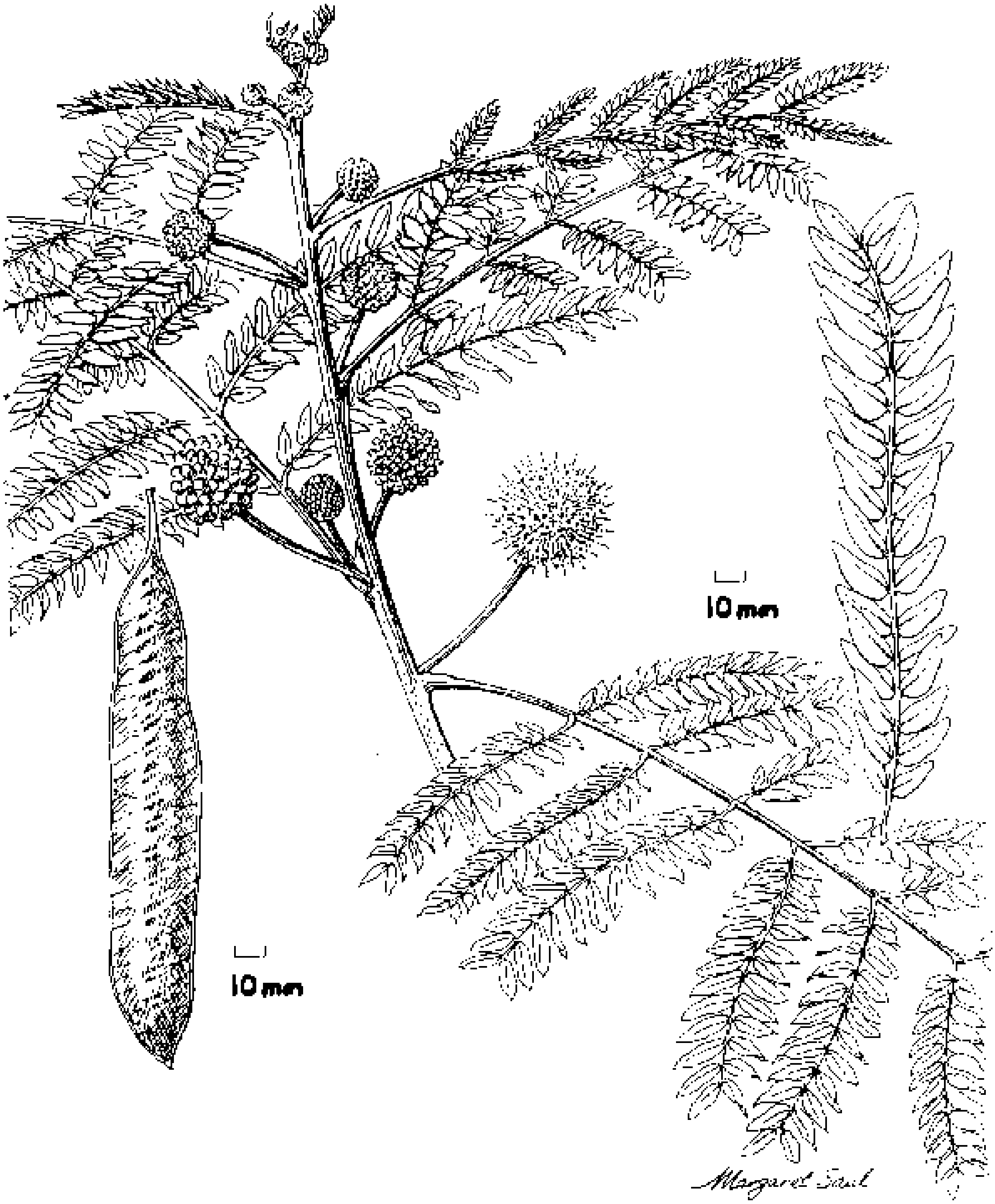
During the 1970s and early 1980s, *Leucaena leucocephala* (Lam.) de Wit (leucaena) was known as the 'miracle tree' because of its worldwide success as a long-lived and highly nutritious forage tree, and its great variety of other uses. As well as forage, leucaena can provide firewood, timber, human food, green manure, shade and erosion control. It is estimated to cover 2-5 million ha worldwide (Brewbaker and Sorensson 1990). However, a better understanding of its constraints, particularly the arrival of the psyllid insect, has now given us a more balanced view of the value of this species.

Leucaena has its origins in Central America and the Yucatan Peninsula of Mexico where its fodder value was recognised over 400 years ago by the Spanish conquistadores who carried leucaena feed and seed on their galleons to the Philippines to feed their stock (Brewbaker *et al.* 1985). From there it has spread to most countries of the tropical world where leucaena was used as a shade plant for plantation crops. It was introduced into Australia in the late 19th century and it was naturalised in parts of northern Australia by 1920 (White 1937).

Botanical Description and Genetic Variation

Leucaena leucocephala, formerly known as *L. glauca,* is a thornless long-lived shrub or tree which may grow to heights of 7-18 m. Leaves are bipinnate with 6-8 pairs of pinnae bearing 11-23 pairs of leaflets 8-16 mm long. The inflorescence is a cream coloured globular shape which produces a cluster of flat brown pods 13-18 mm long containing 15-30 seeds (Figure 2.1.1). Botanically, leucaena belongs to the family Mimosaceae; it is the best known species of the *Leucaena* genus and has a variety of common names (Table 2.1.1). There are, however, at least 14 other species recognised in the genus.

Fig. 2.1.1. Leaves, flowers and pod *of Leucaena leucocephala.*



These are *L. collinsii, L. cuspidata, L. diversifolia, L. esculenta, L. greggii, L. lanceolata, L. macrophylla, L. multicapitula, L. retusa, L. pallida, L. pulverulenta, L. salvadorensis, L. shannoni* and *L. trichodes. Leucaena leucocephala* and *L. pallida,* and one subspecies of *L. diversifolia,* are polyploids (104 chromosomes) while all other species are diploid (52 or 56 chromosomes). *Leucaena leucocephala* and the tetraploid varieties of *L. diversifolia* are self-pollinating while the others are outcrossing.

Table 2.1.1. Some common names of *Leucaena leucocephala*.) de Wit. (Brewbaker *et al. 1985*).

Common name	Countries
Leucaena	Australia, United States
Ipil ipil	Philippines
Lamtoro	Indonesia

Katin	Thailand
Yin ho huan	China
Kubabul, or subabul	India
Koa haole	Hawaii
Tangantangan	Some Pacific islands
Cassis	Vanuatu
Guaje	Mexico
Huaxin	Central America (Maya)

The species may be distinguished on the basis of their tree size, flower colour, leaflet size and pod size (Anon. 1990). These same authors consider the genus *Leucaena* to be an interbreeding complex capable of producing many interspecific hybrids. For instance, *L. leucocephala* crosses readily with *L. diversifolia* and *L. pallida* producing hybrids from which selection for improved growth form, psyllid resistance and cold tolerance is possible. *Leucaena pallida,* in particular, has excellent seedling vigour and hybridisation of this species with *L. leucocephala* has the potential to produce a new highly productive and psyllid resistant Leucaena (Sorensson *et al.* 1993).

There are two forms of the species *L. leucocephala* The most common is the shrubby free-seeding form or 'common' leucaena which tends to be weedy and low yielding (Jones 1979). It was this common form of leucaena which was transported around the world from the 16th to 19th centuries and is now pantropical in distribution. Australians have referred to Peruvian types which are multibranched, leafy, of medium height (3-8 m) and more productive than the common type. Cultivars Peru and Cunningham are examples released by CSIRO in Australia in the 1960s. However, we contend that these varieties are really well branched giant leucaenas. The true giant types are tall (up to 20 m) and sparsely branched with better forage and wood production than the shorter varieties. Examples are K8 and K636.

Uses

Leucaena leucocephala has a wide variety of uses and it was this multiplicity of roles that led to the worldwide reputation of the species as a 'miracle tree'.

First and foremost, the leaves of leucaena are highly nutritious for ruminants and many excellent animal production data have been published confirming the fodder value of leucaena (see Chapter 4). Secondly, leucaena can be used in cropping systems. Contour strips of leucaena have been employed for many years in the Philippines and in Timor and Flores in Indonesia. The strips serve as erosion control on steep slopes and as a form of alley cropping in which leucaena foliage is mulched into the soil to enhance yields of inter-row crops. On some islands of eastern Indonesia, thickets of leucaena are regularly burnt prior to planting crops in an advanced form of 'slash-and-bum' agriculture. The use of leucaena in cropping systems is discussed in detail in Chapter 5.

Leucaena is capable of producing a large volume of a medium-light hardwood for fuel (specific gravity of 0.5-0.75) with low moisture and a high heating value, and makes excellent charcoal, producing little ash and smoke. It also can be used for parquet flooring and small furniture as well as for paper pulp. Leucaena poles are useful for posts, props and frames for various climbing crops (Brewbaker *et al.* 1985). The low seeding varieties are used to provide shade for cacao and coffee and support for climbers such as pepper and vanilla. The high seeding types are a nuisance in this regard because of the high population of seedlings that germinate and compete with the crop. There is opportunity to produce seedless triploid hybrids by crossing self-incompatible diploid species such as *L. diversifolia* (2x) with tetraploid species such as *L. leucocephala* (Brewbaker and Sorensson 1990).

Leucaena hedges are useful as windbreaks and firebreaks, the latter due to the suppression of understorey grass growth.

Other uses include production of necklaces from seeds and the use of young leaves and seeds as vegetables for human consumption. Young green pods can be split open and the fresh immature seeds eaten raw or cooked. Only small amounts can be eaten in this way because of the presence in seed and young growth of the toxic amino acid mimosine. *Leucaena leucocephala* will occasionally produce a gum similar to gum arabic when stressed by disease or insect pests. When *L. leucocephala* was hybridised with *L. esculenta,* some segregating trees produced gum heavily in the dry season. The hybrids were seedless, had good vigour and were psyllid resistant (Brewbaker and Sorensson 1990).

Climate and Soil Adaptation

Temperature

Leucaena is a tropical species requiring warm temperatures (25-30℃ day temperatures) for optimum growth (Brewbaker *et al.* 1985). At higher latitudes and at elevated tropical latitudes growth is reduced. Brewbaker *et al.* (1985) suggest that temperature limitations occur:

- above 1000 m elevation within 10℃ latitude of the equator, and
- above 500 m elevation within the 10-25℃ latitude zone.

Leucaena is not tolerant of even light frosts which cause leaf to be shed (Isarasenee *et al.* 1984). Heavy frosts will kill all above ground growth, although the crowns survive and will regrow vigorously in the following summer with multiple branches. There is some scope for breeding frost tolerance into leucaena Two- and three-way hybrids of *L. leucocephala* with frost tolerant *L. retusa* show promise (Brewbaker and Sorensson 1990). Kendall *et al.* (1989) suggested that populations of *L. leucocephala* originating from more elevated sites in northeastern Mexico showed greater frost tolerance than those originating from lowland sites. Leucaena growth is strongly seasonal in the subtropics with low yields in the cool months and the majority of growth occurring in the summer months (Cooksley *et al.* 1988). For these reasons the best opportunities for developing cool tolerant leucaenas lie with hybridisation of *L. leucocephala* with *L. diversifolia* and *L. pallida.* These latter two species can be found in elevated sites in Mexico and demonstrate cool tolerance. Hybrids of *L. diversifolia* (4x) x *L. leucocephala* averaged 4.5 m per year height increase in a 2 year period at Waimea, Hawaii at 850 m elevation and mean annual temperature 17℃ (Brewbaker and Sorensson 1990).

Light

Shading reduces the growth of leucaena although this plant has moderate tolerance of reduced light when compared with other tree legumes (Benjamin *et al.* 1991). Leucaena seeds will germinate and establish satisfactorily under established leucaena hedgerows or under the weed species *Lantana camara* as a method of rehabilitating infested areas.

It has also been successfully grown under coconuts in Bali as a support for vanilla.

Rainfall requirements and drought tolerance

Leucaena can be found performing well in a wide range of rainfall environments from 650 to 3,000 mm. However, yields are low in dry environments and are believed to increase linearly from 800 to 1,500 mm, other factors being equal (Brewbaker *et al.* 1985). In Hawaii, it is naturalised on Diamond Head which receives only 300 mm p.a. In Australia the leucaena psyllid is much less damaging in drier areas (600-800 mm p.a.) and this is a major advantage for graziers cultivating leucaena in subhumid Queensland.

Leucaena is very drought tolerant even during establishment. Young seedlings have survived extended periods of dry weather and soil and plant studies have confirmed that leucaena exhibits better drought characteristics than a number of other tree legumes (Swasdiphanich 1992). Leucaena is a deep-rooted species which can extend its roots 5 m to exploit underground water (Brewbaker *et al.* 1972). In shallow duplex soils, roots have been observed to branch and grow laterally at only 30 cm depth due to an impermeable clay layer.

Leucaena is not tolerant of poorly drained soils, especially during seedling growth, and production can be substantially reduced during periods of waterlogging (see Figure 3.2.3). However, once established it can survive short periods of excess moisture.

Soil type

Leucaena does best on deep, well drained, neutral to calcareous soils; it is often found naturalised on the rocky coralline terraces of Pacific island countries. However, it grows on a wide variety of soil types including mildly acid soils (pH > 5.2). It is well adapted to clay soils and requires good levels of phosphorus and calcium for best growth.

Establishment

Slow establishment is still considered to be a major limitation to the expanded use of leucaena for grazing in Australia. In subhumid tropical Australia, where the psyllid has been less of a challenge, establishment failures were reported to occur in 64% of plantings made by farmers (Lesleighter and Shelton 1986). Slow seedling growth makes plants vulnerable to weed competition and attack by wildlife. In some cases, leucaena plantings in southern Queensland have taken up to 3 years to reach mature height before regular grazing could commence. Long delays before full utilisation commences adversely affects profitability. However, leucaena seedlings are not naturally slow growing and have been shown to reach 2 m in height within 14 weeks when growing in a fertile soil well supplied with water and nutrients (Ruaysoongnern *et al.* 1985).

Leucaena can therefore be established successfully and rapidly provided growth requirements are met. Full details are provided in Section 3.3 and are briefly summarised here.

Seed treatment

Freshly harvested leucaena often has a high degree of hard seed due to an impermeable waxy coat which must be broken before the seed will imbibe water and germinate. Scarification to break this dormancy usually involves treatment with hot water (boiling water for 4 s) or acid (concentrated sulphuric acid for 5-10 min). Seed must be inoculated before planting with a suitable *Rhizobium* strain. TAL1145 is recommended worldwide and in Australia was found to be more effective than the previously used CB81 to ensure effective nitrogen fixation. Lime pelleting will protect the *Rhizobium* bacteria in very acid soils.

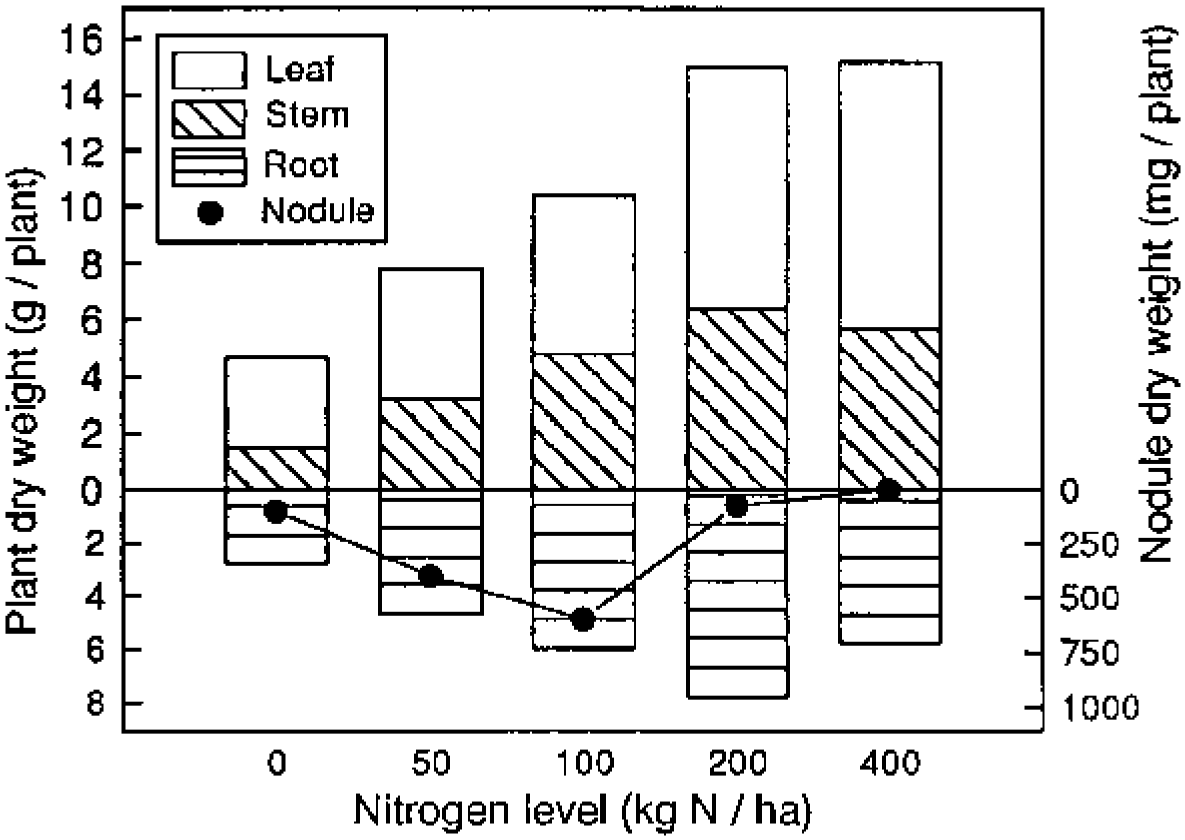
Planting

Leucaena can be planted by seed or 'bare stem' seedlings. Large areas are best planted by seed in rows into fully prepared seed beds or into cultivated strips in existing grasslands. Seeding rates of 1-2 kg/ha at depths of 2-3 cm are usually recommended in rows 3-10 m apart. Sowings are best made early in the growing season but when rainfall is reliable using good weed control measures (cultivation and herbicides) to minimise competition; leucaena seedlings are very susceptible to competition in the root zone. Trifluralin (0.5 kg active ingredient (a.i.)/ha) for grass species and Dacthal (8-10 kg a.i./ha) or 2,4-D amine (6 kg a.i./ha) for broadleaf species are recommended for pre-emergence control of weeds (Brewbaker *et al.* 1985). Fusilade (2 kg a.i./ha) and Basagran (2 kg a.i./ha) are recommended for post-emergence grass and broadleaf weed control respectively. Hand weeding or mechanical cultivation are also effective means of controlling weeds.

Fertilisation

Fertilisation at planting will be necessary on most soils to achieve vigorous seedling growth as many tropical soils are infertile following years of intensive cropping, leaching and erosion from high intensity rains. leucaena is particularly susceptible to phosphorus deficiency and is dependent on vesicular arbuscular mycorrhizae (YAM) to extend the capacity of its root system to access immobile nutrients such as phosphorus. In soils low in phosphorus, or low in natural VAM activity, quite high rates of phosphorus (100 kg P/ha) should be applied. Leucaena is also sensitive to calcium deficiency as this will reduce nodulation. Other nutrients may be necessary if soil tests indicate a deficiency, to ensure vigorous early growth of seedlings. In very acid soils (pH < 5.0), liming is necessary. In the past, 'starter' nitrogen was often applied as *Rhizobium* strains were slow to nodulate and begin fixing atmospheric nitrogen. 'Starter' nitrogen promoted both early growth and nodulation although very high rates tended to suppress nodulation completely (Figure 2.1.2). However, with the more effective *Rhizobium* strains currently available, 'starter' nitrogen should not be necessary although the use of nitrogen in nursery plantings is advised.

Fig. 2.1.2. Growth and nodulation of leucaena in response to applications of inorganic nitrogen (Sivasupiramaniam *et al.* 1986).



Planting configurations

Leucaena may be planted as single plants, single hedgerows or multiple hedgerows depending on its use. In the latter case, hedgerows may be closely spaced (75-100 cm) to achieve maximum yield per hectare for cut-and-carry feeding or more widely spaced (3-10 m) for alley cropping or grazing. Intra-row plant spacings of 25-50 cm are adequate. In widely spaced rows for grazing, grasses may be planted between leucaena rows to increase total fodder supply to animals. In Australia, green panic (*Panicum maximum* var. Trichoglume), setaria (*Setaria sphacelata*), pangola (*Digitaria decumbens*) and buffer grass (*Cenchrus ciliaris*) have been successful companion grasses for leucaena.

Productivity

Dry matter productivity of leucaena varies with soil fertility and rainfall. Edible forage yields range from 3 to 30 t dry matter/ha/year. Deep fertile soils receiving greater than 1,500 mm of well distributed rainfall produce the largest quantities of quality fodder. Yields in the subtropics, where temperature limitations reduce growth rates, may be only 1.5-10 t of edible fodder/ha/year (Brewbaker *et al.* 1985).

The most suitable cutting or grazing intervals to promote high yields vary with environmental factors. In general, longer intervals between defoliation have increased total yield; however, the proportion of inedible wood may also increase leading to a decline in forage quality. At very productive sites, harvest intervals may be 6-8 weeks and up to 12 weeks at less productive locations. Harvest height has less influence on total yield than harvest frequency.

Maintenance fertilisers are rarely applied to mature leucaena stands although nutrient deficiency can limit growth. Stands of leucaena at the Brian Pastures Research Station near Gayndah 400 km northwest of Brisbane were deficient in sulphur yet persisted and were successfully used to fatten steers. An indication of need for fertiliser application can be obtained from the chemical composition of young leaves. Table 2.1.2 shows critical nutrient values in index leaves of young seedlings and some typical nutrient concentrations in young leaves of vigorously growing leucaena plants. Concentrations substantially lower then these values can be regarded as deficient. Colour photographs of nutrient deficiencies on leucaena are shown in Smith *et al.* (1992).

Grazing management

In Australia, it is recommended that regular heavy grazing of leucaena does not commence until plants are mature and well established. This may take 1-3 years depending on growing conditions. However, light grazing can occur in the first year when plants reach 1.5 m in height especially if frosts and wildlife may damage leucaena plants during winter. Grazing promotes branching, results in a protective thickening of main stems and can remove flowers and pods which reduce growth rates.

Regular grazing of well established rows of leucaena leads to the development of quite uniform hedgerows. Taller plants or branches are readily broken and reduced in size by hungry animals. In Vanuatu and Papua New Guinea, cattle graze in leucaena thickets which may be up to 10 m in height. Cattle graze lower branches and newly emerging seedlings and the upper canopy is kept as a drought reserve. The amount of leucaena material available for grazing is reduced in this system of management. Leucaena paddocks are normally rotationally grazed with cattle moved to new areas when most leaf and edible stem have been removed and before serious damage to the wooden framework of the plants has occurred.

Appropriate stocking rates vary greatly from less than 1 beast to 1.5 ha in low rainfall environments (750 mm p.a.) up to 6 beasts/ha in fertile well watered or irrigated stands.

Table 2.1.2. Concentration of various elements in the young leaves of nodulated *Leucaena leucocephala* (Ruaysoongnern 1989, Jones 1979).

Element	Critical concentrations in young leaves of cv. Cunningham	Concentrations in young leaves of cv. Peru	
		Sample 1	Sample 2
N (/D)	4.1	4.1	5.4
P (%)	0.25	0.21	0.32
K (%)	2.0	1.5	2.01
S (%)	0.24	0.27	0.31
Ca (%)	0.49	0.66	0.98
Mg (%)	-	0.31	0.30
Na (%)	-	0.03	0.03
Cu (ppm)	-	7	9
Zn (ppm)	-	29	29
Mn (ppm)	325*	-	45
Fe (ppm)	-	-	164

* Critical concentration for toxicity

Animal production

Leucaena is well known for its high nutritional value and for the similarity of its chemical composition with that of alfalfa (Table 2.1.3). However, leucaena forage can be low in sodium and iodine, but is high in β -carotene. Tannins in the leaves and especially the stems of leucaena reduce the digestibility of dry matter and protein but enhance the 'bypass' value of protein.

Digestibility and intake values for leucaena range from 50 to 71% and from 58 to 85 g/kg$^{0.75}$ liveweight respectively (Jones 1979). The lower values were suggested by Jones (1979) to-be associated with the effects of mimosine on intake when pure diets of leucaena were fed.

Animal production on leucaena based pastures is excellent. In southeast Queensland, cattle on leucaena/setaria pastures gained between 310 and 430 kg liveweight/ha, approximately twice that obtained from siratro (*Macroptilium atropurpureum*) based pastures in the same environment (Jones and Jones 1984). In low frost environments, leucaena foliage can be heldover for feeding in the cool or dry season providing valuable high protein feed during stress periods for grazing ruminants. Under ideal growing conditions under irrigation on the fertile alluvial plains of the Ord River valley, leucaena/pangola (*Digitaria decumbens*) pastures produced annual liveweight gains of 273 kg/head or 1422 kg/ha at a stocking rate of 6 weaner steers/ha (Davison 1987). In central Queensland, on fertile clay soils, cattle are gaining 300 kg liveweight per head per year on leucaena pastures.

Table 2.1.3. Comparative compositions of alfalfa (*Medicago saliva*) and Malawi-grown leucaena (NAS 1977).

(a) General compositor	Leucaena leaf	Alfalfa leaf
Total ash (%)	11.0	16.6
Total N (%)	4.2	4.3
Crude protein (%)	25.9	26.9
Modified-acid-detergent fibre (%)	20.4	21.7
Calcium (%)	2.36	3.15
Phosphorus (%)	0.23	0.36

β -carotene (mg/kg)	536.0	253.0
Gross energy (kJ/g)	20.1	18.5
Tannin (mg/g)	10.15	0.13
(b) Amino acid	**Leucaena**	**Alfalfa**
Arginine (mg/gN)	294	357
Cysteine (mg/gN)	88	77
Histidine (mg/gN)	125	139
Isoleucine (mg/gN)	563	290
Leucine (mg/gN)	469	494
Lysine (mg/gN)	313	368
Methionine (mg/gN)	100	96
Methionine + cysteine (mg/gN)	188	173
Phenylalanine (mg/gN)	294	307
Threonine (mg/gN)	231	290
Tyrosine (mg/gN)	263	232
Valine (mg/gN)	338	356

These production figures are much greater than can be achieved from more traditional herbaceous legume based pastures and can be expected to be sustained over long periods. Leucaena hedgerows at the CSIRO Samford Station have been grazed for 25-30 years and continue to grow vigorously. The half-life of leucaena plants is thought to be over 50 years (Jones and Carter 1989). Such longevity is not available among herbaceous legumes. A more complete exposition of the grazing and supplementary feeding value of leucaena appears in Chapter 4.

Toxicity

The foliage and pods of leucaena contain the toxic amino acid mimosine which may reach 12% of the dry matter in growing tips but is less in young leaves (3-5% of dry matter) (Jones 1979). Although quite toxic to non-ruminant animals, mimosine is broken down by microbes in the rumen to DHP (3 hydroxy-4-(1H)-pyridone) a goitrogen, which is normally broken down further by rumen microorganisms to non-toxic compounds. The microbes are naturally present in ruminants in Indonesia and Hawaii and probably other countries of southeast Asia and the Pacific where there has been a long history of ruminant animals grazing naturalised leucaena.

However, in some countries, notably Australia, Papua New Guinea and perhaps African countries, the appropriate rumen microorganisms are not naturally present leading to an accumulation of DHP which causes goitre (enlargement of the thyroid gland) which results in listlessness, loss of appetite, excess saliva production, hair loss and loss of weight. However, this effect only occurs if leucaena constitutes a high proportion of the animal's diet (>30%) for an extended period. Details of the discovery of the microorganisms which break down DHP by Dr RJ. Jones of the CSIRO Division of Tropical Crops and Pastures are described in Lowry (1987) and in Section 4.4.

Procedures for the transfer of the appropriate rumen microbes among ruminants have been developed in Australia.

Pests and Diseases

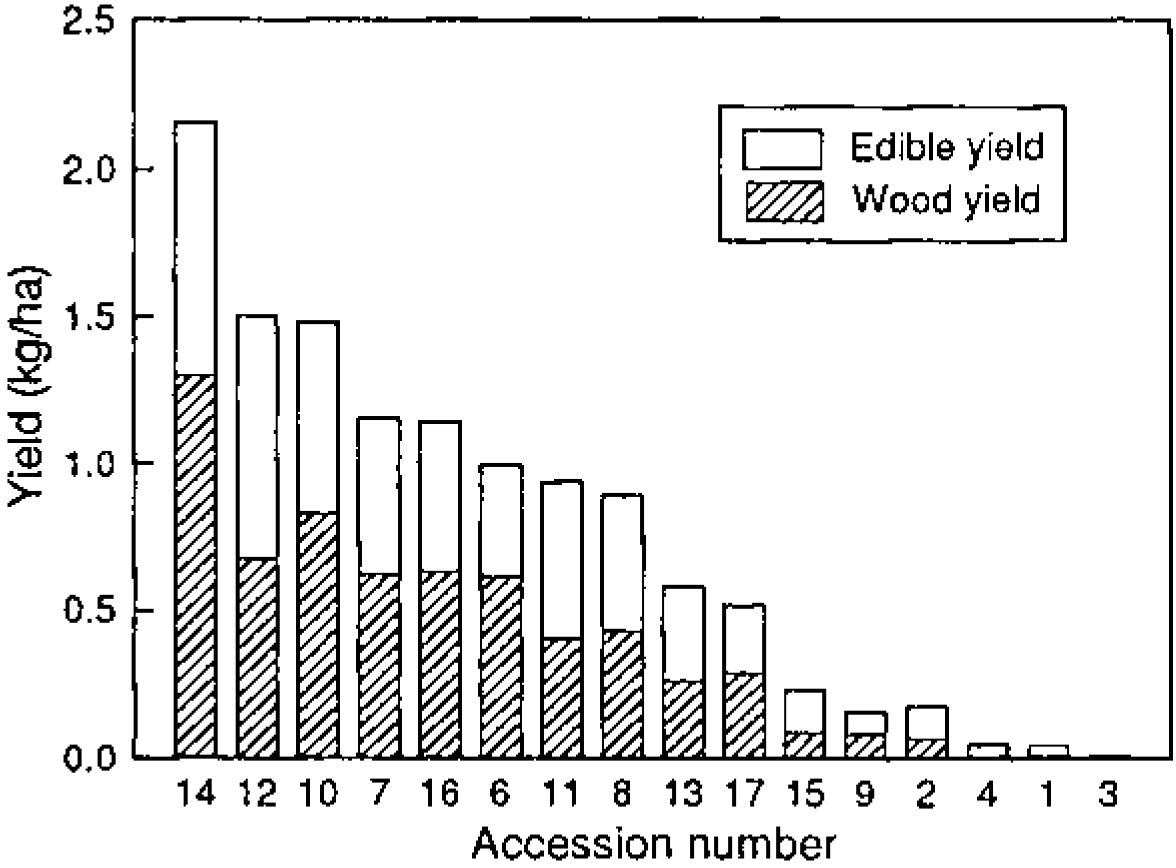
Until relatively recently, there were few pests of leucaena because of the insecticidal properties of mimosine. However, following the rapid movement of the leucaena psyllid (*Heteropsylla cubana* westward from the Caribbean across the Pacific in

1985/86, large areas of previously productive leucaena in the Philippines, Indonesia and Australia have been affected. The psyllids or jumping lice are small aphid-like insects adapted to feeding on the young growing shoots of leucaena. Mild infestations cause distortion of leaves whilst heavy infestations result in loss of leaves and attack by secondary moulds which feed on the sticky exudate of psyllids. The psyllid is native to Central America. Bray and Woodroffe (1991) reported that psyllids reduced the production of edible material by 52% and that of stem by 79% in southeast Queensland. There is some scope for biological control from the beetle *Curinus coeruleus,* the parasitic wasp *Psyllaephagus* nr. *rotundiformus* and from resistance in the *leucaena* genus (Anon. 1990). More will be said of this problem in Section 6.1.

The most probable control of the psyllid will occur through the development of psyllid resistant hybrids. Leucaena hybridises readily with the species *L. pallida* and *L. diversifolia* both of which contain psyllid resistance. Breeding programmes to develop open-pollinated and F1 hybrid cultivars are well advanced (Brewbaker and Sorensson 1993). The yield of these psyllid resistant lines far exceeds that of susceptible *L. leucocephala* lines in high psyllid environments (Figure 2.1.3) and they are exciting prospects for future development.

A serious disease of seedling leucaena in nurseries is damping-off in moist soils caused by the fungal species *Pythium* or *Rhizoctonia* spp. (Brewbaker *et al.* 1985). This is controlled by good nursery techniques (overwatering promotes the disease) and use of well-drained soil media. The use of fungicides such as Benlate or Captan are also an option.

Fig. 2.1.3. Wood and edible forage yields of sixteen 9 month old lines of *Leucaena* grown at Redland Bay in southeast Queensland. Lines are: 1 = *L. leucocephala cv.* Cunningham; 2 = *L. leucocephala* K636; 3 = *L. leucocephala* Q25221; 4 = *L. leucocephala* CPI61227; 5 = *L. pallida* K818; 6 = *L. pallida* K803; 7 = *L. pallida* CSIRO composite; 8 = *L. pallida* K376; 9 = *L. diversifolia* K156; 10 = *L. diversifolia* CPI46568; 11 = *L. leucocephala x L. pallida* (KX2) K8xK376 (F2); 12 = *L. pallida x L. leucocephala* (KX2) K806xK636 (F1); 13 = *L. pallida x L. leucocephala* (KX2) K8xK376 (F1); 14 = *L. leucocephala x L. pallida* (KX2) K748xK636 (F1); 15 = *L. leucocephala x L. diversifolia* (KX3) K636xK156; 16 = *L. pallida* K806xK748; 17 = *L. pallida* K953 (A. Castillo and H.M. Shelton, unpublished data).



The moth *Ithome lassula* which damages leucaena inflorescences and the seed beetle *Araecerus levipennis* reduce the production and viability of seed.

Conclusions

Leucaena has played a valuable role in world agriculture over a long period of time. Its value is multifaceted and the potential for increasing and diversifying the use of this wonderful species is enormous. However, its future use in humid areas is currently in doubt because of the devastation caused by the psyllid. On an optimistic note, we hope for increasing populations of natural predators to give some biological control of the psyllid. Alternatively, the current worldwide coordinated move towards use of psyllid resistant hybrids is likely to lead to the development of genetic resistance. The future role and value of leucaena will depend on the outcome of these programmes.

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2.2 Gliricidia sepium - a Multipurpose Forage Tree Legume

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Introduction

Gliricidia sepium is a medium-sized leguminous tree which occurs in abundance throughout its native range in Mesoamerica. Domestication of gliricidia has been in progress for several millennia and the multitude of indigenous common names from Mayan and Quiche peoples (Pertchik and Pertchik 1951) reveals the importance of this species to early occupants of the region. Spanish colonists adapted the local vernacular in naming the species 'madre de cacao' (mother of cocoa) to describe its use as a cocoa shade tree. The toxic properties of the seeds and bark of *G. sepium* give rise to the generic epithet of this species (*Gliricidia* = mouse killer) as well as a number of common names (e.g. mata-raton). Present day uses of this species throughout the native range (e.g. firewood, living fences, shade, construction and as an ornamental) are likely extensions of early utilisation and popularity (Rico-Gray *et al.* 1991).

Gliricidia sepium has also been used extensively outside its native range in places which include the Caribbean, the Philippines, India, Sri Lanka and West Africa. These landrace populations are largely remnants of colonial introductions used to shade plantation crops although more recently they have been integrated into indigenous farming practices being used for fuelwood, living fences, animal forage, green manure and soil stabilisation.

After *Leucaena leucocephala, G. sepium* is believed to be the most widely cultivated multipurpose tree. In many cases, gliricidia will yield as much as or more biomass than *L. leucocephala* (Stewart *et al.* 1992). One of the reasons for its recent popularity is its complete resistance to the defoliating psyllid (*Heteropsylla cubana*) which has devastated *L. leucocephala* in many parts of the tropics. This section describes the taxonomy, ecology, distribution and general uses of *G. sepium,* as a prelude to discussion of its use as a forage species.

Taxonomy

Botanical description

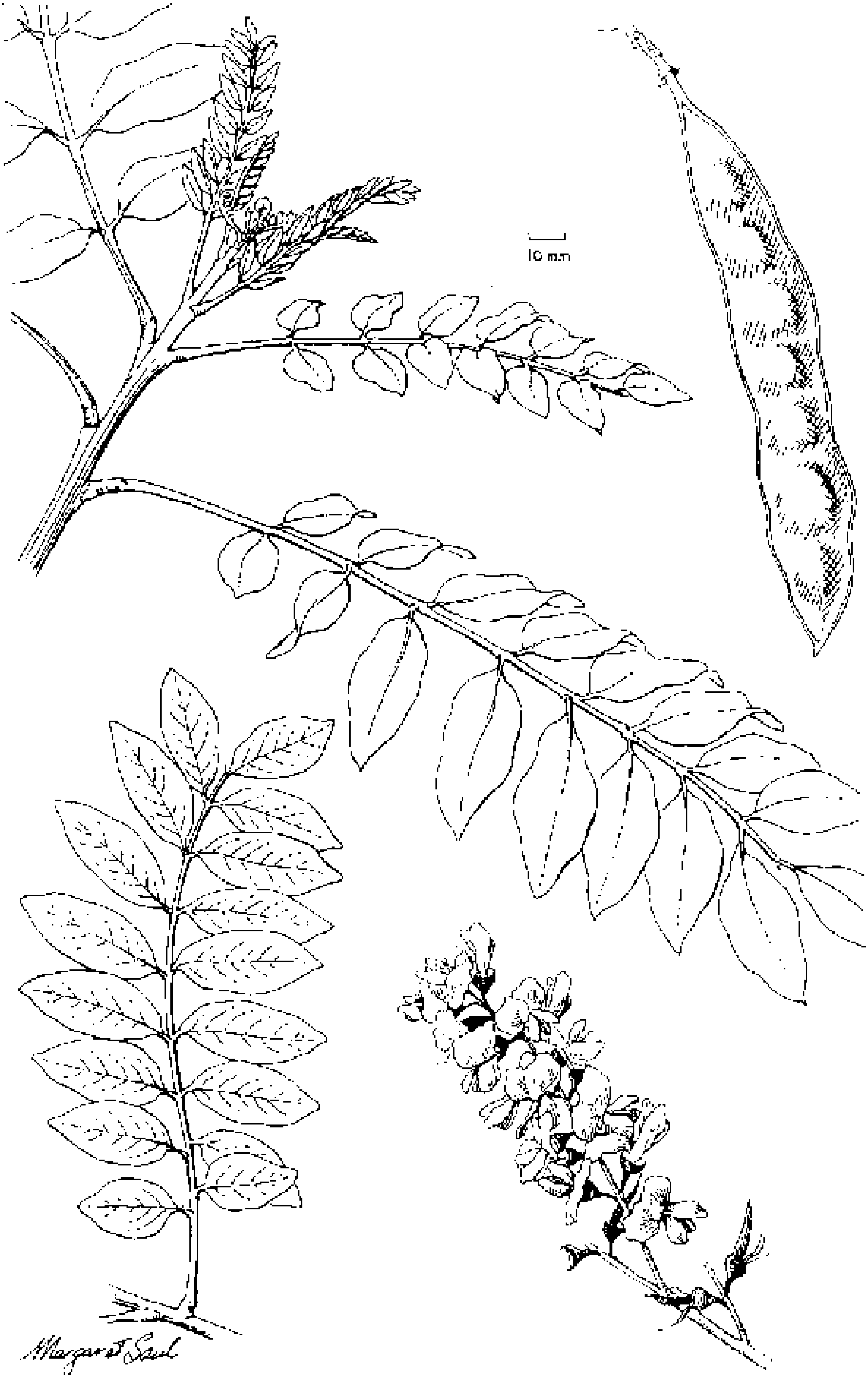
Gliricidia sepium is a small to medium-sized, thornless tree which usually attains a height of 10-12 m. Branching is frequently from the base with basal diameters reaching 50-70 cm. The bark is smooth but can vary in colour from whitish grey to deep red-brown. The stem and branches are commonly flecked with small white lenticels. Trees display spreading crowns. Leaves are odd pinnate, usually alternate, subopposite or opposite, to approximately 30 cm long; leaflets 5-20, ovate or elliptic, 2-7 cm long, 1-3 cm wide. Leaflet midrib and rachis are occasionally striped red. Infloresences appear as clustered racemes on distal parts on new and old wood, 5-15 cm long, flowers borne singly with 20-40 per raceme. Flowers bright pink to lilac, tinged with white, usually with a diffuse pale yellow spot at the base of the standard petal, calyx glabrous, green, often tinged red. Standard petal round and nearly erect, approximately 20 mm long; keel petals 1520 mm long, 4-7 mm wide. Fruit green sometimes tinged reddish-purple when unripe, light yellow-brown when mature, narrow, 10-18 cm long, 2 cm wide, valves twisting in dehiscence; seeds 4-10, yellow-brown to brown, nearly round (modified from C.E. Hughes, unpublished data) (Figure 2.2.1).

Systematics

Gliricidia is a member of the sub-family Papilionoideae and lies within the tribe Robinieae (Lavin 1987). The genus *Gliricidia,* which has been previously ascribed to *Lonchocarpus* and *Robinia,* comprises a small, yet debated, number of taxa. It is most commonly known by its pink-flowered species, *G. sepium,* which is routinely observed throughout its natural range in the dry forest of the Pacific coast of Central America and Mexico (Hughes 1987). A closely related white flowered taxon, *G. maculata,* is less common although it is frequently confused with *G. sepium* despite its disjunct distribution in the Yucatan Peninsula. Most confusion of these two taxa has arisen in exotic locations where they are often treated as synonyms (see for example Falvey 1982) thus resulting in indiscriminate use of nomenclature in forestry literature (Whiteman *et al.* 1986, Reynolds 1988, Joseph *et al.* 1991).

Despite the sexual compatibility of these two taxa (A.J. Simons, unpublished data), there exists substantial evidence to confirm Rydberg's (1924) treatment of the white flowered entity as a distinct species. Lavin *et al.* (1991) showed distinction between *G. sepium* and *G. maculata* based on studies of chloroplast DNA polymorphisms. Simons and Dunsdon (1992) present 12 separate characters that can be used to distinguish these species, some of which have only recently become known (e.g. molecular markers, seed diameter, stem form) with the provision of trial material grown under uniform conditions.

Fig. 2.2.1. Leaves, flowers and pod *of Gliricidia sepium.*



Ecology

Despite the widespread present occurrence of *G. sepium* in cultivation throughout Central American countries and Mexico, it is likely to be native only in the seasonally dry forest (Hughes 1987). It is largely deciduous during the dry season which runs from January to the first rains in May. In areas where sufficient moisture prevails, however, the tree does not become leafless (e.g. Kalimantan, Indonesia; Seibert 1987). Flowering begins at the start of the dry season and can continue in some native populations until the end of March. Altitude was suggested by Hughes (1987) to exert a large influence on the onset of flowering with lower coastal sites flowering well before sites at higher altitudes (i.e. up to 1,200 m). The periodicity of pod ripening is partly dependent upon the climatic conditions and typically takes 45-60 days. *Gliricidia sepium* in cultivation in wet areas may often flower, although sets little if any fruit.

Seeds are shed from pods through explosive dehiscence with seed dispersal distances of up to 40 m (Simons and Dunsdon 1992). No scarification or pretreatment of seeds is required prior to germination, and germination rates above 90% are typical. Following germination, trees grow extremely quickly and may attain a height of 3 m before flowering at age 6-8 months (Simons and Dunsdon 1992). Its rapid growth makes it an aggressive pioneer capable of colonising secondary forest and fallow *Imperata* dominated grassland often forming dense, pure stands (Anoka *et al.* 1991).

Individual trees display vast numbers of flowers (up to 30,000) which attract a wide variety of insect visitors. Foremost amongst these is a conspicuous species of carpenter bee (*Xylocopa fimbriata*) that was suggested by Janzen (1983) and confirmed by Simons and Dunsdon (1992) to be the primary pollinator of *G. sepium. Xylocopa fimbriata* is a large (up to 30 mm in length), solitary bee that is principally attracted to the abundant nectar of *G. sepium,* and is capable of flight distances of several kilometres thus effecting pollen dispersal at great distances between parents. Another genus of large bees (*Centric* sp.) was also observed to visit *G. sepium* trees in Guanacaste, Costa Rica (Coville *et al.* 1986).

The temperature requirements of *G. sepium* are not too exacting as shown by the wide variation in mean monthly temperature (20.7-29.2℃) at native sites. It will, however, not tolerate frosts which partly explains its absence above 1,200 m in the native range. Whiteman *et al.* (1986) in southeast Queensland, found that trees became leafless when night temperatures fell below 15℃. Gliricidia can, however, be managed in a coppice system in areas with light frost, by cutting the new growth before frosts occur (Stewart *et al.* 1992).

The 30 sites sampled by Hughes (1987) in his range-wide collection of populations of *G. sepium,* represent a great diversity of soil types. Most of the soils were highly eroded, of acid reaction (pH 4.5-6.2) originating from volcanic parent material but also included sands, heavy clays and calcareous limestone soils which were slightly alkaline. At exotic locations, such as Peru, Szott *et al.* (1991) suggested that *G. sepium* was suitable for acid, infertile soils. Furthermore, Whiteman *et al.* (1986) considered *G. sepium to* be well adapted to low calcium soils in Australia, although *G. sepium* was seen to have poor survival on Indonesian soils with high aluminium saturation (Dierolf and Yost 1989).

A common feature of seasonally dry regions of Central America and Mexico is the perennial fires which burn through fallow agricultural land and secondary forest. *Gliricidia sepium* tolerates fires well and trees quickly resprout with arrival of the rains. The increased frequency of fires through deliberate burning may be responsible for the high occurrence of *G. sepium* in secondary vegetation and agricultural fallows.

Holm *et al.* (1979) report *G. sepium* as a severe weed in Jamaica, whereas Hughes and Styles (1984) consider *G. sepium* to have only a slight weediness hazard.

Distribution

Native range

Standley and Steyermark (1946) were the first to document the native distribution of *G. sepium* and recorded its occurrence up to an altitude of 1,600 m from Mexico through Central America to northern South America. Acceptance of this distribution by later reviews include those of NAS (1980) and Falvey (1982). Given Lavin's (1987) investigations, however, the higher elevation specimens may have been *Hybosema ehrenbergii.*

Hughes (1987) was the first to distinguish between native and naturalised distributions of *G. sepium* in his comprehensive genecological survey of the native range. In his tentative distribution map, Atlantic coastal populations and northern South American populations were assigned as naturalised thus restricting native sites to only the dry forests of the Pacific coast in Mexico and Central America. The sites sampled by Hughes ranged in altitude from sea level to 1,100 m, and in annual rainfall from 650 to 3,500 mm.

Exotic distribution

The earliest documented case of the use of *G. sepium* as an exotic is provided by Wiersum and Dirdjosoemarto (1987) who cite the Spaniards as taking it to the Philippines in the early 1600s. It has also been used for several centuries in the Caribbean where again the Spanish introduced it to shade cocoa (Ford 1987). *Gliricidia sepium* was introduced into Sri Lanka in the 1700s to shade tea plantations, although the Sri Lankan material came from Trinidad where it is not native. This introduction was purportedly from seed of just one tree (Hughes 1987). Liyanage (1987) records the presence of both white (*G. maculata*) and purple (*G. sepium*) flowered trees of gliricidia in Sri Lanka indicating several later introductions may have ensued. From Sri Lanka, it has spread out to India, Indonesia, Malaysia and Thailand. Similar introductions occurred in West Africa and Uganda to provide shade trees for plantation crops (Atta-Krah 1987, Tothill 1940).

Most exotic introductions are from unknown origin and are likely to be narrowly based. This supposition is supported by the findings of Bumatay *et al.* (1987) who found local seed sources from the Philippines to be inferior to the new collections made by Hughes (1987). Local landraces in Sri Lanka, Indonesia and Nigeria have also been shown to be outperformed by populations collected by Hughes (Simons and Dunsdon 1992).

Certain problems have emerged as a result of growing *G. sepium* in exotic environments. Foremost among these are pest and pathogen considerations. A number of insect pests attack *G. sepium* in the Caribbean including aphids, mealy bugs and scale (Ford 1987). In India, Subramaniam (1977) and Devasahayam *et al.* (1987) reported predation of *G. sepium* by a bud weevil and a hepialid (*Sahyadrassus malabaricus*), respectively.

Agnihothrudu (1961) reported problems with a foliar disease (*Pellicularia filamentosa*) of *Paraserianthes falcataria* being pathogenic to *G. sepium.* In addition, a root fungus attacked *G. sepium* in Trinidad although Ford (1987) did not consider this to be serious. Two foliar diseases were recorded on *G. sepium* in Nigeria, namely *Colletotrichum gloeosporioides* and *Cercosporidium gliricidiasis* (Lenné and Sumberg 1986). Lenné (1992) attributes the lack of many diseases on gliricidia to its tendency to be leafless for periods of the year thus reducing the likelihood of epidemics (Section 6.2).

Other biological problems have also arisen when *G. sepium* is used as an exotic. The lack of flowering at sites where no distinct dry season exists (e.g. Kalimantan, Indonesia; Seibert 1987) is undoubtedly climatically induced. Where flowering occurs but no fruit develop to maturity, climate is also likely to be implicated; however, the lack of suitable pollinators may also account for this. Pod set was reported by Sumberg (1985) to be particularly low in Nigeria Furthermore, Akkaseng *et al.* (1986) emphasised the importance of identification of suitable rhizobial strains for *G. sepium* when used as an exotic.

Uses

Few non-industrial tree species embody the concept of a multipurpose tree better than *G. sepium.* Throughout both its native and exotic ranges it is used to supply tree products such as fuelwood, construction poles, crop supports, green manure, fodder and bee forage. In addition, it is used in living fences, to stabilise soils and prevent erosion, to shade plantation crops, as an ornamental and in traditional medicine for eczema. Generally, however, it is cultivated for a particular purpose and the additional benefits are appreciated but not necessarily demanded, thus the concept of one individual tree supplying all of the above products is illusory.

A review of the main uses of *G. sepium* is given below.

Fuelwood

The easy coppicing nature of *G. sepium* contributes to its acceptability as a source of fuelwood. Fuelwood is obtained in its native range through the occasional lopping of branches or by completely coppicing trees to low levels above ground. Smaller diameter wood is not prized as much as larger diameters because of its lower specific gravity. Most wood of *G. sepium* that is collected is for self-consumption.

Wood of gliricidia burns slowly thus producing good embers, and gives off little smoke or sparks explaining its general acceptability (CATIE 1986). It has a good heating value (19.8 MJ/kg) with an average specific gravity of 0.5-0.6 (Withington *et al.* 1987).

Accumulation of woody biomass by trees of *G. sepium* is very much dependent on climate and soils, management, planting density, length of rotation and the provenance used. Salazar (1986) reports dry wood yields of up to 6.3 t/ha/year from trees in Costa Rica, whereas Wiersum (1982) quotes yields of 1520 m^3/ha/year. In the Philippines, where *G. sepium* is grown in woodlots on a three-year rotation to provide wood for tobacco curing, yields of up to 23-40 m^3/ha/year have been obtained (Wiersum and Dirdjosoemarto 1987).

An International Provenance Trial Series of *G. sepium* was set up by the Oxford Forestry Institute (OFI) in the mid-1980s. In total, more than 100 trials were established throughout the tropics under one of two management systems, namely (i) pure-plot plantations for wood production and (ii) hedgerow system for leaf production. The results from these trials indicated that there were marked differences between provenances with up to 500% differences in biomass production at some sites (Simons and Dunsdon 1992). One provenance from Guatemala, Retalhuleu, showed stable and superior production for both leaf and wood production across a wide range of sites. Another provenance from Guatemala, Monterrico, showed poor growth in terms of wood production yet was outstanding for leaf production. Progeny trials have now been set up of some superior provenances so that genetic parameters may be calculated with a view to converting the trials into seedling seed orchards to satisfy the demand for seed of this species.

Living fences

A distinct advantage of *G. sepium* is its ability to root from cuttings or stakes with high attendant survival. Stakes up to 2 m in length and 10-15 cm diameter can be placed directly in the ground, a point reflected by one of its common names, 'quick stick'. The benefit of using long stakes is that they are not grazed out and compete better with other vegetation relative to seedlings. Liyanage and Jayasundera (1989), however, reported that plants of *G. sepium* grown from seed were more productive, hardier and developed a deeper rooting system than plants derived from cuttings.

Several thousands of kilometres of living fences have been planted in both dry and wet sites throughout Central America and Mexico. These are commonly pollarded at a height of 1.0-2.5 m, and generally at least once per year. Individual posts may last beyond 30 years whilst loppings provide a ready supply of replacement posts. Loppings may also be used for animal forage or firewood whilst the spreading crowns of fenceline trees give shade and shelter to livestock. Living fences are used in the native range by a wide cross-section of the community from wealthy cattle ranchers who use it for pasture fences to resource-poor campesinos who use it to mark boundaries and keep livestock out of cropped fields. Homestead gardens or domestic livestock may also be fenced off with closely spaced living fences of *G. sepium.*

At exotic locations, gliricidia has also been used extensively as a living fence. In Bali, slanting interweaved cuttings of close spacing are used to create wire-free fences (Figure 2.2.2), or alternatively, larger cuttings are used to support bamboo poles strung between them. Sri Lankans frequently use very closely spaced smaller diameter cuttings to create a dense barrier around home gardens.

Considerable research has been carried out on the appropriate age of cuttings, method of propagation, best length and diameter, and even on the optimal lunar phase when cuttings should be taken (Duguma 1988, Yamoah and Ay 1986, Withington *et al.* 1987).

Fig. 2.2.2. *Gliricidia sepium* used as a living fence in Bali, Indonesia.

Green manure

A less historic use of gliricidia but one that is increasing in occurrence is the use of leaves as a green manure; however, only isolated examples of mulching or incorporation of leaves into soil (e.g. El Gariton, Guatemala) are evident in the native range. Greater use of gliricidia as a green manure has been made outside the native range with reports as early as the 1930s in Malaysia (Anon. 1934) and Sri Lanka (Joachim and Kandiah 1934) on its benefits.

In Sri Lanka, gliricidia has been grown between rows of coconuts and found to be an excellent organic fertiliser (Liyanage 1987). In Western Samoa, taro yields have been increased by up to 54% with the addition of gliricidia leaf mulch (Kidd and Taogaga 1985). Leaf mulch of *G. sepium* increased the yield and reduced time to harvest of yam tubers in the Ivory Coast (Budelman 1989). Similarly, rice yields were boosted by up to 77% through the use of *G. sepium* mulch (Gonzal and Raros 1988). In addition, where *G. sepium* was used as a mulch in rice fields, the incidence of a rice leaf blight disease was reduced through stimulating growth of saprophytes parasitic to the causal organism (Rajan and Alexander 1988).

Patil (1989) stated that 1 tonne dry weight of leaves was equivalent to 27 kg N while Kang and Mulongoy (1987) reported that up to 15 t/ha/year of gliricidia leaf biomass could be produced on good soils in Nigeria providing the equivalent of 40 kg N/ha/year. These figures are likely to be underestimates since they do not account for nutrients arising from the sloughing of roots and nodules after pruning. Bindumadhava Rao *et al.* (1966) reported that 400 coppiced trees grown around the field perimeter could provide sufficient fertiliser for 1 ha of paddy rice.

The half-life of prunings of *G. sepium* reported by Wilson *et al.* (1986) to be 20 days, has been found to be relatively short compared with that of *Leucaena leucocephala* and *Flemingia macrophylla* (Budelman 1988).

The timing and frequency of coppicing to produce the most biomass at the right time of year was investigated by Ella *et al.* (1989) in Sulawesi, Indonesia. They found that the optimal cutting interval of hedges of *G. sepium* was 12 weeks and that higher densities, even up to 40,000 trees per hectare, were preferable to lower densities. Widiarti and Alrasjid (1987), also in Indonesia, concluded there was no difference in biomass production from coppicing heights of 20, 40 or 60 cm above ground.

Shade

Gliricidia sepium derives many of its common names (e.g. madre de cacao) from its use in its native range to shade cocoa and coffee plantations. As an exotic, *G. sepium* has also been used extensively as a shade tree and the largest single cocoa plantation in the world (12,000 ha), in Indonesia, uses *G. sepium* as the sole shade tree (Seibert 1987). The landraces which have developed in exotic locations are largely remnants of populations chosen for their arboreal form and may not be optimally suited for other uses.

An additional benefit found from shading tea in Sri Lanka with trees of *G. sepium* was reduction in the incidence of termites (Kathiravetpillai 1990).

Use of Gliricidia as a Forage

Gliricidia is an important forage crop in cut-and-carry systems in many parts of the tropics including southeast Asia, Sri Lanka and the Caribbean (Falvey 1982, Chadhokar 1982). In other areas such as West Africa, India and the Philippines, however, its use is severely limited by apparent palatability problems (Mahadevan 1956, Trung 1989). Gliricidia is also little used as forage within its native range in Central America This is partly because extensive grazing systems are preferred over stall feeding in Central America but there may also be a palatability constraint since little grazing of trees is evident. In Costa Rica, for example, prunings from live fences are sometimes left outside the fields, out of reach of the cattle, even where the pasture is in poor condition.

Despite these mixed perceptions of gliricidia as a forage crop, its use has been widely promoted and researched, due largely to its high productivity and quality. Interest in gliricidia for fodder has increased in recent years following the widespread defoliation of *Leucaena leucocephala* by the psyllid. Gliricidia is one of the few forage tree species capable of leaf yields comparable to those of leucaena and it will grow on a wider range of soils tolerating low pH provided that this is not associated with high aluminium saturation.

Leaf biomass production

Gliricidia resprouts vigorously after lopping and will tolerate repeated cutting. Moreover, its phenology is affected by cutting, with resprouts retaining their leaves in the dry season in the tropics when older shoots are deciduous. Management by lopping thus greatly enhances the value of gliricidia as a dry season forage.

Numerous studies have measured leaf biomass (dry matter) production under a range of climatic and edaphic conditions, and under various management regimes differing with respect to variables such as establishment methods (seedlings versus stakes of various sizes), plant spacing, lopping height and lopping frequency. Values reported for gliricidia annual leaf dry matter production generally range from about 2 t/ha/year (Wong and Sharudin 1986) to 20 t/ha/year (Sriskandarajah 1987).

Ella *et al.* (1989) found that as plant spacing was reduced, yield per plant decreased owing to competition, but total forage yield per unit area increased, as did the leaf:wood ratio. They also obtained the highest leaf yields at a planting density of 4 trees/m^2, the highest density tested. In hedgerow plantings, however, intra-row spacing seems to have little effect on overall yield, as lower individual tree productivity is compensated for by higher plant density. Atta-Krah and Sumberg (1987) recommended an intra-row spacing of 10 cm, but found only small differences in productivity for spacings ranging from 4 cm to 50 cm. In the same study, plants propagated from stakes were initially much more productive than those grown from seed, but by the fifth harvest (one year after the first) the difference was no longer significant.

The ease of propagation from stakes is a major advantage of gliricidia, especially as trees managed for leaf production with frequent cutting may not flower and thus set no seed. Furthermore, seed production in gliricidia depends on a marked dry season. Large (up to 1 m long) stakes are generally found to give the best establishment and subsequent growth (e.g. Adejumo 1991).

The optimum frequency of lopping for leaf production depends on the local climate; clearly trees can be lopped more frequently in the wet than in the dry season. In general, total annual biomass yield increases with less frequent cutting, but as this also increases the wood:leaf ratio the effect of cutting interval on leaf yield is less pronounced (Ivory 1990). For gliricidia grown in the humid tropics and used only for forage, a cutting interval of 6-12 weeks is usually recommended. On a subtropical site in Australia, however, Gutteridge and MacArthur (1988) obtained higher leaf yields from one harvest per year than from three to six harvests.

Nutritive value, anti-nutritional factors and palatability

Gliricidia sepium leaves have a high feeding value, with crude protein comprising 20-30% of the dry matter, a crude fibre content of only about 15%, and in *vitro* dry matter digestibility of 60-65% (Göhl 1981, Adejumo and Ademosun 1985). Panjaitan (1988) found that in Indonesia, gliricidia leaves had higher crude protein content in the wet season than in the dry season. Perera *et al.* (1991) reported high digestibility of gliricidia in the rumen relative to other multipurpose tree forages. Moreover, the dry matter digestibility was increased by the addition of energy sources such as cassava to the diet (Ademosum *et al.* 1985). Conversely, the digestibility of low quality feeds can be increased by the addition of legume leaves (Ivory 1990) (Section 4.2).

The apparent high quality of gliricidia leaves, combined with high and sustainable biomass production, should make gliricidia at least as important a forage crop as leucaena, but its use is severely limited by palatability problems, as well as by concern over possible toxicity.

The toxic effects of gliricidia are well known in its native range in Central America, where the leaves or the ground bark, mixed with cooked maize, are used traditionally as a rodenticide (Standley and Steyermark 1946). This toxicity is thought to be due to the conversion by bacteria of coumarin to dicoumerol, a haemorrhagic compound, during fermentation. There have also been reports of toxicity and growth inhibition in other monogastric animals including poultry (Raharjo *et* al 1987) and rabbits (Cheeke and Raharjo 1987). There is little evidence, however, of toxic effects on ruminants fed either fresh or wilted leaves and gliricidia is also relatively low in tannins compared with other forage tree legumes such as *Calliandra calothyrsus.* According to Lowry (1990), the only real constraint to its feed value for ruminants lies in its palatability. Animals seem to refuse gliricidia leaves on the basis of smell, often rejecting it without tasting it, which suggests that the problem lies with volatile compounds released from the leaf surface.

The apparent variation in the acceptability of gliricidia to animals remains a major enigma. In some areas such as Colombia and Sri Lanka, there appears to be no palatability problem and gliricidia is therefore one of the most important dry season forages in these areas. In an experiment in Guatemala, voluntary intake of gliricidia by lactating cows was higher than either leucaena or *Guazuma ulmifolia* (Vargas *et al.* 1987). Elsewhere, however, gliricidia is perceived as completely unacceptable to animals and is not used at all as forage despite its high nutritive value. In feeding trials in Nigeria where a Panicum/gliricidia mix was offered, Ndama cattle selected out the grass and left the gliricidia (J. Cobbina, personal communication). A number of methods are used to increase its acceptability. These include wilting, addition of molasses or salt, and accustomisation of the animals by prolonged exposure and/or penning with adapted animals.

Wilting gliricidia leaves for 12-24 h before feeding is found to increase intake markedly in many of the areas where gliricidia is used as forage, and is therefore recommended wherever palatability problems occur (e.g. Hawkins *et al.* 1990). The reason for this effect is not known but if, as suggested above, acceptability is limited by volatile compounds given off from the leaves, wilting presumably changes the composition of these volatiles resulting in a more acceptable odour.

Differences in management do not, however, fully explain the apparent differences in palatability. For instance, Perera (1992) reported that in Sri Lanka gliricidia cannot be used as a live fence in goat pastures because of browsing of stems and bark as well as leaves, whereas in other areas, the animals will not even eat the leaves unless they are wilted. In the Philippines, Perino (1979) found that gliricidia was seldom browsed by either wild or domestic animals. Other possible reasons for the variation in palatability in different parts of the world include climatic or edaphic effects on leaf chemical composition, differences in behaviour or in rumen flora between animals in different places (whether genetically or environmentally caused), or genetic variation in the gliricidia itself. There is some anecdotal evidence to support this last theory: according to Glander (1977), for instance, howler monkeys foraging in Costa Rica feed selectively on only a few gliricidia trees in a large population. In a 'cafeteria' trial in Nigeria using 30 provenances of gliricidia, sheep showed clear preferences for some provenances over others (A. Larbi, personal communication). The hypothesis that differences in acceptability are genetically determined is currently being tested in a project based at the OFI using a combination of analytical techniques and feeding trials. If significant differences between provenances are found, palatability should be included among the selection criteria in future genetic improvement of gliricidia.

Use of gliricidia as a feed

Gliricidia is generally used as a high protein supplement to low quality basal feeds such as grass, straw and other crop residues. Supplementation levels vary but are usually in the range 20-40%. There are numerous reports of increases in weight gain and milk production in both large and small ruminants when gliricidia forage is used as a supplement. Nochebuena and O'Donovan (1986) reported that for Tabasco sheep in Mexico, both intake and dry matter digestibility increased when gliricidia was used as a supplement, up to 30% of the diet, with grass hay. Chadhokar and Kantharaju (1980) found that gliricidia supplementation levels up to 80% increased survival and growth of Bannur ewes and lambs in Sri Lanka, and Van Eys *et al.* (1986), among others, have demonstrated an increase in live weight gain for goats fed Napier grass supplemented with gliricidia. For large ruminants, Chadhokar and Lecamwasam (1982) and Premaratne (1990) reported increases in live weight gain for milking cows and buffalo respectively on low protein diets supplemented with gliricidia, although supplementation levels over 50% are reported to cause tainting of the milk.

Carew (1983) has suggested that *G. sepium* may also be used as a sole protein source for ruminants. Indeed, in Sri Lanka during the dry season, gliricidia is commonly the sole feed of domestic goats (Perera 1992). Liyanage and Wijeratne (1987), however, found that with Sri Lankan heifers, a gliricidia/*Bracharia milliformis* (*grass*) mixture (1:1) gave greater live weight gain than gliricidia alone. Kabaija and Smith (1989) concluded that *G. sepium* could also provide all livestock mineral requirements if fed as sole feed, except for Cu and P which may need to be supplemented. However, the use of pure gliricidia is unusual, even during the dry season. According to Preston and Leng (1987), the growth rate of steers in Colombia fed on King grass supplemented with gliricidia increased curvilinearly with supplementation level, with the highest growth rate at about 30% gliricidia. This result is in agreement with much of the research published to date, that about 30% is the level at which the gliricidia protein is most effectively used, in mixture with low quality basal feeds.

Conclusions

Gliricidia sepium is an extremely versatile plant which can fulfil a number of roles in smallholder agricultural production systems. It is considered by many to be the second most important multipurpose tree legume after *Leucaena leucocephala* in the humid tropics. It is a species of wide-ranging soil and climatic adaptations. Consequently, it has been transported to most tropical countries and is now pantropical in distribution.

However, its value and benefits are not universally accepted as there is still debate concerning the quality of its forage. Mackenzie (1986) suggested it may not be a really useful exotic in rural communities in West Africa despite its abundance in the landscape. Hughes (1987) suggested that one reason for its poor performance in some areas may be a result of early exotic introductions coming from a very narrow genetic base.

Nevertheless, gliricidia is an extremely valuable plant in tropical farming systems and recent provenance evaluations coordinated by the OFI have highlighted superior genotypes. These and other evaluation studies will produce material that will further improve biomass production and extend the ecological range of the plant and also help to overcome some of the perceived deficiencies within the currently used provenances.

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2.3 The Perennial Sesbania Species

R.C. Gutteridge

Introduction

The perennial species of *Sesbania* establish easily, grow in difficult sites and do not require complex management to maintain productivity. They have many attributes that make them attractive as multipurpose plants and potentially useful species for agricultural production systems.

Gillett (1963) suggested that the chief economic value of the genus *Sesbania* is likely to be as a green manure and livestock forage as nearly all of the species are palatable to stock. This section describes the species and their origins, their utilisation, productivity, management and forage value with particular emphasis on the agriculturally most important species - *S. sesban* and *S. grandiflora.*

Origins and Botanical Description

The exact origin of *S. grandiflora* is not known but it is considered native to many southeast Asian countries. A closely related species, *S. formosa,* is native to northern Australia (Burbidge 1965).

Sesbania grandiflora is a loosely branching tree up to 15 m tall. Its leaves are pinnately compound up to 30 cm long with 20-50 leaflets in pairs, dimensions 12 44 x 5-15 mm, oblong to elliptical in shape. Flowers are large, white, yellowish, rose pink or red with a calyx 15-22 mm long. The standard has dimensions up to 10.5 x 6 cm. Pods are long (20-60 cm) and thin (6-9 mm) with broad sutures containing 15-50 seeds (Figure 2.3.1).

The origins of *S. sesban* are also unclear but it is widely distributed and cultivated throughout tropical Africa and Asia. It is a short-lived shrub or small tree up to 8 m tall. Its leaves are pinnately compound, 2-18 cm long with 6-27 pairs of linear oblong leaflets (26 x 5 mm). The raceme has 2-20 flowers which are yellow with purple or brown streaks on the corolla. Pods are subcylindrical, straight or slightly curved up to 30 cm long and 5 mm wide containing 10-50 seeds (Figure 2.3.2). Five varieties of *S. sesban* are recognised botanically but their differences do not correlate strongly with their agricultural value. *Sesbania sesban* var. *sesban, S. sesban* var. *bicolor* and *S. sesban* var. *nubica* are all similar and have been noted for their vigorous growth and high yields. The other lesser known varieties are *S. sesban* var. *zambesiaca* and *S. sesban* subsp. *punctata.* Unless otherwise stated, reference to *S. sesban* in this section will indicate the variety *S. sesban* var. *sesban.*

Fig. 2.3.1. Leaves, flowers and pod of *Sesbania grandiflora.*

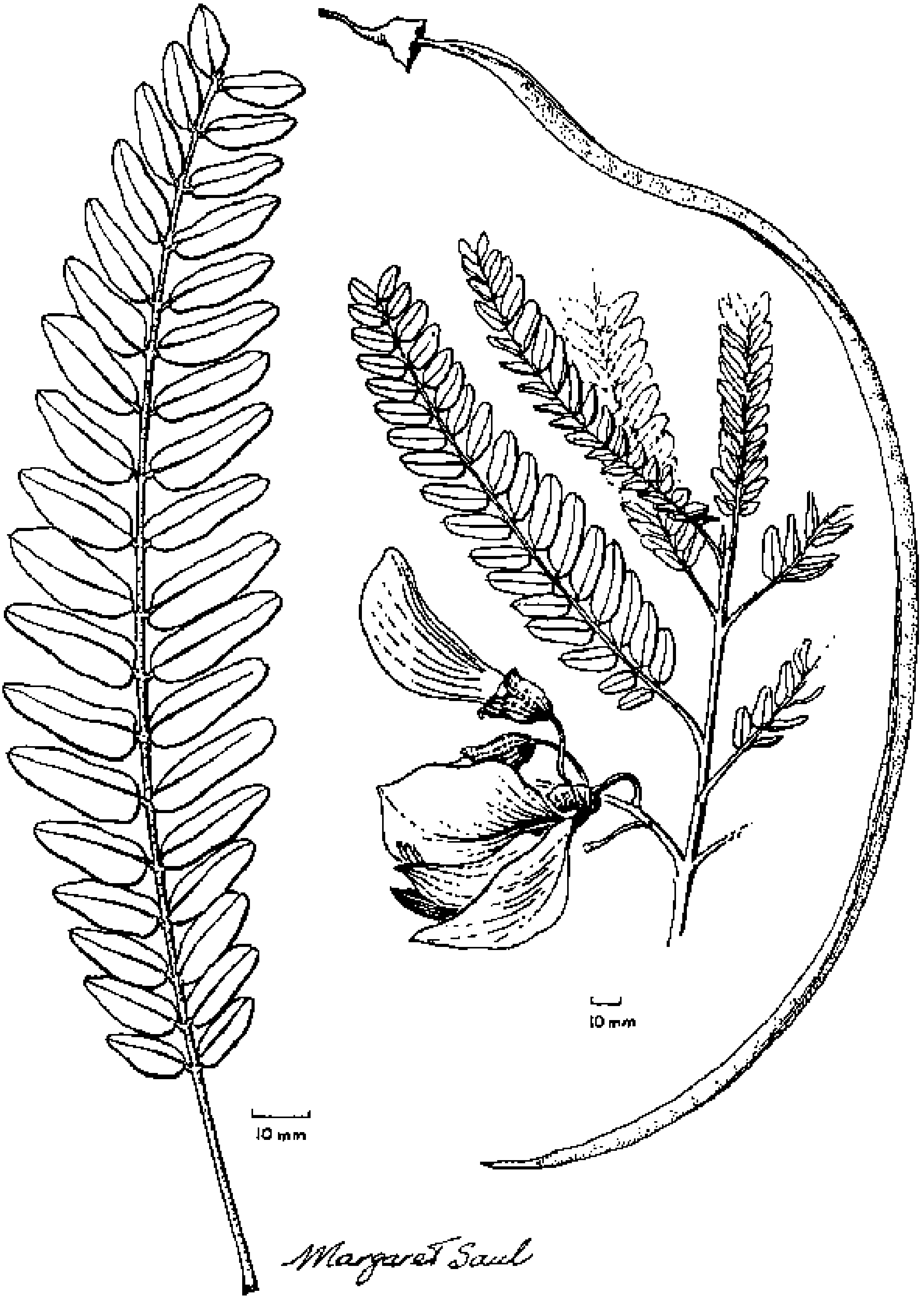
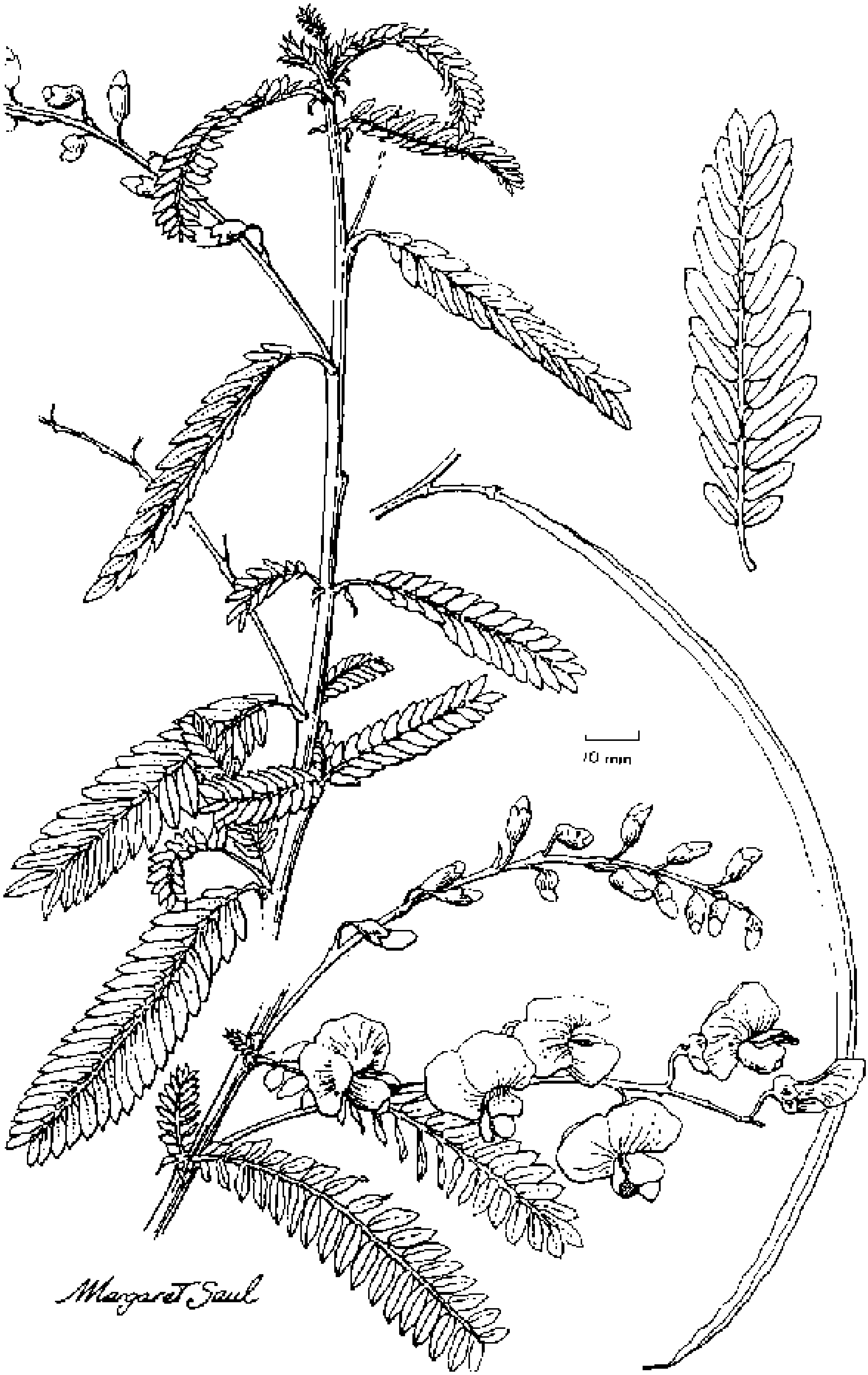


Fig. 2.3.2. Leaves, flowers and pod of *Sesbania sesban.*



Environmental Adaptation

Sesbania grandiflora is well adapted to hot, humid environments and it does not grow well in the subtropics particularly in areas with cool season minimum temperatures below about 10℃ (Wood and Larkens 198 7). On the other hand, *S. sesban* shows some cool tolerance. It grows well in the subtropics and is significant in extending the nitrogen fixing forage trees into cooler, higher elevation regions of the tropics up to 2,000 m (Anon. 1987a). Both species are outstanding in their ability to tolerate waterlogging and are ideally suited to seasonally environments. When flooded, they initiate floating adventitious roots and protect their stems, roots and nodules with spongy, aerenchyma tissue. Evans and Macklin (1990) report the rainfall range of *S. sesban* as 500-2,000 mm while *S. grandiflora* is adapted to higher rainfall conditions of 2,000-4,000 mm but will grow in areas receiving only 800 mm. Thus both species show some tolerance of moisture stress.

Another outstanding feature of both species is their tolerance of both saline and alkaline soil conditions (Hansen and Munns 1985). However, their tolerance of highly acid, aluminium saturated soils is not known.

Geographical Areas of Use

Until recently, the use of perennial *Sesbania* species has largely been restricted to south and southeast Asia. In India, these species have had a long history of agricultural use, primarily as green manures and as sources of forage (Anon. 1924, Whyte *et al.* 1953). Most of the early research on the use of perennial *Sesbania* for forage production was conducted in India (Patel 1966, Kareem and Sundararaj 1967).

In northern Thailand, Holm (1973) reported that *S. grandiflora* was an excellent supplement to dairy cows fed predominantly grass hay. In central Java, Sumarna and Sudiono (1974), cited by Evans and Rotar (1987a), detailed a two-tier forage production system in which *S. grandiflora* was used in a mixture with other tree legumes. Nitis (1985) indicated that *S. grandiflora* is widely used in Bali and Lombok while Field (1989) reported it as the main source of high protein forage in Timor following the devastation of leucaena by the psyllid insect. Nao (1979) reported that leaves of *S. grandiflora* were used as a forage to supplement rice straw in animal diets and as a mulch for home gardens in the Mekong Delta of Vietnam.

The use of these species is now spreading to other regions. *Sesbania sesban* has shown particular promise in Ethiopia to altitudes of 2,000 m (Anon. 1987a). Dougall and Bogdan (1958) suggested that *S. sesban* is a useful browse in Kenya where it is commonly found growing on either stream banks or swamp edges. It is also reported to be cultivated for forage in Iraq (Townsend 1974) and west tropical Africa (Dalziel 1937). In coastal areas of the Chinese province of Liaoning, *Sesbania* species have been used for saline soil reclamation (den *et al.* 1965). *Sesbania grandiflora* has shown promise in Western Samoa (A. Ash, personal communication) and in the Solomon Islands. In a trial conducted in southeast Queensland where 71 tree and shrub species were evaluated, *S. sesban* was the most productive species in the first 18 months (Gutteridge 1990).

Establishment

The perennial *Sesbania* species are usually established from seed. There are reports (Evans and Rotar 1987a) that both *S. grandiflora* and *S. sesban* can be propagated vegetatively using stem cuttings but this is not a widespread practice. Seeds of *S. sesban* have a hard seed coat and scarification is recommended to ensure uniform seed germination. *Sesbania grandiflora,* however, is not hard-seeded and usually germinates well without scarification.

One of the major advantages of perennial *Sesbania* species over other forage trees and shrubs is their rapid early growth rates. Dutt *et al.* (1983) reported that *S. sesban* attained a height of 4-5 m in 6 months in India In an experiment comparing the productivity of *S. sesban* and *S. sesban* var. *nubica* with 15 other trees and shrubs in northeast Thailand, Gutteridge and Akkasaeng (1985) found that they gave the highest yields (approximately 600 g edible dry matter/tree) in the first 6 months after planting. In southeast Queensland, shoot dry matter yield at 11 weeks after planting was 294, 239, 66, 25 and 21 g/m row for *S. sesban, S. formosa, Leucaena leucocephala, Acacia angustissima* and *Calliandra calothyrsus* respectively (Maasdorp and Gutteridge 1986). Woodhead (1992) also found that *S. sesban* established rapidly and grew much faster than six other tree legume species, reaching a height of 285 cm in 190 days. The rapid early growth rate of the *Sesbania* species could be exploited by combining them with other slower establishing species to provide earlier yield.

Productivity and Management

The yield potential of the perennial *Sesbania* species has been evaluated under a range of cultural practices throughout their area of use. Soil type, climate and management practices such as fertiliser use, height and interval of cutting as well as inter-cropping all affect yield.

High yields have been recorded under favourable growing conditions from a number of regions including Hawaii (Evans and Rotar 1987b), India (Gill and Patil 1983) and northern Australia (Palmer *et al.* 1989).

Cutting management has a very important influence on the productivity of perennial *Sesbania* species. *Sesbania grandiflora* cannot survive repeated cutting (Home *et al.* 1986, Evans and Rotar 1987a, Panjaitan 1988, Ella *et al.* 1989, Akkasaeng *et al.* 1989). Farmers in Lombok, Indonesia have devised a system where only the side branches of trees are cut for fodder leaving the main growing stem untouched. The trees are grown on rice paddy walls at 1.5-2 m intervals and forage is harvested in this manner for 3-4 years, yielding up to 2 kg dry matter per harvest per tree. When the foliage is no longer within easy reach the trees are felled and the long straight pole can be used for firewood or for construction (Gutteridge 1987).

By contrast, *S. sesban* thrives under repeated cutting and coppices readily with many branches arising from the main stem below cutting height (Figure 2.3.3). Cutting frequencies have generally been in the order of three or four cuts per annum but up to eight cuts per year have been taken in some areas (Gore and Joshi 1976). Yields have ranged from 4 to 12 t dry matter/ha/year depending upon location (Anon. 1924, Dutt *et al.* 1983, Galang *et al.* 1990).

Cutting height can also influence yield in *S. sesban.* Mune Gowda and Krishnamurthy (1984) reported higher yields at a low cutting height of 50 cm. However, in other reports, cutting at 76 cm was found *to* favour plant survival and productivity in India (Anon. 1924), while in southeast Queensland, a cutting height of 100 cm for *S. sesban* var. *nubica* gave higher yields than heights of 150 and 50 cm (Galang *et al.* 1990).

There are few studies on the reaction of perennial *Sesbania* species to direct grazing by livestock. There are several reports that both *S. grandiflora* and *S. sesban* are browsed (Gillett 1963, Lamprey *et al.* 1980, Dougall and Bogdan 1958) but no indication of their rate of recovery after browsing. P.R.D. Philp (personal communication) reported that young *S. grandiflora* trees were destroyed by goats grazing in the dry season in Sumbawa, Indonesia At Mt Cotton, southeast Queensland, goats grazed an 8 month old stand of *S. sesban* var. *nubica* that had reached a height of 3 m and 'ringbarked' the main stem 10-15 cm above ground level causing 75% plant mortality (Kochapakdee 1991).

The only long-term grazing study sighted was that of Gutteridge and Shelton (1991) in southeast Queensland. They reported the results of a 15 month cattle grazing study in which a 2 ha area of forage comprising 4 m wide rows of *S. sesban* interplanted with *Brachiaria decumbens* was grazed by belmont red heifers at 1.5 beasts/ha. Although excellent liveweight gains were achieved (Figure 2.3.4), the grazing cattle caused breakage and splitting of many side branches of *S. sesban* trees. This was due to the brittle nature of these branches and resulted in a shortened longevity of trees from 5-6 years in an adjacent cutting management trial (Galang *et al.* 1990) to 2-3 years under grazing management.

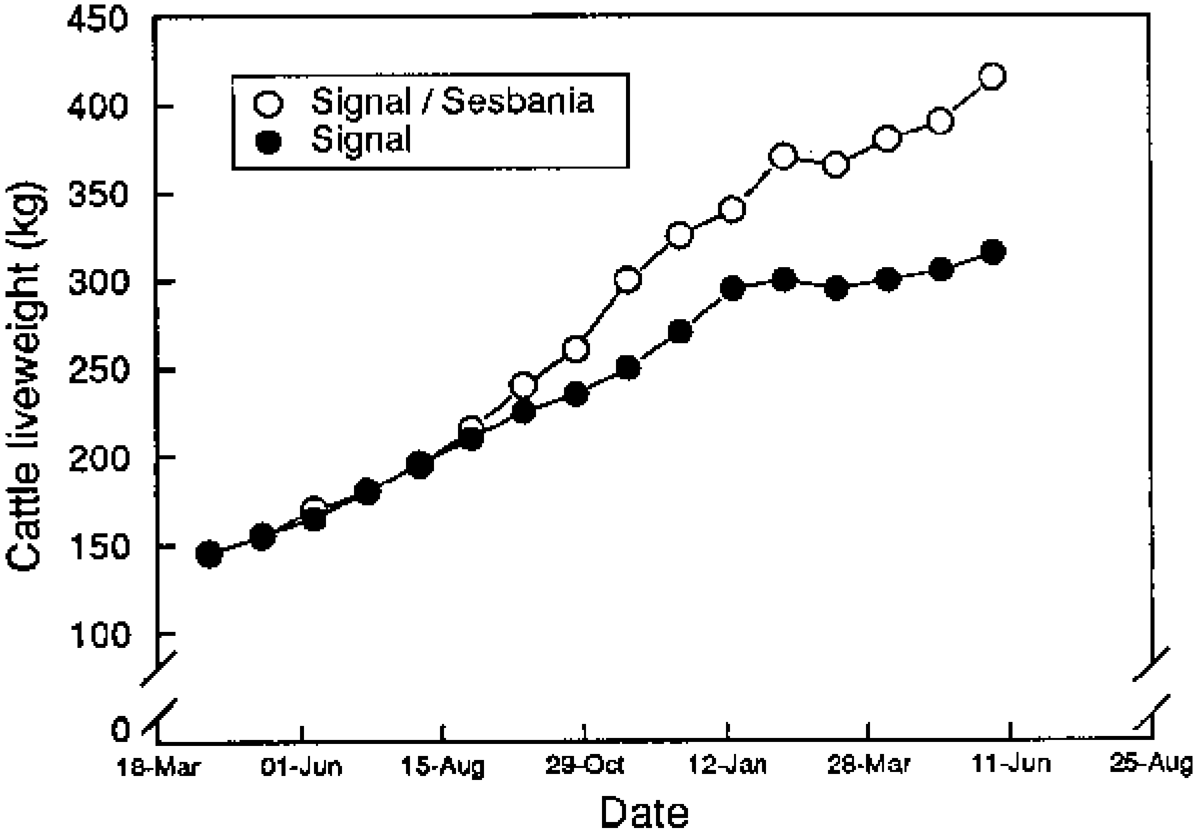
Nutritive Value

Many reports in the literature confirm that the leaves and young branches of both *S. grandiflora* and *S. sesban* are readily eaten by ruminants such as cattle and goats (Verboom 1966, NAS 1979, Gohl 1981, and Hutagalung 1981). P.R.D. Philp (personal communication) observed that smallholder farmers in Timor, Indonesia preferred *S. grandiflora to Leucaena* stating that the former was more palatable and more nutritious for their stock.

Fig. 2.3.3. *Sesbania sesban* cut at 6 week intervals in southeast Queensland.

Most reports indicate that the crude protein content of both *S. sesban and S. grandiflora* foliage is generally greater than 20% and often above 25% (Table 2.3.1). Dry matter digestibility of *Sesbania* species is superior to that of most other tree and shrub legumes. In northeast Thailand, Akkasaeng *et al.* (1989) found that the *in vitro* dry matter digestibility of *S. grandiflora, S. sesban* and *S. sesban* var. *nubica* was 66, 75 and 66% respectively, all higher than that of 15 other tree legumes that were tested. van *Eys et al.* (1986) reported that *S. grandiflora* contained more crude protein but less fibre than *Gliricidia sepium* and *Leucaena leucocephala* while their *in vitro* dry matter digestibilities were 73.3, 65.2 and 62.2% respectively.

Fig. 2.3.4. Mean liveweight gain of heifers grazing *Sesbania sesban*/signal grass mixture or signal grass alone fertilised with 200 kg N/ha/year.



Singh *et al.* (1980), in a feeding trail with goats, reported dry matter digestibilities ranging from 66.5 to 71.4% for *S. sesban.* In an experiment reported by Reed and Soller (1987), *S. sesban* had the lowest acid detergent lignin (4% dry matter) and the highest N retention (1.2 g/day) of four browse species. Ahn *et al.* (1989) reported that the nylon bag dry matter digestibility and nitrogen digestibility of dried leaf of *S. sesban* was 90.7% and 96.7% respectively. The digestibilities of *S. sesban* were the highest of the 12 forage trees tested in the experiment.

These data together with the generally low crude fibre content and high phosphorous levels indicate the potential of these species as high quality forage sources.

Animal Production

Data from feeding experiments with perennial *Sesbania* species are limited. In most instances the herbage of *Sesbania* has been fed as a supplement to low quality straws or grasses and for relatively short periods.

Table 2.3.1. Chemical composition of *S. grandiflora, S. formosa* and *S. sesban* (% dry matter).

	CP	CF	Total CHO	Ash	P	Ca	Reference
S. grandiflora							
leaf	22.6	18.4	-	9.3	0.32	1.10	1
leaf	36.2	9.2	46.1	9.2	-	-	2
flowers	14.5	10.9	77.3	4.5	-	-	2
leaf	30.1	5.1	42.3	10.4	-	-	3
leaf	25.6	17.8	-	-	0.45	1.46	4
leaf	34.8	7.5	-	12.5	0.33	2.33	5
leaf	20.1	-	-	6.2	-	-	6
S. formosa	21.3	-	-	6.5	-	-	6
leaf							
S. sesban							
leaf	19.4	32.9	70.0	7.4	0.09	1.42	7
leaf	26.0	14.4	-	7.6	0.27	1.11	8
leaf	25.3	-	-	8.4	-	-	6
fresh leaf	21.3	15.3	-	8.0	0.25	-	9
dried leaf	26.4	16.6	-	7.7	0.24	-	9

CP = crude protein
CF = crude fibre
CHO = carbohydrate

References: 1. Devendra (1979); 2. NAS (1979); 3. Skerman (1977); 4. Hutagalung (1981); 5. Brewbaker (1986); 6. Akkasaeng *et al.* (1989); 7. Singh *et al.* (1980); 8. Gohl (1981); 9. Robertson (1988)

In experiments in Java, NAS (1979) reported that 1.8 kg of fresh *S. grandiflora* leaf fed daily to cattle on a rice straw diet achieved growth increases comparable to those obtained by feeding formulated diets. Robertson (1988) obtained a growth rate of 7 g/kg$^{0.75}$/day with goats fed dried *S. sesban* as a 30% supplement to rice straw over a period of 4 weeks. Singh *et al.* (1980) found that goats fed a diet of *S. sesban* forage *ad lib* for a period of 8 weeks gained an average of 17.1 g/head/day compared with 30.3 g/head/day when 20% of the forage was replaced with a concentrate mixture.

In the previously mentioned study of cattle grazing *S. sesban,* Gutteridge and Shelton (1991) reported liveweight gains of 0.7 kg/head/day over 15 months for young heifers grazing a mixed *S. sesban/Brachiaria decumbens* pasture in southeast Queensland. This compared with liveweight gains of 0.4 kg/head/day for similar cattle grazing *B. decumbens* alone fertilised with 200 kg N/ha/year (Figure 2.3.4). The heifers were at first reluctant to graze *S. sesban* but once they became accustomed to it they consumed it readily at up to 20% of their diet.

Even though the perennial *Sesbania* species have generally higher *in vitro* digestibilities and better apparent nutrient status than many other browse trees, the liveweight gains achieved in feeding experiments are often no better than for other tree forages. This may be associated with anti-nutritive factors in the *Sesbania* forage. When van Eys *et al.* (1986) fed goats *Gliricidia, Leucaena* or *S. grandiflora* as a 15% supplement to Napier grass hay, there was no difference between the legumes in intake or liveweight gain, which averaged 20 g/head/day.

When *Acacia seyal, A. nilotica* and *S. sesban* were fed as supplements to teff straw (*Eragrostis tef*) *to* both sheep and goats in Ethiopia, the growth rates of sheep fed the three supplements were 40, 42 and 35 g/head/day while those for goats were 19, 17 and 4 g/head/day respectively (Anon. 1987b). Even though the nitrogen digestibility and N balance of the *S. sesban* supplement were the highest of the three forages, lower growth rates occurred in both classes of animal. In contrast, Reed (1988) reported that sheep fed dried *S. sesban* as a supplement to teff straw gained weight at the relatively high rate of 48 g/day over 90 days. This was similar to weight gains of sheep fed vetch and more than double those fed *Acacia cyanophylla, A. sayel* or *A. sieberiana.* In Kenya, Semenye *et al.* (1987) reported that young goats fed a sole diet of *Sesbania sesban* hay developed severe ill-thrift symptoms after only 2 weeks and by 4 weeks, two of the six animals had died.

Information on anti-nutritive factors in the forage of perennial *Sesbania* species is limited. An analysis of the phytochemical components of the foliage and flowers of *S. grandiflora* indicated the presence of sterols, saponins and tannins (Fojas *et al.* 1982). Ahn *et al.* (1989) found that *S. sesban* var. *nubica* contained no condensed tannins in fresh or oven-dried material but the concentration of total phenolics was 2.8% and 2.5% in the fresh and dried material respectively.

It appears that the most economically efficient and safest use of perennial *Sesbania* forage for ruminants is as a protein supplement to low quality roughages such as crop residues or dried grasses. This dilutes the effects of anti-nutritive factors and greatly improves the utilisation of the roughages. Gutteridge and Shelton (1991) found no toxic or anti-nutritive effects of *S. sesban* on the health of heifers grazing a mixture of *S. sesban* and the grass *Brachiaria decumbens* for a period of 15 months.

Perennial *Sesbania* forage is less suitable in the diets of monogastric animals. *Sesbania grandiflora* leaf meal progressively depressed chicken feed intake and body weight when incorporated at rates of 0, 5, 10 and 15% of the total ration (Prasad *et al.* 1970). Williams (1983), cited by Evans and Rotar (1987a), fed dried, encapsulated leaves of *S. grandiflora, S. formosa* and two varieties of *S. sesban* to week old chicks at 1% of body weight. All chicks died before the 5th day when fed *S. grandiflora* and *S. sesban* but no toxic signs were observed in those fed *S. formosa.* A. Ash (personal communication) reported high mortality of chicks fed *S. grandiflora* leaf meal in Western Samoa but Raharjo and Cheeke (1987) found that rabbits fed a concentrate diet with a supplement of *S. grandiflora* foliage gained 12.7 g/day with no apparent ill effects. Most of these reports indicate the need for caution before using perennial *Sesbania* species in the diets of monogastric animals.

Fuelwood and Timber

Information on the wood yields of the perennial sesbanias is limited. Onim *et al.* (1989) reported a yield of 16 t/ha of sun-dried wood from a 4 year old stand of *S. sesban* at a density of 1,600 plants/ha in Kenya while much higher yields of 63.5

t/ha were reported for *S. sesban* grown under rainfed conditions in Haryana, India (Singh 1989).

Despite the lack of detailed information on yield, von Carlowitz (1989) pointed out that *S. sesban* is popular for fuelwood because it produces a high woody biomass in a short time which, though soft, is a relatively smokeless, quick, hot burning kindling. The wood of *S. grandiflora,* on the other hand, is not highly valued for cooking as it has poor burning qualities and produces much smoke. The density of *S. grandiflora* wood increases with ageing and the timber from 5-8 year old trees can be used in house construction or as craftwood.

Soil Fertility Improvement

Annual *Sesbania* species such as *S. cannabina, S. rostrata* and *S. bispinosa* are widely used in Asia as green manures in paddy rice cultivation because of their ability to withstand waterlogging. *Sesbania sesban* is used to a lesser extent in this context but probably because it is not as fast growing as the annual species. Sivaraman (1951) reported a 20-40% increase in rice yields with the use of *S. sesban* leaf as a green manure in southern India. In an upland crop of maize in Sri Lanka, Weerakoon (1989) obtained grain yields of 1.9, 3.9 and 4.4 t/ha for control, *S. sesban* green manure and 96 kg N fertiliser/ha treatments respectively. In the green manure treatment, 4.4 t dry matter/ha was incorporated after 84 days growth with an N equivalent of 83 kg N/ha.

Onim *et al.* (1987) speculated that the perennial *Sesbania* species could fix up to 600 kg N/ha/year. They felt this was possible because *Sesbania* roots are readily infected by the less specific cowpea types of *Rhizobium* giving large numbers of active nodules. Under experimental conditions they reported a total nitrogen yield of 448 kg N/ha from the aerial biomass of *S. sesban* var. *nubica.* This was higher than that from *Cajanus cajan* but less than that from *Leucaena leucocephala.* Incorporation of up to 13 t dry matter/ha of *S. sesban* mulch improved maize and bean yields by 78% and residual effects lasted up to 3 years (Onim *et al.* 1989).

Yamoah and Getahun (1989) suggested that *S. sesban* is a promising shrub for alley cropping because it is easy to establish, it grows rapidly, coppices readily and provides mulch of high nutrient content (particularly N). Prunings from *S. sesban* in combination with moderate amounts of N and P fertilisers, increased yields of maize and beans in alleys 6 and 8 m wide in Rwanda (Yamoah and Burleigh 1988). However, these authors cautioned that the species is relatively short-lived and susceptible to nematodes and some crop pests and therefore should be combined with a longer lived truly perennial species for best results.

Sesbania grandiflora was declared inappropriate for alley cropping in the lowland humid tropics of Nigeria because it showed a high mortality of up to 80% when coppiced and produced less biomass than leucaena and gliricidia (Duguma *et al.* 1988).

Other Uses

The flowers and young leaves of *S. grandiflora* are edible and are often used as a vegetable to supplement meals. Tender pods may also be eaten as string beans. The dried leaves of both *S. grandiflora* and *S. sesban* are used in some countries as a tea which is considered to have antibiotic, anti-helminthic, anti-tumour and contraceptive properties.

Bark exudate and seed endosperm gums are produced by many species of *Sesbania,* but are not seen as an alternative to gum arabic (Anderson 1989). The taller species of perennial *Sesbania* such as *S. grandiflora, S. formosa* and *S. sesban* can also be used as shade trees for coffee, tea and cocoa as well as living trellises for pepper and as windbreaks for citrus, bananas and coffee.

Conclusions

Although perennial *Sesbania* species play an important role as forage and green manure plants in a number of regions in the world, they are still relatively underutilised in many tropical and subtropical areas. There is scope for greater use of *Sesbania* species in ruminant feeding systems, particularly as high quality supplements to low quality roughages.

More research is required to determine appropriate management systems to maximise yields of edible material. More studies on the effects of direct grazing in extensive feeding systems are also warranted, particularly for *S. sesban,* to determine the effects of grazing on plant longevity.

It appears that the use of the perennial *Sesbania* species should be restricted to ruminants because of the deleterious effects often observed when they are used as feed sources for monogastrics. However, even with ruminants, there may be adverse effects on animal productivity and health when *Sesbania* comprises a high proportion of diets for long periods. Research is required to determine whether anti-nutritive factors are present in *Sesbania* forage and whether they can be controlled or reduced by management practices.

Greater use could be made of the ability of the perennial *Sesbania* species to grow in 'inhospitable' sites. Both *S. sesban* and *S. grandiflora* show some tolerance of soil salinity and alkalinity and both grow well in waterlogged environments. There are many situations in the tropics and subtropics where periodic inundation and/or saline encroachment severely restrict agricultural productivity. Perennial *Sesbania* species could be used to help reclaim some of these sites by providing green manure, mulch or high quality forage.

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2.4 Calliandra calothyrsus - a Multipurpose Tree Legume for Humid Locations

B. Palmer, D.J. Macqueen and R.C. Gutteridge

Introduction

Calliandra calothyrsus Meissn. (calliandra) is a small, thornless leguminous tree native to Central America and Mexico. It is rarely utilised in its native range but it has been introduced to many tropical regions where it is used in agroforestry systems for fuelwood, plantation shade, as an intercrop hedgerow and more recently as livestock forage.

It is particularly favoured in Indonesia where over 170,000 ha have been planted for reforestation of eroded, poor quality land around villages (NAS 1983).

This section describes the species, its origin, ecology, agronomy and some of its many uses throughout the tropics.

Taxonomy

Systematics

There is confusion regarding the taxonomy of the genus *Calliandra* due to the morphological similarity of *C. calothyrsus* to *C. grandiflora* and *C. houstoniana,* and the observed hybridisation between the latter species (Hernandez 1991). *Calliandra calothyrsus* Meissn. is one of seven species in a subgroup of the genus, the Racemose delimited by Bentham (1844) and belonging to the family Mimoseae. *Calliandra calothyrsus* was described by Meissner (1848) and the later names *C. confusa* and *C. similis* have now been placed in synonymy. *Calliandra acapulcensis,* the closest relative of *C. calothyrsus,* is now considered to be only a subspecies extending its known range to Colima in Central Mexico.

Botanical description

Calliandra calothyrsus Meissn. is a small tree (2-12 m high), with a trunk diameter of up to 30 cm, with white to red brown bark and a dense canopy. Leaves are bipinnate and alternate; the rachis is 10-19 cm long, without glands; pinnae are (3)-6-20 jugate; rachilla are 2-11 cm long; there are 19-60 pairs of leaflets; leaflets are linear, oblong and acute, 5-8 x 1 mm. Inflorescences are particulate with flowers in umbelliform clusters of 10-30 cm length. Flower sepals and petals are green, calyx 2 mm long, corolla 5-6 mm long. The numerous red stamina! filaments are 4-6 cm long. Fruits are broadly linear, flattened, 8-11 cm x 1 cm linear oblong with thickened and raised margins, finely pubescent or glabrous, brown dehiscent, 8(12) seeded. Seeds are ellipsoid, flattened, 5-7 mm long and mottled dark brown (Weirsum and Rika 1992) (Figure 2.4.1).

Origin and Geographic Distribution

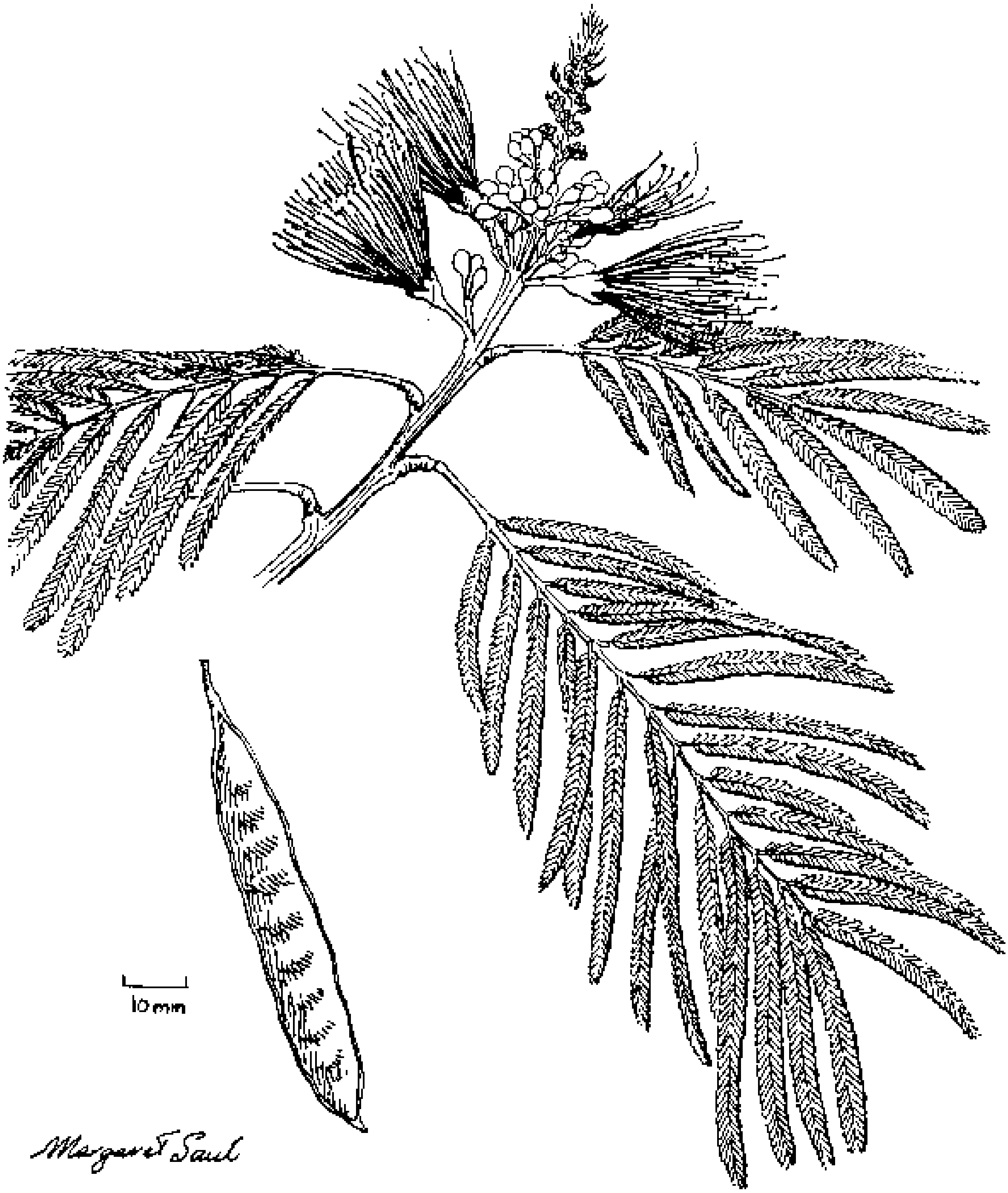
The plant is native to the humid and subhumid regions of Central America and Mexico and is found from southern Mexico to Central Panama, approximately between 8°and 19°N (Macqueen 1992). It was introduced from Guatemala to Java, Indonesia in 1936 (Verhoef 1939) as a possible source of green manure and shade for coffee plantations and is now found throughout the Indonesian archipelago. During the 1970s, sponsored by the Indonesian State Forest Corporation, *C. calothyrsus* was planted in many areas of Java and elsewhere in Indonesia in what has been termed 'a true self perpetuating greening movement'.

More recently it has been introduced to other areas of southeast Asia and is also under experimental evaluation in Africa, Australia, Brazil, Bolivia and Hawaii.

Ecology

Calliandra calothyrsus is a riverine colonist with relatively rapid early growth. It is outcompeted in later successional stages but may often invade areas of continual disturbance such as roadsides or shifting cultivations. In its native Central American habitat, it grows at altitudes from sea level to 1,860 m in areas where the annual precipitation ranges from 700 to 3,000 mm (Lowry and Macklin 1989). The plant is not very drought tolerant although it is able to withstand dry periods. In humid climates, the tree is evergreen, whereas in areas with a long dry season it is semi-deciduous. Under severe drought conditions, the tree will die back but will generally recover after the onset of the rainy season although Akkasaeng *et al.* (1989) reported only 20% survival of *C. calothyrsus* after 30 months in a monsoonal environment in northeast Thailand.

Fig. 2.4.1. Leaves, flowers and pod *of Calliandra calothyrsus.*



Pollination is achieved in the native range by hawkmoths and bats of the genus *Glossophaga.* Protandrous flowering and the difference in length between stigma and style suggest outcrossing. Pod ripening is basipetal over several months and seed dispersal is through apical dehiscence of the pods.

Calliandra calothyrsus grows well on a wide range of soil types ranging from deep volcanic loams to more acidic metamorphic sandy clays. It appears naturally well suited to the light textured slightly acidic soils of volcanic origin which are common to the humid and subhumid tropics of southeast Asia. The precipitation pattern in these areas shows a well defined wet and dry season and an annual rainfall of 2,000-4,000 mm. The plant is not tolerant of low oxygen tensions in waterlogged situations (Galang 1988) and does not grow well on poorly drained calcareous soils.

Within its native environment, *C. calothyrsus* occupies areas with mean monthly maximum temperatures between 24 and 28℃ and mean minimum temperatures of 18-24℃ (Wiersum and Rika 1992). These areas are frost free but *C. calothyrsus* appears to have some cool tolerance since it grows up to 1,800 m in Guatemala.

It is thought that the introduction of *C. calothyrsus* to Indonesia in 1936 was based on only two seed samples from Guatemala (NAS 1983). This accounts for the lack of variation in the Indonesian material. The evaluation of a range of provenances is therefore desirable and the species has now been collected by the Oxford Forestry Institute at over 40 sites from seven countries in Central America covering a large range of edaphic and climatic regimes. A programme to evaluate these provenances is underway and seed is available on request (Macqueen 1991, 1992).

Agronomy

Calliandra calothyrsus does not take well from stakes and is therefore best propagated from seed in the field or raised in a nursery. Seeds germinate without pre-treatment, but considerable improvement has been obtained after mechanical scarification (Verhoef 1939, Halliday and Nakao 1984). Caution should be exercised when using hot water treatment to improve germination as the seed appears more sensitive than seed of other tree legume species and some failures have resulted. It is commonly stated that inoculation with *Rhizobium* is not necessary (Zhou and Han 1984) but use of an appropriate strain is advised when introducing the plant to new areas.

Calliandra calothyrsus, like many other tree legumes, often displays slow early growth (Evans 1984, Glover and Heuveldop 1985, Jama *et al.* 1989). This may be linked to poor or ineffective mycorrhizal associations (B. Palmer, unpublished data). However, once it is mycorrhizal, *C. calothyrsus* grows quite vigorously and can achieve a height of 3.5 m in 6 months (Wiersum and Rika 1992). This rapid growth allows the plant to be used as a smother crop in *Imperata cylindrica* infested areas.

While there are no reports of serious pest or disease problems some insects may cause minor damage. Nair (1982) reported seedlings of *C. calothyrsus* attacked by the teak sapling borer (*Sahyadrassus malabaricus*)*,* while in Kenya, *Pachnoda ephippiata* feeds on the flowers, fruits and foliage causing floral abortion and poor seed production (Kaudia 1990) (Section 6.3). If the plants are coppiced too low immediately prior to rain, or during the wet season, they may be susceptible to fungal attack. This problem is, however, common to most shrubs and trees. Seed production may commence in the first year but usually the plant fruits well only after the second year (Section 3.6).

The use of fertiliser, particularly on infertile soils, will improve the early growth and yield of *Calliandra,* but it is less responsive to fertiliser than some other tree legumes and will often outyield other species on infertile soils. Palmer *et al.* (1989) found this when comparing the growth of *C. calothyrsus, Leucaena leucocephala* and *Gliricidia sepium* at two sites in Indonesia and at two sites in Australia (Table 2.4.1).

However, on more fertile, less acidic soils, yields of *C. calothyrsus* were similar to those of other species. On a Typic Humitropept derived from basalt in Western Samoa, *C. calothyrsus* and *G. sepium* gave similar biomass dry matter yields of approximately 10 t/ha/year in 4 m alleys over 4 years (Rosecrance *et al.* 1992b). In Hawaii, in an experiment to evaluate nine leguminous trees for alley cropping, *C. calothyrsus* yielded 4.3 t/ha and was fifth behind *Sesbania sesban, G. sepium, Leucaena pallida and Cajanus cajan* in yield (Rosecrance *et al.* 1992a).

Uses

The uses of calliandra have been detailed in a number of publications including NAS (1983), Lowry and Macklin (1989), Wiersum and Rika (1992) and Macqueen (1992). In its native area, it was unused and it was not until it was introduced into Indonesia that its potential value and multipurpose uses became apparent.

The common uses of *C. calothyrsus* are as follows:

- firewood,
- fodder,
- reforestation,
- soil stabilisation,
- soil improvement,
- minor secondary production (pulp and paper, honey and shellac, leaf meal).

Table 2.4.1. Soil parameters and annual leaf yield (t/ha) of three tree legumes at four sites with and without fertiliser application (after Palmer *et al.* 1989).

		Cation exchange capacity (meq/100 g)	***C. calothyrsus***		***G. sepium***		***L. leucocephala***	
Sites	**pH**		**Fertiliser application***					
			-	**+**	**-**	**+**	**-**	**+**
(a) Fertile sites								
Utchee Creek (Australia)	5.3	2.39	11.3	12.6	7.8	7.8	5.5	7.3
Sei Putih (Indonesia)	5.3	2.69	6.6	11.8	5.2	7.5	4.0	7.5
(b) Less fertile sites								
Silkwood (Australia)	5.3	0.83	3.0	7.7	1.5	5.2	0.4	3.1
Sembawa (Indonesia)	4.9	0.87	2.3	6.8	1.1	3.1	0.5	2.1

* The fertiliser treatment was an application of 33 kg P, 20 kg Mg, 3 kg Cu, 3 kg Zn, 0.2 kg Mo, 1.5 kg B and 2 t lime/ha (at Sembawa and Silkwood) or 0.4 t lime/ha (at Sei Putih and Utchee Creek)

Firewood

The wood of *C. calothyrsus* has a volumetric mass of 510-780 kg/m^3 and a calorific value of about 4,720 kcal/kg (Yantasath *et al.* 1985, Lowry and Macklin 1989). It is therefore a good fuelwood. The moisture content of calliandra wood (9-12%) is lower than that of other woods (e.g. leucaena 13.5%) and hence less drying is needed. The wood is suitable for charcoal production and as a smoking fuel for the production of smoked sheet rubber. There is a demand for smoking fuel since old rubber trees, the traditional source, are increasingly used by furniture manufacturers. Annual wood yields have been reported in the order of 15-40 t/ha with annual coppice harvests continuing for 10-20 years (Wiersum and Rika 1992).

Fodder

In Indonesia, annual forage yields of *C. calothyrsus* in the order of 7-10 t/ha of dry matter have been recorded over a wide range of edaphic and climatic zones (Ella *et al.* 1989). Kidd and Taogaga (1984) reported fresh fodder yields of up to 46.2 t/ha/year from Western Samoa.

There are varying reports on the acceptability of *C. calothyrsus* to domesticated animals in Indonesia. However, it appears to be readily eaten by animals although only limited information is available on its nutritional value. It is routinely fed to goats on the islands of Java, Sumatra, Flores and Sumbawa and to dairy cattle in West Java, where the animals readily eat the fresh herbage. In several experiments in Australia, calliandra has been shown to be highly palatable for both grazing and pen-fed animals (B. Palmer, unpublished data). However, Raharjo and Cheeke

(1985) reported that its palatability to rabbits was low. Wiersum and Rika (1992) reported 22% crude protein, 30-70% fibre, 4-5% ash and 2-3% fat in dried leaves of *C. calothyrsus.* No toxic substances have been found but high concentrations of condensed tannins (up to 11%) have been reported (Akin *et al,* 1989). These levels may be responsible for the rather low (around 40%) *in sacco* digestibilities measured on oven-dried material in a number of experiments (Baggio and Hueveldop 1984, Robertson 1988). An advantage of the tannin is that it ensures protected (bypass) protein but high levels of tannin may reduce the digestibility of protein for livestock.

However, recent work in both Australia and Indonesia has indicated that forage of *C. calothyrsus* may have higher value when fed fresh. When leaf material of *C. calothyrsus* was fed fresh to sheep, voluntary intake was 59 g dry matter/kg $W^{0.75}$ whereas for dried material it was 37 g dry matter/kg $W^{0.75}$ ($W^{0.75}$ is the metabolic weight of the animal). The higher level of voluntary intake was associated with a higher *in sacco* digestibility of fresh material compared with oven-dried or freeze-dried material (Palmer and Schlink 1992). In feeding trials conducted in Indonesia with both goats and sheep, the in vivo estimates of digestibility were in the order of 60% (Mahyuddin *et al.* 1988). These data suggest that the nutritive value of *C. calothyrsus* is not yet fully understood, but the high digestibility of fresh material (60-80%) shows the potential of calliandra as a feed for browsing animals (Palmer and Schlink 1992).

Reforestation and soil stabilisation

Calliandra calothyrsus has been used to rehabilitate erosion prone areas such as recently cleared forests and steep slopes with high erosion risks (Kan and Hu 1987). The combination of a deep and well developed lateral rooting habit provides a structure to stabilise the soil.

Furthermore, it has been reported from Indonesia that it can be aerially seeded successfully. This could be a strategy for the reforestation of mountainous or otherwise inaccessible terrain (NAS 1983).

Soil improvement

Calliandra calothyrsus as a nitrogen fixing tree has been used as a green manure to improve the fertility status of soil in rotation with sugar cane and in alley cropping with corn (Gichuru and Kang 1989). Calliandra produces high yields of high protein leaf material on less fertile soils and is therefore very suitable as a green manure. However, the relatively high levels of polyphenols (tannins) present in the leaves of calliandra slow the rate of microbial breakdown of the organic matter reducing its value as a soil ameliorant (Gutteridge 1992).

Minor secondary production

Calliandra calothyrsus has proved useful in a number of different ways. It flowers prolifically and is a favoured source of nectar for honey bees. The honey produced is considered to be of exceptionally high quality (Nadiar 1979). It has also been shown to be a suitable host for shellac producing insects. As an additive to leaf meal it has shown promise both as a protein source and as a source of carotene to maintain yolk colour in commercially produced eggs.

Conclusions

Calliandra calothyrsus is a versatile plant being used in a number of agroforestry applications throughout the tropics. It produces high quality fuelwood which can be harvested on an annual coppice rotation. It grows over a wide range of soil types and is often outstanding on infertile sites where it is used extensively for reclamation.

Its high yielding ability and high protein content indicate its potential as a valuable forage source. However, it has not been widely accepted in this role partly because of the apparent low acceptability of cut forage to stock. Recent studies have shown higher digestibility and intake of fresh forage and further work on the effects of direct grazing of *C. calothyrsus* appears warranted to help determine appropriate management systems for this potentially useful forage species.

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2.5 Albizia lebbeck - a Promising Forage Tree for Semiarid Regions

J.B. Lowry, J.H. Prinsen and D.M. Burrows

Introduction

Albizia lebbeck is a tree well known in the Indian subcontinent for its range of uses. Although geographically widespread, little is known about the species outside India. It appears to have potential for increasing pastoral production in extensive systems in the wet-dry tropics where the major problem is low feed quality of the basal diet, mature tropical grasses. *Albizia lebbeck* addresses this problem in three ways: as a feed, as a supplement and by improving grass quality.

Nomenclature

Albizia lebbeck (*L.*) Benth (Mimosaceae) has a variety of vernacular names including siris, koko, vagai (India), tekik (Javanese), kitoke, tarisi (Sundanese), khago, ka se (Thai), East Indian walnut and Indian siris (timber trade). A number of names are trivial (mother-in-law's tongue, rattle-pod (West Indies)) or misleading (acacia, raintree (northern Australia)). The Indian name siris is most commonly used (Anon. 1980). Use of 'albizia' as a common name should be avoided as it is often applied to *Paraserianthes falcataria,* a species of major importance in the wet tropics, and very different from siris. *Albizia* is a genus of about 100 species, very similar to *Acacia* but formally distinguished by the stamens being fused at the base rather than free. The genus is more restricted to the tropics than the acacias, and none of the species is phyllodinous.

Botanical Description

A medium to large tree, of multi-stemmed widely spreading habit (to 30 m diameter) when grown in the open, but capable of good log form in plantation. Height to 20 m. Bark rough, grey; inner bark reddish. Leaves bipinnate, rachis 70-90 mm, rachillae 1-5 pairs, 50-70 mm. Leaflets 3-11 pairs, oblong to elliptic-oblong, asymmetrical, 15-65 mm x 5-35 mm, glabrous, entire, initially bright green and folding at night, maturing to a duller glaucous green and fixed rachis. Fully but briefly deciduous in the dry season. Inflorescence an axillary cluster of 15-40 pedicellate flowers. Peduncle to 100 mm, pedicel 1.5-5 mm, corolla inconspicuous, free filaments numerous, 15-30 mm. Entire inflorescence, fluffy, 60 mm diameter, yellow-green with distinctive pleasant fragrance. Pod flat oblong 120-350 mm x 30-60 mm, stiff-papery when ripe, swollen over seeds, dehiscent. Seeds 3-12 per pod, brown, flattened, 7 x 1.5 mm (Figure 2.5.1).

Distribution and Ecology

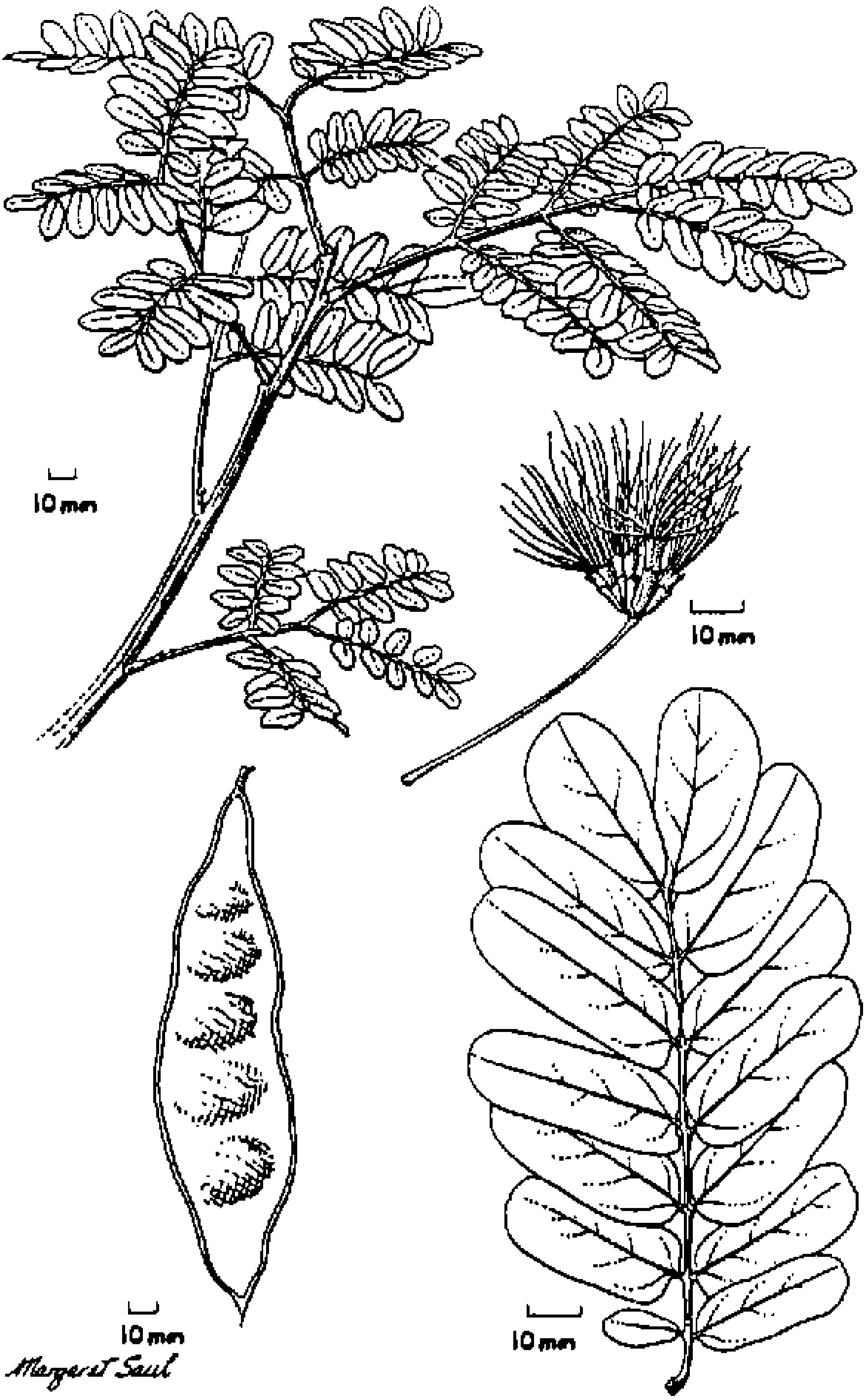
Siris is indigenous to the Indian subcontinent, to those areas of southeast Asia with a marked dry season (e.g. northeast Thailand, eastern islands of Indonesia) and to the monsoon areas of northern Australia. In this latter region, it has been recorded in such formations as 'semi-deciduous mesophyll vine forest' (Kabay and Burbidge 1977). Herbarium notes often place it at the rainforest-eucalypt woodland ecotone. These indigenous populations are probably declining as seedlings cannot establish under continuous grazing by cattle. It has been distributed widely around the tropics, mainly as a shade tree, and has occasionally naturalised. It can grow well under a wide range of rainfall regimes (600-2,500 mm) yet can be seen in areas with only 400 mm. It may be established in areas of highly variable rainfall but in its natural habitat probably requires a reliable wet season. In the Himalayas it is found to 1,600 m altitude. It is found on a wide range of soil types including those that are alkaline and saline (Prinsen 1986) but not subject to waterlogging.

Siris seedlings will not tolerate frost. Reserves in the root system enable young plants to survive total defoliation from fire or grazing, but with obvious setback to growth. Growth is opportunistic when conditions are suitable but ceases for 2-3 months before leaf drop. Trees are leafless for only 4-6 weeks, with new leaf produced at the height of the dry season, followed in the tropics by a gregarious flowering. Flowers are insect-pollinated. Seed dispersal seems to occur mainly due to strong wind, when intact pods can be carried hundreds of metres. Seeds are retained in pods until they fall. Some seed passes through the intestinal tract of cattle but not of smaller ruminants.

Productivity

Comprehensive yield data have not been published. However, it is evident that the species is productive when actively growing or regenerating or as undisturbed mature trees. Under best conditions, plants can grow to 5 m in one year; however, growth in areas with under 800 mm annual rainfall is much slower.

Fig. 2.5.1. Leaves, flower and pod of *Albizia lebbeck.*



Fuelwood plantations produce 5 m^3 ha/year (Anon. 1980). Isolated mature trees produce edible dry matter at the rate of 100-120 kg/year (Lowry 1989). Leaf litter fall under plantation conditions was 5,000 kg/ha/year (Pradhan and Dayal 1981).

Wayside trees in the dry tropics show a crown diameter expansion of 22.2 m/year until mature (Lowry and Lowry 1991). Stands of mature trees with triennial pollarding yielded 1,700 kg/ha/year of edible material. Hedgerow stands browsed by cattle twice a year yielded 2,500 kg/ha/year in a subtropical low rainfall area where leucaena yielded 1,500 kg/ha/year (J.H. Prinsen, unpublished data). In Puerto Rico, plantings of 2,500, 10,000, and 40,000 trees/ha had leaf dry matter yields in the first 24 months of 1,710, 2,560 and 3,670 kg/ha respectively (Parrotta 1988).

Silviculture

Seeds are freely produced and are relatively large (7,000-8,000 seeds/kg). The species is not particularly hard-seeded and a proportion of seeds germinate immediately without any treatment, but for best results a 10 s immersion in boiling water is desirable. Siris is not *Rhizobium* specific and naturalised. forms are nearly always capable of producing an abundance of nodules. Plants can be sown directly, container grown, or raised in a massed seedbed and planted out as bare-rooted stumps (Anon. 1970).

Establishment is of course dependent on initial provision of water and protection from grass or weed competition, but there are few published data on this (Lowry 1991). Observations at a 725 mm annual rainfall site in southeast Queensland indicate that at least 3 years are required from planting to initial utilisation by cattle (D.M. Burrows, unpublished data).

Diseases and Pests

Establishment can be affected by attack on young plants by mice or rabbits, marsupials and domestic ruminants. Leaves are largely unaffected by insects, but young leaves may be subject to heavy predation by larvae of the grass yellow butterfly (*Eurema hecoba*). This appears to be a very short-lived effect. The most serious pests are bark-feeding larvae of longicorn beetles. These do not affect small stems and have little effect on large stems, but complete girdling can cause dieback in stems in the diameter range 40-100 mm. There is considerable variation in susceptibility of individual trees. Trees may be more susceptible under prolonged water stress. Recently a psyllid, probably of the genus *Heteropsylla,* was reported as seriously affecting seedlings in India (Hegde and Relwani 1988). The infestation was controlled by two applications of Nuvacron (0.05%) but not by Malathion.

Animal Production Value

Trees may adapt to a semiarid environment in two divergent ways that are very relevant to animal nutrition. Leaves may be long-lived, heavily cutinised, durable and sclerophyllous, as in the phyllodinous acacias, or they may, as with siris, be less lignified, short-lived and deciduous. The latter are of potentially higher feed value because of the lower lignified fibre content but may be protected from browsing by secondary compounds.

Leaves of siris are remarkably free of toxins and tannins, and low in soluble phenolic compounds. It is one of the very few tree legume species where the leaves are utilised by fruit bats (Lowry 1987). Rabbits have shown good growth performance when fed siris leaf comprising 50% of the diet (Lowry *et al.* 1992). Flowers contain no adverse constituents but pods contain saponins (Varshney *et al.* 1971) which may limit intake but appear to have no other adverse effect. Protein and neutral detergent fibre contents are as follows: green leaf, 16-23 and 41-35%; fallen leaf, 10 and 49%; fallen flower, 23 and 51%; pods, 19 and 55%. *In vitro* digestibility values for leaf have been reported in the range 45-70% and are usually around 50% for mature leaf. Results of feeding experiments are presented in Table 2.5.1. The overall conclusion is that the leaf is of high digestibility early in the season, or in regrowth after cutting, but of only moderate digestibility when mature although still of higher quality than mature grass. Young leaf tastes bitter and intake may be limited when offered as the whole diet. This does not affect its value as a supplement.

The fallen leaf has shown surprisingly high voluntary intakes by sheep, probably due to its rapid fragmentation. Schlink *et al.* (1991) showed that all fractions fed as supplements produced an increase in digestible dry matter intake of low quality basal diet. The effect was greater with the lower quality basal diet of black spear grass. Fallen flowers are an excellent feed. The pods are of particular interest as animal response was poor when fed alone but was positive when fed as a supplement to poor quality grass (Table 2.5.1).

There is a direct supplemental value of siris in extensive grazing systems. Leaves, flowers and pods drop sequentially during the dry season and can be utilised directly by grazing animals without any management effort being necessary. In mature trees, leaves, flowers and pods fall in comparable amounts (Lowry 1989). However the potential benefits have not yet been measured in grazing experiments.

Trees in pasture

One of the most interesting aspects of siris is that, in addition to providing feed directly, it appears to enhance pasture production and quality. Isolated siris trees in tropical woodlands frequently have a conspicuously greener sub-canopy area in which black spear grass (*Heteropogon contortus*), dominant in the open grassland, has been replaced by higher quality *Panicum maximum.* On one site in the dry tropics, dry matter yields under the trees were much higher (1,710 kg/ha) than between trees (753 kg/ha) during the early wet season (Lowry *et al.* 1988). Subsequent studies at the same site showed that grass quality was maintained under the trees for about 2 months longer into the dry season than in the surrounding area. Similar observations of a 'canopy effect' have been made in widely separated areas of coastal Queensland (Prinsen 1986, J.H. Wildin, unpublished data). The cause of this effect is thought to be related to improved soil moisture status in the surface litter layer of shaded soil which increases litter breakdown and mineralisation of organic matter (Wild *et al.* 1993). It appears that the tree provides a biological solution to the problem of pasture quality decline in the dry season.

Table 2.5.1. Results from feeding experiments with *Albizia lebbeck.*

(a) Fed as entire diet						
Plant part	**Animal**	**DM**	**DMD**	**DDMI**	**ND**	**Reference**
		(g/day)	(%)	(g/day)	(%)	
Fresh green leaf	sheep	55.2	64	474	82	1
Dry green leaf	sheep	61.5	48	396	66	1
Fallen leaf	sheep	84.0	42	473	46	1
Fallen flower	sheep	71.5	57	546	70	1
Pod	sheep	20.4	44	120	71	1
Leaf	sheep	93.7	44	464	60	2
Leaf and 10% molasses	sheep	100.0	44	484	69	2
Leaf	goats	-	57		65	3
(b) Fed as supplement with mature spear grass (*Heteropogon contortus*)						
		DMI grass (g/day/kg $W^{0.75}$)	**DMI supplement (g/day)**	**DMD whole diet (%)**	**DDMI (g/day)**	

Control		29.5	0	30	141	4
Green leaf		31.7	6.3	38	229	
Flower		33.6	6.3	38	241	
Pods		28.4	6.3	39	215	
Fallen leaf		26.3	6.3	34	171	
(c) Fed as supplement with mature Mitchell grass (*Astrebla squarrosa*)						
Control	34.6	0	43	138	5	
Leaf	34.2	20.8	41	208		
Flower	36.6	18.5	60	251		

1. Lowry (1989); 2. Gupta (1981); 3. Murugan and Kathaperumal (1987); 4. Schlink *et al.* (1991); 5. Dwatmadji *et al.* (1992).

DMI = dry matter intake (g/day/kg $W^{0.75}$)*;* DMD = dry matter digestibility (%); ND = nitrogen digestibility (%);
DDMI = digestible dry matter intake (g/day)

Shading and animal production

Heat stress affects production of grazing animals in the dry tropics and the requirement for shade is well known although there are few quantitative data. Shading in northern Australian eucalypt dominated woodlands is typically diffuse. Light transmission through the canopy is about 80% even with a high population of trees, whereas transmission through the canopy of mature siris trees is 40-50%. Provision of such shade would itself benefit animal production.

The above considerations suggest a number of management options for incorporating siris trees in pastoral systems:

- grow trees intensively in rows or woodlots, as a protein supplement, for feeding weaners or as a drought reserve, lopping annually or as necessary,

- establish trees at low density in open woodland with no management once established, and

- develop agroforestry regimes in which animal production benefits are combined with wood production.

Other Uses

India has a well developed trade in siris for sawn timber. The heartwood is dense (specific gravity 0.55-0.60), easily worked and dark brown, with a very distinct boundary from pale sapwood. A range of uses as cabinet timber have been listed, including the doors of Chinese temples (Burkhill 1966).

More generally, it is useful as an amenity tree although the leaf, flower and pod fall that are valuable for animal production can become a litter problem. It is valued as a fuelwood species because of its high productivity (Anon. 1980). Calorific value of air-dried wood is 5,200 kcal/kg. It is also valued as a honey tree due to its production of both nectar and pollen.

A variety of traditional medicinal uses have been recorded (Dastur 1951). Bark extracts have documented anti-inflammatory activity (Tripathi *et al.* 1979).

Allied Species of Interest

In northern Australia siris is easily confused with *A. canescens,* although there is little problem with identification when either flowers and pods are examined. The latter species usually forms a smaller tree and appears to be palatable, but is uncommon in woodland under grazing.

Albizia procera (red siris) is a closely allied species that deserves further attention. It is accepted as a source of high quality timber in Australia (Hall *et al.* 1975). Although regarded as a rainforest species it can be found in woodland habitats well away from rainforest, and can have good form even as an isolated tree. Preliminary results (J.B. Lowry, unpublished data) suggest that the feeding value is similar to that of siris, and herbarium notes indicate it was regarded as a fodder tree by early settlers. This species appears an ideal candidate for a combined wood production and grazing regime.

Albizia basaltica (dead finish) is a shrub or small tree native to areas of central Queensland. The leaves are eaten by livestock, but are usually shed during the dry season (Everist 1986).

Conclusions

Albizia lebbeck has potential for use in silvopastoral systems with a number of benefits to graziers. Its foliage is of high quality for animals and the shade of its canopy is likely to benefit livestock directly, by reducing temperatures in hot environments, and indirectly by stimulating improved grass growth. Finally, the wood of Indian siris has value as a timber. Other species in the genus also show potential for exploitation and should be further investigated.

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2.6 Erythrina Species - Pantropical Multipurpose Tree Legumes

D.L. Kass

Introduction

Unlike many other genera of forage tree legumes, *Erythrina* is pantropical, consisting of some 112 species, 70 neotropical, 31 African and 12 Asian. Only one species, *Erythrina fusca,* occurs in both the New and Old Worlds. The genus is probably of South American origin but the ability of the seeds to float and retain viability after prolonged immersion in salt water and the probable riverine, coastal or estuarine environments inhabited by the ancestral species have resulted in worldwide distribution. Pollination by birds and a marked ability to hybridise have resulted in a tremendous amount of ecological and morphological diversity, both within and between species, but within rather close cytological and phytochemical relationships. The alkaloids of *Erythrina* are distinct from those of other legumes and they all possess an unusual high activity, low affinity nitrate reductase system distinct from known nitrate reduction patterns in other angiosperms (Neill 1988). The base chromosome number of n = 21, shared by all *Erythrina* species that have been counted, is found in no other legumes.

Botanical Description

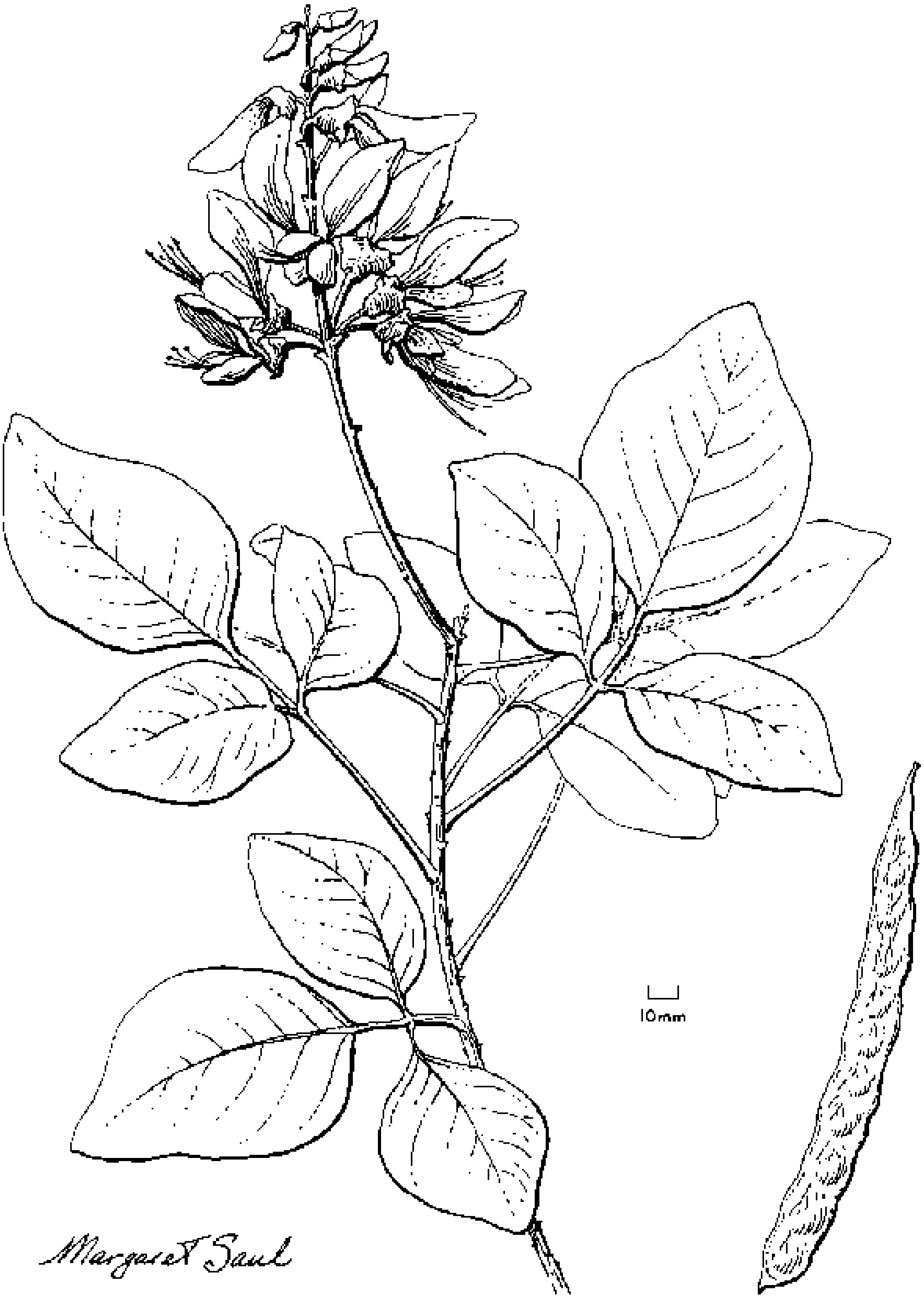
Erythrina L. species are distributed throughout the tropics and extend into warm temperate areas such as South Africa, the Himalayas, southern China, the Rio de la Plata region of Argentina and southern United States. Most species are trees or shrubs but about ten species which occur in climates with pronounced dry and/or cool seasons are perennial herbs with large, woody rootstocks. Because of their characteristic trifoliate leaves, *Erythrina* has been placed traditionally in the subtribe Erythrininae of the tribe Phaseoleae (Neill 1988). The trunk, young branches, petioles and petiolules are often armed with blunt, conical thorns or recurved prickles. Leaves are pinnately trifoliate, often clustered at the ends of branches; leaflets are broad-ovate, elliptic, often deltoid or rhomboid, entire, lateral leaflets often asymmetric, terminal leaflet largest, symmetric; stipels are fleshy, glandlike, turning black upon drying, usually one at base of lateral leaflets, paired stipels at base of terminal leaflet; stipels are small, ovate, or linear, caducous or persistent. *Erythrina* species exhibit great diversity in floral structure, inflorescence orientation, fruit morphology, seed coat coloration, and vestiture and epidermal ornamentation of foliage and calyces. Flowers appear before or with the first leaves, very showy, mostly red, some salmon, pink, orange or yellow, solitary, paired or fasicled in erect, terminal racemes leafy at the base or in axillary racemes (Allen and Allen 1981) (Figure 2.6.1).

The diversity of floral structure reflects adaptation to different pollination mechanisms. All *Erythrina* species have red or orange flowers with copious nectar and are adapted to pollination by nectivorous birds. All 42 paleotropical and some 15 of the neotropical species are pollinated by 'perching birds' of the order Passeriformes; inflorescences of passerine-pollinated species are oriented in such a way that the birds can perch while feeding on the floral nectar. The corolla standard is usually broad and the flowers are open with exposed reproductive parts. Pollen is deposited on the feeding bird's breast. The diversity of size, form and orientation of passerine-pollinated *Erythrina* flowers would appear to reflect variation in the size, morphology and behaviour of the pollinators (Neil 1988). The remaining 55 neotropical species are pollinated by hummingbirds (Trochilidae). The corolla standard of hummingbird-pollinated *Erythrina* is narrow and conduplicately folded to form a 'pseudotube' concealing the wing and keel petals as well as the reproductive parts. The flower resembles the tubular corollas of many gametopetalous hummingbird-pollinated plants but the pseudotube is not sealed on the ventral side where the margins of the corolla standard meet. The inflorescence of the hummingbird-pollinated species is erect, and the flowers are oriented outward, providing no perch for the hummingbirds, which are the only nectivorous birds which hover while feeding.

Origins

The origin of *Erythrina,* like its relationship to the rest of the Leguminosae, is obscure. No fossil record of the genus has been reported. Distribution patterns, pollination and dispersal mechanisms and the known history of the Leguminosae indicate an upper Eocene to upper Oligocene origin for the genus (30-40 million years ago) followed by ocean-drift or other long-distance dispersal among the tropical regions of America, Africa and Asia-Oceania. Much diversification of *Erythrina* has occurred independently in Africa and America and to a lesser extent in Asia. South America seems the most likely place of origin since the majority of putative ancestral groups within the genus occur there. Africa is a possible candidate because it also contains a number of endemic groups. Although *Erythrina* almost certainly originated after the breakup of Gondwanaland, it has a basically South American-African distribution that is shared by many angiosperms including the Leguminosae as a whole. The *Erythrina* taxa in 'tropical Laurasia', i.e. Asia and Mesoamerica, are clearly derived groups. In Mesoamerica, the genus has undergone extensive recent speciation within a single lineage (Neill 1988).

Fig. 2.6.1. Leaves, flower and pod of *Erythrina fusca.*



The origins of *Erythrina* beyond the species level are somewhat difficult determine. *Erythrina fusca* is the only species to occur in both the neotropics and paleotropics. With its wide distribution and presumably primitive features, *E. fusca* or a fusca-like ancestor may represent the original progenitor of the entire genus. The other species of the subgenus *Microptaryxx* are confined to South America in the Orinoco, Rio de la Plata and Amazon basins, thus indicating riverine areas of South America (Neill 1988) as a possible source of origin.

Environmental Adaptation

Erythrina can presumably be found anywhere in the tropics or subtropics with the possible exception of extremely dry areas although *Erythrina* species are apparently found in the Kalahari desert of southwest Africa. Several species are limited to specific ecological zones. *Erythrina edulis* occurs only in high elevations of the Andes, where it is used as human food. *Erythrina fusca* is found throughout coastal regions of the tropics where it shows considerable tolerance to flooding and saline conditions. *Erythrina berteroana* is widely used as a live fence from sea level to elevations of 2,000 m in Central and South America with rainfalls ranging from 800 to 5,000 mm per year. It has also shown tolerance to soils with high aluminium saturation. Production of 12-16 t/ha/year has been maintained by selected clones of *E. peoppigiana* and *E. berteroana* on a soil with pH 4.0 and 50% aluminium saturation (Typic Fulvudand) near Turrialba, Costa Rica (Camacho *et al.* 1993). An *Erythrina* species, presumably *E. berteroana,* also showed considerable tolerance to a soil with even higher levels (75%) of aluminium saturation in Yurimaguas, Peru (Salazar and Palm 1987). Another widely distributed species, *E. variegata,* the most utilised *Erythrina* on the Indian subcontinent, is a coastal-strand, ocean-dispersed species similar to *E. fusca* found all along the Indian Ocean from Madagascar to Indonesia and extending to New Guinea, Polynesia, Micronesia and the Marquesas (Neill 1988).

While generally considered intolerant of frosts, two species, *E. herbacea* and *E. flabelliformis,* extend into the southern United States where they exist as herbaceous perennials whose above-ground stems die back each winter. An Asian species, *E. aborescens,* occurs in Himalayan forests and in the mountains of western China to 3,000 m elevations and is evidently highly tolerant of frosts. Three sections of the subgenus *Erythrina* endemic to southern Africa, encompassing five species, *E. caffra, E. lysistemon, E. humeana, E. zeyheri* and *E. acanthrocarpa,* show some degree of frost tolerance. It is also presumed that the South American species, *E. berteroana* and *E. edulis,* which are common at high elevations where frosts generally occur, are also frost tolerant.

Establishment and Cultivation

Erythrina is traditionally reproduced from large cuttings although seeds are usually viable. Due to the high level of outcrossing, there should be considerable variability in trees produced from seed. It has been shown in Mexico, that a hummingbird must visit more than one tree per day to obtain sufficient energy (Neill 1987), resulting in a high degree of hybridisation While large cuttings are generally used for establishment of live fences and shade for plantations (Ramirez *et al.* 1990, Hegde 1993), seed is generally used when *E. variegata* is utilised as a support for vine crops such as betel (*Piper biter*)*,* black pepper (*Piper nigrum*)*,* vanilla (*Vanilla fragrans*)*,* grapes (*Vitis* spp.) and yams (*Dioscorea* spp.). In India, this is the most important use of the species (Hegde 1993). The trees are usually established by planting two or three seeds directly in each pit or by planting seedlings raised in a nursery. Since spiny forms are favoured for support purposes and non-spiny forms for shade, use of vegetative propagation may be a means of ensuring non-spiny forms. However, rapid establishment is generally a priority when used for shade or live fences, favouring the use of large stakes. Smaller stakes may be used for other purposes such as protein banks where it has been found that planting 60 cm long stakes laid horizontally has resulted in good establishment.

Production and Management

Erythrina spp. are universally recognised for their high biomass productivity and utilisation almost always involves frequent pruning. When used as a support tree for pepper vines, *E. variegata* may be pruned at 6-8 week intervals; when used as a coffee shade or in live fences, it may be pruned once yearly, while for timber or pulpwood, the tree may be left to grow for 25 years without pruning (Hegde 1993). In

Costa Rica, *E. peoppigiana* in coffee plantations is generally pruned twice yearly while *E. berteroana* and *E. fusca* in living fences are generally pruned once yearly. Experimental work has shown that *E. berteroana* can be pruned at intervals of 4 months to produce higher quality forage for ruminants. Pruning at more frequent intervals will reduce biomass yield over time (Pezo *et al.* 1990). As early as 1934, Joachim and Kandiah (1934) determined that cutting *E. lithospermum* at intervals of 5 months would maximise nutritional content of green manure materials in Sri Lankan tea plantations.

Utilisation of Erythrina

Although species vary with region, the general uses of *Erythrina* are principally as a shade and support tree, followed by live fences whence it can be used for green manure and animal feeding. Some species are used as ornamentals; flowers are frequently eaten or used to make tea, and seeds for jewellery. The wood is too light and porous for most purposes but it finds special uses for surfboats, canoes and carving.

Shade and support tree

Throughout the world, the principal use of the genus *Erythrina* is as a shade and support tree. *Erythrina fusca* is widely appreciated as a cocoa shade throughout the Americas, principally because of its adaptation to humid areas where cocoa is generally grown. *Erythrina burana* is a component of the forest in the original range of *Coffea so* the use of *Erythrina* as a coffee shade may date to the domestication of the crop (Teketay 1990). *Erythrina variegata* is used in India as both a coffee and cocoa shade while *E. poeppigiana* was introduced to Costa Rica early in the 20th century as a coffee shade. It successfully replaced *Inga* species traditionally used in the more humid zones of Costa Rica. Nutrient cycling studies with coffee and cocoa under shade of *E. fusca* or *E. poeppigiana* have demonstrated the value of these species in Brasil, Costa Rica (Fassbender 1987, Alpizar 1987, Fassbender *et al.* 1991) and Venezuela (Herrera *et al.* 1987). *Erythrina* species are favoured for shade because of their rapid establishment and high biomass production. With increasing labour costs and falling cocoa and coffee prices, some of these advantages have become less favourable in recent years and *Erythrina* has either been replaced by or combined with shade species requiring less frequent pruning or which produces marketable by-product such as fruit or timber.

Live fences

Various *Erythrina* species are used in live fences. *Erythrina berteroana, E. fusca, E. peoppigiana, E. costarricensis* are widely used in Central America (Budowski 1987). *Erythrina golmani, E. chiaspasana, E. folkserii* and *E. pudica* are widely used in southern Mexico (Neill 1988). One species commonly found in fence-rows, *E. caribea,* is apparently sterile and is propagated by taking cuttings from existing fenceposts. *Erythrina variegata* is favoured as a live fence in southern India because, as the trees have little value as fuel, they are rarely stolen (Hegde 1993) (Figure 2.6.2). Although live fences can be pruned at intervals of 4-5 months, the relatively low population of trees in a live fence restricts the value of this practice as a source of animal feed. Cut at 4 month intervals, a live fence of E. berteroana produced 1.7-4.0 t/ha/km of dry matter compared with 1.0-5.6 t/ha/km for *Gliricidia sepium* (Pezo *et al.* 1990).

Fig. 2.6.2. *Erythrina variegata* used as a living fencepost in Western Samoa.

Large stakes (2-2.5 m) are almost universally favoured for live fence production so that cattle will not eat the young sprouts (Viquez *et al.* 1993). The lower part of the stake (20-40 cm) is buried in the soil at planting. The top is cut at a diagonal to avoid water accumulation. If the soil is soft, the bottom of the stake can be cut to a point and the stake driven into the ground. If the soil is hard, a hole should be dug. If drainage is poor, small incisions should be made in the bark below the soil level to increase rooting (Viquez *et al.* 1993). Farmers generally favour cutting posts with the waning moon and planting with the waxing moon although no scientific basis for this practice has yet been determined.

Livestock forage

There has been considerable research on *Erythrina* species as livestock forage even though most species, with the apparent exception of *E. edulis,* have yielded alkaloids having curare-like poisoning action (Allen and Allen 1981, Payne 1991). However, these alkaloids appear to be more concentrated in the seeds and bark than in the leaves. In a study of alkaloid content of different clones of the species *E. berteroana, E. poeppigiana* and *E. costarricensis,* Payne (1991) identified the major alkaloid as β -erythroidine, a naturally derived drug used in the 1950s and 1960s as a neuromuscular blocking agent in surgery and electroshock treatments. Other biologically active alkaloids identified were a-erythroidine, erybidine, erythraline, erysodine and oxo-β -erythroidine. There was a difference of more than two orders of magnitude in the β -erythroidine contents of the clones of the species tested, indicating at least partial genetic control of the alkaloid content. A feeding study performed with goats demonstrated that the β -erythroidine present in the foliage of *Erythrina* species is hydrogenated in the rumen and that these metabolites are detected in milk. Synthetic studies showed that the dihydroerythroidine isomers present in the milk and rumen samples were not the same isomers produced by catalytic hydrogenation. The toxicology of the rumen and milk derived compounds is therefore unknown (Payne 1991).

Of the *Erythrina* species utilised in Costa Rica, *E. peoppigiana* has the highest crude protein content (42%), protein solubility (49%) and *in vitro* dry matter digestibility of edible biomass followed by *E. berteroana* and *E. costarricense.* The lowest values are found in *E. fusca.* There is considerable variability in the nutritive value among clones of these species, especially *E. berteroana* (Pezo *et al.* 1990). In *E. berteroana, E. costarricense* and *E. fusca,* a greater percentage of the nitrogen is linked to the acid-detergent fibre, resulting in lower protein availability and less degradation of the protein in the rumen. All *Erythrina* species tested had relatively high cell wall contents (61%) when compared with other forage legumes although the levels of lignification (17%) were similar. Diets which contain *Erythrina* should therefore contain supplemental energy sources which are readily degradable in the rumen (Kass *et al. 1993).*

Ruminants find the foliage of the various *Erythrina* species used in Costa Rica more palatable than *G. sepium.* Higher milk yields were obtained in goats fed *E. peoppigiana* (1.26 kg/animal) than *G. sepium* (1.11 kg/animal) due to differences in intake. Supplemental *E. peoppigiana* foliage did not result in as great a weight gain in calves or milk production of cows as those fed soybean or fish meal. However, economic analyses indicated that greater returns to the farmer were obtained from using legume tree foliage and locally available energy sources such as green bananas (Pezo *et al.* 1990).

Source of green manure

Farmers recognise the value of *Erythrina* mulch for improving soil fertility. Farmers have responded quite favourably to the planting of *E. fusca* along contour lines in crop fields in Costa Rica (Hernandez 1993). *Erythrina* species have figured in almost all alley farming studies carried out in Latin America (Alavez 1987, Kass 1987, Salazar and Palm 1987, Kass *et al.* 1989, Sanchez 1989, Jimenez 1990, Nygren 1990, Delgadillo *et al.* 1991, Garzon 1991, Haggar *et al.* 1991, Jimenez *et al.* 1991, Salazar 1991, Szott *et al.* 1991, Lebeuf 1993, Soto *et al.* 1993).

Despite its reputation for high biomass production, *Erythrina* has generally produced less biomass in alley farming experiments than other nitrogen fixing trees (*G. sepium* and *Inga edulis*). Nutrient return from *Erythrina* to alley cropping systems varied with soil type and was substantially higher on more fertile soils (Table 2.6.1). Kass *et al.* (1989) estimated nitrogen fixation at 50 kg/ha/year during a 30 month period.

Human food

Despite the alkaloid content, the flowers of many *Erythrina* species are consumed in Mesoamerica. *Erythrina edulis* in the Andean regions of Colombia and Peru would appear to be the only species whose seeds are eaten. The seeds are ground into flour to make a variety of products (Federacion Nacional de Cafeteleros 1991).

Table 2.6.1. Annual contribution of nutrients from *Erythrina* in alley cropping systems on three soil types (kg/ha/year).

Soil type	Nutrient					Reference*
	N	P	K	Ca	Mg	
Typic Humitropept	278	24	156	82	34	1
Paleudult	69	8	38	16	8	2
Tropofluvent	489	61	362	274	64	3

* References: 1. Kass *et al.* (1989); 2. Szott (1987); 3. Salazar (1991)

Medicinal uses

Erythrina has been used in folk medicine for treatment of insomnia malaria fever, venereal disease, asthma and toothache. South American Indians used *Erythrina* as a fish poison. In addition, there are reports of its use as a narcotic and antihelminthic. The first compounds isolated from *Erythrina* were alkaloids. β -Erythroidine was used for a brief time as a muscle relaxant in surgery and in treatment of schizophrenia Tea from *Erythrina* flowers is regularly used as a relaxant in Mesoamerica. Subsequently, homoerythrina alkaloids were investigated for their anti-cancer activity. Recently, research involving *Erythrina* has focused on other chemical effects, primarily the antimicrobial action of *Erythrina* lectins and the enzymology of proteinase inhibitors isolated from *Erythrina* (Payne 1991).

Ornamental

Various species of *Erythrina,* known as coral trees, are used as ornamentals in California, Mexico, South Africa, India, Australia and Pacific countries.

Wood

Erythrina wood is greyish white, spongy, lightweight and strong but not durable. It is used for sieve frames, surfboards, dugout canoes, outrigger canoe floats, boxes and small art carvings. *Erythrina monosperm* Gaud. is a favourite canoe wood of the Polynesians. The dry wood of this species and the bark of *E. suberosa* Roxb. are used for the manufacture of composition cork (Allen and Allen 1981).

Conclusions

Despite the alkaloid content, *Erythrina* foliage continues to be fed to cattle and goats around the world without reports of ill effects. Use as a non-ruminant feed is probably risky. It has high biomass productivity and is frequently used as a living fence, shade or support tree. However, *Erythrina* requires constant pruning in support and alley farming systems (Muschler 1991). Increasing labour costs have made this a less attractive feature of the genus and its use in shaded plantations is decreasing. Insect pests are sometimes a problem (Salazar and Palm 1987). It serves as an alternative host for *Phyllophaga* in Central America and the fruit piercing moth *Othreis fullonia* in the Pacific islands. The latter pest has slowed its introduction in the Pacific.

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2.7 Other Species of Multipurpose Forage Tree Legumes

R.C. Gutteridge

Introduction

There are many species of multipurpose forage tree legumes in use throughout the tropical and subtropical regions of the world. In the preceding sections of Chapter 2, the most well known species are described but many others have shown potential for exploitation while others have yet to be identified as valuable multipurpose forage trees. Brewbaker (1986) listed about 80 species which are known to serve as animal fodder. One approach to developing new material is to encourage intensive activity with well known species as their genetic reservoirs of diversity have hardly been tapped. Another approach is to identify promising new species from other genera to increase the number of species in common use and broaden the genetic base.

It is not possible to examine all 80 species in this section but eight selected species representative of those which have shown potential, or are currently used in certain regions, are now reviewed in more detail. A tabular summary of the characteristics of the eight species is given in Table 2.7.1.

Acacia angustissima, A. boliviana and A. villosa

All three of these species are closely related and are often confused botanically. They are virtually interchangeable with respect to habit, environmental adaptation and productivity. They have all received increased attention as alternatives to *Leucaena leucocephala* following its devastation by the psyllid insect. *Acacia angustissima* will be described here as representative of the group.

Acacia angustissima is a multi-branched, thornless shrub or small tree which grows to a maximum height of about 5 m (Figure 2.7.1). Flowers are mimosoid and it is a prolific seed producer. The species is native to Central America and it is now common in southeast Asia, particularly Indonesia. It is well adapted to free draining acid, infertile soils and shows excellent drought tolerance. It retains green leaf in the long (8 month) dry season in Timor, Indonesia (Field 1989).

Table 2.7.1. Characteristics of eight forage tree legume species.

Fig. 2.7.1. *Acacia angustissima* growing near Darwin, Australia.

Its branching habit enables it to withstand frequent cutting or defoliation. Cutting heights of 50-100 cm at frequencies of 8-10 weeks have been used in a number of regions (Benjamin 1988). Leaf yields of up to 5 t/ha/year have been reported (Benjamin 1988).

There is conflicting information regarding its palatability and intake by livestock. Reports from some areas in Indonesia suggest its palatability is low although condensed tannin levels in the leaf are not especially high (up to 6%) (Akin *et al.* 1989). The same authors reported an in *sacco in vitro* dry matter digestibility of 48% after 24 h indicating that digestibility may be low. In other areas, however, the leaf is reported to be well eaten by livestock and it is regarded as an important source of forage (Keoghan 1987). In central Queensland weaner steers were given access to a 2 ha area planted to *A. boliviana* CPI 40175 in rows 3 m apart. In two weeks, two thirds of the leaf material had been eaten (C. Middleton, unpublished data).

In Timor, Indonesia, *Acacia villosa* is used as a fallow species to provide fuelwood and to enrich the soil prior to cropping. In Lombok, it is used on sloping sites dominated by *Imperata* grassland to prevent soil erosion and stabilise the landscape (Field 1989). Nitis (1986) has used it in Bali as the shrub stratum in a 3-tier forage production system using grasses, herbaceous legumes, forage shrubs and forage trees.

Acacia saligna - Golden Wreath Wattle

Acacia saligna is a dense bushy shrub 2-5 m tall with long straggling branches. Phyllodes are dark green, long (up to 20 cm) and narrow. It occurs naturally in the southwestern comer of Western Australia but has been introduced to other regions of Australia and to many other countries. It grows on a wide range of soil types but is outstanding on sandy coastal plains and sand dunes. It is used extensively for sand dune stabilisation and reclamation (NAS 1980). It prefers an annual rainfall range of 350-600 mm but will grow well in areas with rainfall as low as 250 mm and as high as 1,200 mm. It is moderately tolerant of soil salinity. The phyllodes of *A. saligna* are often used as supplementary feed for sheep and goats in countries such as Libya (El Lakany 1986). Crude protein content of phyllodes varies from 12 to 16% and *in vitro* dry matter digestibility has been measured at 40% (Vercoe 1989). Le Houerou (1984) recorded daily consumption rates of 1.6 kg/head/day for sheep over prolonged periods without apparent detrimental effects.

It is reasonably tolerant of browsing and defoliation and some reports indicate it can be completely defoliated without harming the plant (NAS 1980). However, Gutteridge (1990) reported 50% mortality with regular defoliation over 4 years. The wood is sappy and light and reported not to be particularly good as fuel although in many arid regions, plantations of *A. saligna* have been established for fuelwood as it is the only species which is fast growing and productive in such unfavourable sites.

Chamaecytisus palmensis, Tagasaste or Tree Lucerne

Tagasaste is a member of the Fabaceae family and is native to the Canary Islands. It holds promise for use in tropical highlands, Mediterranean climates and temperate regions. It grows to a height of 5-6 m, is thornless and generally well branched. Flowers are white and seed production is prolific.

It is suited to sandy well drained soils of pH range 5-7. It is very susceptible to root rot fungus on poorly drained soils such as in southeast Queensland on a grey podzolic duplex soil where 100% mortality of plants occurred within 2 years (Gutteridge 1990). Responses to applications of superphosphate have been obtained on phosphorus deficient soils (Snook 1982). It is reasonably drought tolerant because of its deep taproot and grows well in the rainfall range 350-1,600 mm per annum.

Forage production

In the Canary Islands, farmers are completely dependent on tagasaste for forage during the long dry summers. In Australia, edible dry matter yields of up to 11 t/ha/year have been achieved under favourable conditions (Snook 1982). Radcliffe (1985) obtained 4-5 t dry leaf/ha/year in Canterbury, New Zealand. Borens and Poppi (1990) reported that leaf dry matter digestibility ranged from 71 to 78% with a crude protein content of 21-24%. They suggested that the feeding value of tagasaste was similar to that of other conserved forages but less than that of intensively managed temperate pastures. During the establishment phase, young tagasaste seedlings are susceptible to browsing by livestock; Snook (1982) suggested that they should be protected from grazing for up to 3 years after sowing to allow proper development. During this time, inter-row areas could be cropped for grain or hay in an alley cropping system which could continue even after tree maturity.

Tagasaste has been used extensively in drier regions as a windbreak and shelter belt and also has some potential as a fuelwood species as the wood is fairly dense with a specific gravity of 0.7.

Codariocalyx gyroides

Also known as *Desmodium gyroides,* this species is an erect, much branched shrub to 2.5 m in height. Blue to purple papilionoid flowers are borne in dense racemes which produce typical *Desmodium* segmented pods.

It is native to Indonesia and is adapted to acid, infertile soils with high soluble aluminium content. It is more tolerant of waterlogging than *L. leucocephala* but its drought tolerance is not high although it will retain green leaf in the dry or cool season. It is resistant to fire.

Ahn *et al.* (1989) reported lower digestibility than *L. leucocephala* at around 55% with approximately 7% condensed tannins occurring in fresh leaves.

It is a relatively short-lived species and at Manado in Indonesia most plants died after 18 months. Jones (1984) reported that *Codariocalyx* was initially much more vigorous than *L. leucocephala* but its persistence was poor under a moderate cutting regime.

Although its palatability, intake and quality are often reported to be low (Keoghan 1987), it will grow on very difficult sites where there are very few other leguminous shrub options.

Desmanthus virgatus

The species displays a range of morphology and habit from erect shrubs 2-3 m tall to prostrate herbaceous types less than 50 cm in height. Originally from Central and South America *Desmanthus virgatus* is now naturalised in many countries, including those in southeast Asia and the Pacific (Allen and Allen 1981). It belongs to the Mimosaceae family and is more tolerant of acid infertile soils than leucaena with a similar drought tolerance.

Little is known about its feeding value but it appears to be less palatable than leucaena (R.C. Gutteridge, unpublished data). However, it does not contain mimosine and therefore can be fed to non-ruminants without restrictions. Leaves contain 24-30% crude protein with an *in vitro* dry matter digestibility of 45-60% depending on stage of maturity. Kharat *et al.* (1980) found that the crude protein digestibility of *D. virgatus* was 58% while that for leucaena was 65%.

High yields from dense stands of *D. virgatus* have been obtained from a number of regions. Takahashi and Ripperton (1949) in Hawaii recorded yields of up to 23 t/ha total dry matter from four cuts per year. At the Kimberley Research Station in northwestern Australia, Parberry (1967) obtained whole plant dry matter yields of 35 t/ha/year. *Desmanthus virgatus* appears resistant to regular severe defoliation as there was no mortality in plants cut 5-7 cm above ground four times per year for 4 years (Takahashi and Ripperton 1949).

In the last 2-3 years *D. virgatus* has been widely promoted in Indonesia as an alternative to leucaena. In Queensland, the Department of Primary Industries is testing lines of *D. virgatus* for use in subtropical grazing systems particularly on heavy clay soils. Three cultivars, Marc, Bayamo and Uman, have recently been released.

Faidherbia albida

Faidherbia albida is native to Africa and highly regarded by herdsmen and farmers in arid and semiarid regions from Senegal to the Sudan and south to the savannahs of Kenya, Tanzania and Zimbabwe (Wickens 1969). It is a thorny species and one of the largest forage trees, reaching a height at maturity of over 30 m with a canopy spread of up to 45 m. It is commonly found on flood plains and banks of large rivers on alluvial soil but it will grow on a wide range of soils including sand dunes and shallow rocky soils. Mature trees tolerate mild frosts and temperatures up to 44℃. Flowers are arranged in spikes 7.5-10 cm long. Pods are indehiscent and it is suggested (Lamprey 1967) that passage through an animal is necessary to stimulate germination.

Early growth rate is slow as the taproot establishes rapidly at the expense of top growth. On better sites, trees can reach 1.5 m in height in the first year. Although the tree is thorny, seedlings should be protected from grazing which can cause distortion of form.

Faidherbia albida is extremely important both for providing fodder to livestock and for enhancing soil fertility for crops. It retains its leaves through the dry season and sheds them just as the rainy season commences so that forage is available throughout the dry season when many other trees are leafless. This also means that it provides shade in the hottest time of the year. At the end of the dry season (the most crucial period of shortage of animal feed), protein-rich pods mature and fall from the tree in large quantities.

The leaf fall, root nodulation and continuous presence of livestock near the trees greatly enrich the soil by cycling the nutrients nitrogen, phosphorus and exchangeable calcium. This makes it an excellent agroforestry species as crops can be grown among scattered trees without shading during the wet season. Charreau and Vidal (1965) found that millet yields were 2.5 times greater and protein content of the grain 3- to 4-fold higher near the tree. Sorghum has been grown continuously for at least 30 years with *F. albida* without yield decline (Hocking 1987). However, a study by Vandenbeldt and Geiger (1991) indicated that improved soil fertility might precede the tree. They suggested that trees which survived and grew well had established on microsites of higher fertility.

Forage value

The nutritional value of leaf is reported not to deteriorate on drying so that it is often fed dry in many parts of Africa (Hocking 1987). Boudet (1970) reported a crude protein content of 17.8% in dried *F. albida* leaf. Trees can produce an average of 135 kg pods/tree/year and a stand of 12 trees in the Sudan produced 200 kg crude protein from the pods alone (Wickens 1969).

In Niger, dry savannahs support about 10 cattle/km^2 but this stocking rate can be doubled where *F. albida* trees are present (NAS 1979). An initial planting density of 10 x 10 m with thinning to wider spacings as the canopies closed was suggested. Typical densities in the Sahel, where the tree is most widely used, range from 10 to 50 trees/ha.

Although the tree is widely used throughout Africa, more research is required on the effects of protracted feeding of livestock with pods and leaf, techniques for better cultivation and propagation, and techniques for stimulating or increasing forage production.

Flemingia macrophylla

Flemingia macrophylla is a member of the Fabaceae family. It is an erect woody shrub up to 3 m in height. Its leaves are trifoliate, relatively tough and papery. Flowers are borne in dense racemes with red blotches or stripes on a greenish-yellow background. Pods are small (11-15 mm long) and contain two shiny black seeds (Figure 2.7.2).

Flemingia macrophylla is native to Asia where it occurs in brushwood, forest margins, along waterways and in shaded locations. It is a hardy plant that can resist long dry periods but also tolerates some degree of waterlogging. In Indonesia, it has grown well on acid (pH 4-6) infertile soils with high soluble aluminium levels (80% saturation) (Budelman 1989).

Forage value

Asare (1985) reported that *F. macrophylla* remained green throughout the year in Ghana and retained most of its leaf during the dry season making it suitable as a dry season browse species. Although the *in vitro* dry matter digestibility of leaf was less than 40%, palatability of young immature growth was adequate and much higher than that of older herbage. Asare (1985) found that crude protein levels in leaf varied from 14.5 to 18.3% depending on cutting frequency and height. A 14 week cutting frequency at 35 cm cutting height gave the highest leaf dry matter yields of 9.0 t/ha. Budelman (1989) reported leaf yields of 12.4 t/ha with four cuts per year at a plant density of 10,000 plants/ha. In southeast Queensland, Gutteridge (1990) found that *F. macrophylla* had a relatively high green leaf retention over the cool dry season with a mean leaf yield over 2 years of 125 g/plant.

Green manure and mulch

Because the leaf of *F. macrophylla* is relatively resistant to breakdown in soil, it has some potential for suppressing weeds in alley cropping and green manuring systems. Budelman (1989) found that 40% of a flemingia leaf mulch layer was still present after 7 weeks in comparison with only 20% of leucaena leaf. The mulch from *F. macrophylla* formed a solid layer that effectively prevented germination of weed seeds for 100 days. Yamoah *et al.* (1986a) showed that decomposition after 120 days was 96, 58 and 46% for *Gliricidia sepium, F. macrophylla* and *Cassia siamea* respectively. These data indicate that *F. macrophylla* may also be less digestible for livestock.

Flemingia macrophylla generally has lower levels of leaf nutrients than leucaena or gliricidia. Budelman (1989) reported concentrations of: N 2.352.83%, P 0.19-0.25%, K 0.98-1.40%, Ca 0.65% and Mg 0.20%. In alley cropping studies, maize yield from plots mulched with the leaf of *F. macrophylla* was lower than that mulched with leaf from either gliricidia or *C. siamea* but yields were similar when supplemental N was applied (Yamoah *et al.* 1986b). A mixture of *F. macrophylla* and leucaena or gliricidia may be an ideal alley cropping combination to provide a longer lasting mulch for weed control and soil moisture retention as well as more rapid release of nutrients.

Fig. 2.7.2. Leaf, flowers and pods of *Flemingia macrophylla.*

Other uses

Although F. *macrophylla* does not produce a large woody biomass, Yamoah *et al.* (1986b) obtained 6.8 t dry stems/ha from a 2 year old stand indicating some potential for fuelwood production. In India, the plant is used as a host for the lac insect while hairs from the pods are used as a dye. It is also used as a shade and cover crop for coffee, sisal and cocoa

Prosopis Species

At least 44 species of *Prosopis* have been described and there is still much confusion over the taxonomy of the genus. Most species are native to the Americas ranging from the southwestern United States, through Mexico and Central America into South America as far south as Argentina.

At least three species, *P. glandulosa, P. juliflora* and *P. ruscifolia,* are aggressive woody weeds that cause major problems in grasslands. *Prosopis glandulosa,* the mesquite of southern USA, has reduced the livestock carrying capacity of over 30 million hectares of rangeland by competing with grasses for nutrients and water. These species spread rapidly due to their ease of propagation and ability to withstand adverse conditions and heavy grazing. They should never be introduced to new locations (NAS 1979).

Fortunately, other *Prosopis* species lack the aggressiveness of these weedy types but retain many of their desirable features. They are very drought tolerant and are adapted to the heat and poor soils of arid and semiarid regions. Most require at least 250 mm annual rainfall but some species have been found in areas receiving less than 100 mm.

Prosopis species are generally medium sized shrubs or short bunked, spreading trees. Most have spines and although spineless forms do exist they are generally less vigorous than the spiny types. Flowers are most often arranged in elongated spikes or spherical heads. Leaves are compound, bipinnate and feathery in appearance.

Usually found on poor land, *Prosopis* trees thrive on light sandy or rocky soils. Some species like *P. pallida* are remarkably salt tolerant and dominate arid, saline coastlines. *Prosopis tamarugo* is the only tree that survives on the arid salt flats of Chile's northern desert plateau where it produces the only available forage, timber and firewood (NAS 1979).

Forage

Prosopis pods are among the earliest leguminous foods known to have been used by man and are still a valuable source of carbohydrate and protein for many desert dwellers. Livestock also relish the pods which in many species contain a sweet, dry yellow pulp. The seeds in the pods are high in protein (34-39%) and the nutritious pods can sustain livestock in dry seasons when little other feed is available. However, when pods of some species (*P. pallida* and *P. glandulosa*) are fed as an exclusive diet for long periods, livestock, particularly cattle, can become malnourished and show ill-thrift symptoms. Thus, it is preferable that livestock consuming *Prosopis* pods should also have access to other feeds to balance their diet.

Several *Prosopis* species also provide edible foliage which can also be used as a livestock feed.

Other uses

Perhaps the greatest use of *Prosopis* species is for fuelwood. The wood burns slowly, produces little ash and smoke and makes charcoal of very high quality. Many natural stands of *Prosopis* in South America have been virtually eliminated due to over-harvesting for fuelwood. *Prosopis* species are also used extensively for land reclamation, erosion control, windbreaks and shelter belts in inhospitable environments. In India, Douglas (1967) reported that a belt of *Prosopis* trees 3 km wide and 650 km long was planted to try to stop the advance of the Rajputana Desert.

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3.1 Diversity within Tropical Tree and Shrub Legumes

R.A. Bray

Introduction

Although there is a wide range of genera that can be considered 'tropical tree and shrub legumes' (Williams 1983) few of these have been studied to any great extent. The best known is *Leucaena leucocephala,* which has become naturalised over large areas of the tropics. Other commonly grown tree and shrub legumes are *Gliricidia sepium, Calliandra calothyrsus, Sesbania sesban* and *S. grandiflora,* and many species of *Desmodium* (including *Codariocalyx*). In this section discussion will concentrate mainly on variation within *Leucaena* as that is where most information is available. References such as Le Houerou (1980) can be consulted for a broader perspective.

Leucaena

Leucaena leucocephala is probably the most widely grown tropical tree legume in the world. However, the genus *Leucaena* comprises a wide range of species and genotypes, some of which are very different from this well-known species. In the past, research and development has concentrated almost entirely on *L. leucocephala,* but it is likely that in the future more use will be made of the other species in the genus. The various species of *Leucaena,* their particular characteristics and what uses they might have, will be discussed here.

Leucaena is one of 60 genera in the tribe Mimoseae of the subfamily Mimosoideae. Although *L. leucocephala* has spread worldwide, the genus is indigenous only to Texas (USA), Mexico, Central America and the Caribbean, and the northern parts of South America. It is intolerant of highly acid or waterlogged soils, and is not often found at altitudes above 2,000 m. All species contain mimosine, a non-protein amino acid. It is a very variable genus, and taxonomic efforts in the past have created a bewildering array of 'species' (Britton and Rose 1928). Brewbaker (1987) simplified the taxonomy to include only 12 species but taxonomists currently recognise 16 species (Hughes 1991).

These are listed in Table 3.1.1, together with some of the characteristics by which they may be distinguished. Of these, pairs of pinnae, pinnule number, pinnule size and inflorescence size are likely to be the most useful in practical terms. A full key to the determination of species is given by Brewbaker (1987). However, recent taxonomic studies based on extensive collections in Mexico and neighbouring countries provide an alternative viewpoint by delineating new species and by again dividing some species into subspecies (see for example Hughes 1991). In the discussion below, the simpler terminology of Brewbaker will be used.

Characteristics of individual species

Leucaena leucocephala

This species probably originated in the Yucatan Peninsula of Mexico. One 'common' variety is now widely distributed throughout the tropical world, often appearing to be a weed. Extensive collections have now been made in Mexico, from a wide range of environments. The species is almost never found above an altitude of 1,500 m (and generally much lower), suggesting that there are unlikely to be frost tolerant types although regrowth after frost is vigorous enough to make it a commercial species in southern Queensland and south Texas, USA. Some accessions have come from very dry areas (rainfall c. 300 mm) but these have probably been growing in favoured situations (e.g. runoff from roadsides) and again there is little reason to hope to find genotypes well adapted to arid conditions.

Morphologically, the species is quite variable. It is generally accepted that there are two major varieties (in the botanical sense). These are the 'giant' or 'Salvador' type, and the 'common'. It is this latter type which has spread throughout the world, often as a weed. It is generally not very vigorous, but is a prolific seeder. Thus, as a general rule, it should be possible to find higher yielding types than those currently naturalised. in most tropical countries. The 'giant' types tend to be faster growing, with fewer branches, and moderate seed production.

Until the 1970s, only relatively small collections of germplasm existed. Early selections from the Hawaiian programme included the cultivars K8 and K28. These were selected mainly on the basis of good wood production, but when cut regularly produce high leaf yields also. In Australia, the cultivars Peru and Cunningham were developed. These were selected for high yield and branching, to provide a plant form suitable for grazing by cattle. In recent years, many hundreds of accessions have been collected in Mexico and screened in programmes all over the world. Superior lines have been isolated in most programmes. These include CPIs 58396, 61227, 85176 and 90814 in Australia, ML1 and ML2 in Malaysia, and a range of material such as K584 and K636 in Hawaii (see e.g. Bray *et al.* 1988). However, the recent problems with the leucaena, psyllid (see Section 6.1) have tended to obscure differences in potential productivity, although some lines such as K420 and K636 show more tolerance than others.

Table 3.1.1. Characteristics of *Leucaena* species (after Brewbaker 1987).

L. diversifolia

There are two main subdivisions of this species. These are the 'diploid' and 'tetraploid' groups, which have 52 and 104 chromosomes respectively. The diploid group occurs naturally in southern Mexico and Guatemala and, due to self-incompatibility, members of this group are obligately outcrossing. The tetraploid group occurs only in Veracruz, and is self-fertile. Tetraploids can generally be distinguished morphologically from diploids by having larger, more open flower heads, fewer florets per inflorescence, more pairs of pinnae and pairs of pinnules, and longer pinnules (Pan 1984). There has not been extensive testing of *L. diversifolia* germplasm. Most trials have been concerned with wood yield, but some accessions (e.g. CPI 46568) can yield as well under regular cutting as *L. leucocephala* (Bray *et al.* 1988). However, there are some indications that this species may not survive well under dry conditions. Because it often occurs naturally in the mountains, it has been evaluated as a source of cold tolerance, and some lines (CPI 46568) again show promise in this regard (R. Wheeler, personal communication). However, it is unlikely that any really frost tolerant genotypes exist. Although the genus is not found on acid soils, it has been used successfully in the breeding of lines that grow well in such conditions (Hutton 1990). It is also potentially useful as a source of psyllid resistance (Section 6.1) and some lines isolated from old plantations in Indonesia show promise in this regard.

Little is known about the value of this species as animal feed (although its mimosine content is less than that of *L. leucocephala*), or about its agronomic limitations. Its seeds are considerably smaller than those of *L. leucocephala* and consequently it may be difficult to establish in the field. Seed production of the diploid types is sometimes sparse, and any seed orchard needs to contain a reasonable number of trees (30 at a minimum) to ensure adequate pollination and to minimise inbreeding. The diploid group often have a characteristic almost two-dimensional branching habit, and may have potential as a support for growing vines or other scrambling plants.

L. pallida

This species has only recently been recognised (Pan 1985) and probably is an ancient hybrid between *L. diversifolia* and *L. esculenta.* It has some cold tolerance (being found mainly in mountain areas) and psyllid resistance. It yields reasonably well under cutting (Wheeler and Brewbaker 1989), but its real agronomic potential is not known. It is another outcrossing species, and thus seed orchards should contain a reasonable number of trees.

L. pulverulenta

Interest in this species has largely been due to its low mimosine content and arboreal habit. However, it can produce yields of edible material approaching that of *L. leucocephala* Hybrids between *L. leucocephala* and *L. pulverulenta* can be very vigorous, with moderate levels of mimosine (Bray 1984). Such hybrids have long been used as shade trees for coffee.

Little is known about the other species although about one thousand accessions, including all 16 species, have been grown in University of Hawaii trials. However, they are all browsed in the wild, and therefore have some potential as forage plants. The pods and seeds of some species (especially *L. esculenta*) are eaten by humans. *Leucaena retusa* and *L. greggii* come from relatively cool climates, and may have potential for these areas. Other species, such as *L. lanceolata,* have attractive foliage and flowers, and may have potential as ornamentals. Others (*L. macrophylla*) may have potential as timber producers. Some features of all 16 species are given in Table 3.1.1.

The potential of hybrids

Most *Leucaena* species are outcrossing, the exceptions being *L. leucocephala* and tetraploid *L. diversifolia.* This means that seed harvested from any of the cross-pollinated species will not breed true. In fact, all *Leucaena* species, even the predominantly self-pollinated ones, will cross readily with other species. This has both advantages and disadvantages. If seed is harvested from a nursery containing a range of species, hardly any of it will be 'true to type'. It is common to find a wide range of different plant types in samples of open pollinated seed, and, if these are interspecific hybrids, they may not look like any of the known species, being intermediate between the two parents. These interspecific hybrids are often sterile, but fertility levels are sometimes sufficient to enable enough seed to be produced for selections to be made. The ability to make interspecific crosses easily is of course of great interest to the plant breeder, but it is likely to be a long and difficult job to combine the desired characters of any two parents, together with satisfactory seed production. By careful selection of parents, it may be possible to produce large quantities of seed. This has been suggested for hybrids between *L. leucocephala* and *L. pulverulenta* (Bray 1984), which have considerable potential as high yielding forage plants. Brewbaker *et al.* (1990) have also discussed this possibility in a wider context. The Hawaiian program is well advanced in the development of cool tolerant and psyllid resistant hybrids based on the interspecific crosses of *L. leucocephala* with *L. pallida* (KX2) and with *L. diversifolia* (KX3).

Gliricidia

Gliricidia is classified in the tribe Robinieae, subfamily Papilionoideae. This genus has not been collected to the same extent as *Leucaena.* There are considered to be only four species (Polhill and Sousa 1981), of which *G. sepium* (common name 'gliricidia') is the only species of real agronomic potential; it is only recently that an effort has been made to collect a representative range of germplasm of this species. This has been undertaken by the Oxford Forestry Institute, which has organised a series of trials using 28 provenances collected from a range of environments in Central America and Mexico. Collection sites ranged from 7 to 19°N. altitude from sealevel to 1,650 m, and rainfall from 650 to 3,500 mm. From preliminary results, it is clear that there is considerable variation in growth form and yielding ability. However, the performance of the best lines is fairly consistent across environments. One provenance from Guatemala, Retalhuleu, showed superior production for both leaf and wood while another from Guatemala, Monterrico, showed poor growth in terms of wood production but was outstanding for leaf production (Simons and Dunsdon 1992). There is also considerable variation in digestibility within this collection (Bray *et al.* 1993) suggesting that it may be possible to isolate superior lines with both high yield and high digestibility. Gliricidia is a cross-pollinated species; seed supply is often a problem as seed set is sporadic and uncertain in environments without a marked dry season. However, since the usual method of propagation is by cuttings, this is a difficulty largely confined to experimental situations. One danger arising from vegetative propagation is the existence of large monogenotypic stands, with no inherent variation to combat new pests and diseases. Such a situation is undesirable, and efforts should be made to ensure diversity by planting from a wide range of clones. Even widespread distribution of a single elite variety is perhaps best avoided.

Calliandra

Calliandra (Ingeae, Mimosoideae) contains more than 200 species (Williams 1983). Some of these have been grown for horticultural purposes, but only two have had any widespread agricultural use, *C. calothyrsus* and *C. tetragona.* The latter, a white flowered species, has proved to be slower growing than the red flowered *C. calothyrsus,* and will not be considered further.

Until recently, *C. calothyrsus* has not been comprehensively collected in the wild and testing has only been on a very narrow genetic base. The extensive plantings already made in Indonesia can be traced to only one or two accessions introduced in the 1930s. However, the geographical range of the species has been found to be more extensive than was formerly believed (Chang and Martinez 1984, MacQueen 1991). Collecting activities in Central America by the on have now secured over 20 provenances, mainly *C. calothyrsus,* but also including such agronomically unknown species as *C. acapulcensis, C. grandiflora, C. houstoniana, C. juzepczukii,* and *C. physocalyx* (D.J. MacQueen, personal communication). Testing of these provenances could reveal variation in yield, adaptation and feeding value.

Sesbania

The genus *Sesbania* (Sesbanieae, Papilionoideae) is indigenous to much of the tropical world; it is estimated that there are 70 species (Williams 1983) of which 10 are indigenous to Australia and 13 are woody perennials. The two most promising perennial species are *S. grandiflora* and *S. sesban,* both being used extensively in traditional agroforestry systems. *Sesbania grandiflora* is a tetraploid species native to Asian countries including India, Malaysia, Indonesia and the Philippines where it is commonly grown on bunds between rice paddies, along roadsides and in backyard gardens. *Sesbania formosa* is a closely related tetraploid species found in northern Australia. *Sesbania sesban* is a diploid species that occurs throughout Africa and most of western and southern Asia; it is a highly variable species, with two subspecies and four varieties recognised. *Sesbania* species are adapted to a wide range of environments and are noted for tolerance to alkaline and saline soils and to waterlogging. Germplasm collection and screening has been initiated by ILCA, CSIRO (Wood and Larkens, 1987) and the University of Hawaii, but systematic regional collections have been limited to Tanzania. Considerable variation exists, both in dry matter production and quality (see Evans and Rotar (1987) and Macklin and Evans (1990) for detailed discussions).

Desmodium and Codariocalyx

Desmodium (Desmodiae, Papilionoideae) is one of the largest of the tropical legume genera; it has been estimated that there are about 150 species with forage potential (Williams 1983). Some authorities include *Codariocalyx, Dendrolobium* and *Phyllodium* in the genus *Desmodium,* while others prefer to maintain them as distinct genera. The distribution of *Desmodium* is pantropical, with southeast Asia as an important centre of species diversification. Of the shrubby species, *D. rensonii, D. discolor* and *Codariocalyx gyroides* (syn. *D. gyroides*) are the most promising. However, of these only *C. gyroides* has been studied to any extent (Jones 1984). In this species the outstanding accession is CPI 76104, which has been circulated around the world, gaining many different identifying numbers in the process. More extensive collections are needed to document adequately the extent of variation.

Conclusion

Because of the diversity within all tree and shrub legume species, it is important, when planning experiments or evaluating results, to be certain of the identity of the particular cultivars or accessions being used. It is not sufficient to quote yields of a particular species (e.g. *L. leucocephala*) but is necessary to include all known details (e.g. *L. leucocephala* CPI 61227). Only by doing this is it possible to get accurate comparisons between various experiments.

Another point worthy of emphasis is the need for diversity in tree legume plantings. The damage wrought by the leucaena, psyllid is a good example of the perils of relying too much on one species or one cultivar. Future plantings should contain not only a range of species, but probably a range of varieties within species. This should safeguard against major disasters due to disease or insects.

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3.2 Environmental Adaptation of Forage Tree Legumes

H.M. Shelton

Introduction

Agriculturalists require forage tree legumes which are adapted to a wide range of environments. Species are needed which are suited to a variety of climates such as the hot humid environments of some Pacific island countries, the seasonally dry tropics, the cooler drier regions of the subtropics where frosts may occur, and the cool environments of the high altitude tropics. Similarly, adaptation to the great range of edaphic conditions that occur in each of these climatic environments is sought.

This section reviews our knowledge of the climatic and edaphic adaptation of the principal forage tree legumes and presents some new information from recent work by the University of Queensland and other research groups.

A tabular summary of the environmental tolerances of the principal tree legume species is given in Table 3.2.1.

Climatic Adaptation

Temperature

The majority of the forage tree legume species considered in this book are tropical in origin and therefore exhibit generally poor cool season growth with little frost tolerance. Nevertheless, tolerances of such stresses are important qualities in both the subtropics and high altitude tropics.

Of the main species considered (Table 3.2.1), tagasaste (*Chamaecytisus palmensis*), *Faidherbia albida* and *Acacia aneura* have moderate frost tolerance although a number of the lesser known species such as *Leucaena retusa* and *Robinia* species also exhibit frost tolerance (Table 3.2.2). *Albizia lebbeck, Calliandra calothyrsus, Leucaena diversifolia* and *Sesbania sesban* are known to have some cool season growth potential. Work of Swasdiphanich (1993) demonstrated the outstanding growth of *S. sesban* at mean temperatures of 18.5-23°C compared with *L. leucocephala* (Table 3.2.3). Unfortunately, field experience with *S. sesban* at other sites suggests that it is not tolerant of frost. Both *L. diversifolia* and *L. pallida* have shown outstanding cool season growth in southeast Queensland and at the high altitude site at Mealani (1,000 m) on the island of Hawaii. These species originate from high altitude sites in Mexico. *Leucaena leucocephala* accessions performed poorly at the Mealani site due to the low temperatures.

Table 3.2.1. Environmental and edaphic tolerances of some fodder tree legumes.

Table 3.2.2. Frost tolerance of three tree legume species measured in terms of dieback and survival 1 day and 1 month following treatment (Long 1989).

	% Dieback after 1 day				% Tree survival			
Species	**0°**	**-5°**	**-10°**	**-15°**	**0°**	**-5°**	**-10°**	**-15°**
Leucaena leucocephala	9a	87b	100b	100b	100a	20b	0b	0a
Leucaena retusa	0a	26a	43a	81a	100a	100a	90a	0a
Robinia neomexicana	17a	17a	67a	100b	83a	83a	33c	0a

Different lower case letters denote values that are statistically different ($P < 0.05$)

Scope exists for selection of ecotypes within species for improved cold and frost tolerance. Kendall *et al.* (1989) compared the frost tolerance of three populations of *L. leucocephala* from northeastern Mexico and found greater tolerance among populations originating from higher altitudes (800-2,000 m). However, *L. retusa* is the only *Leucaena* species demonstrating significant frost tolerance.

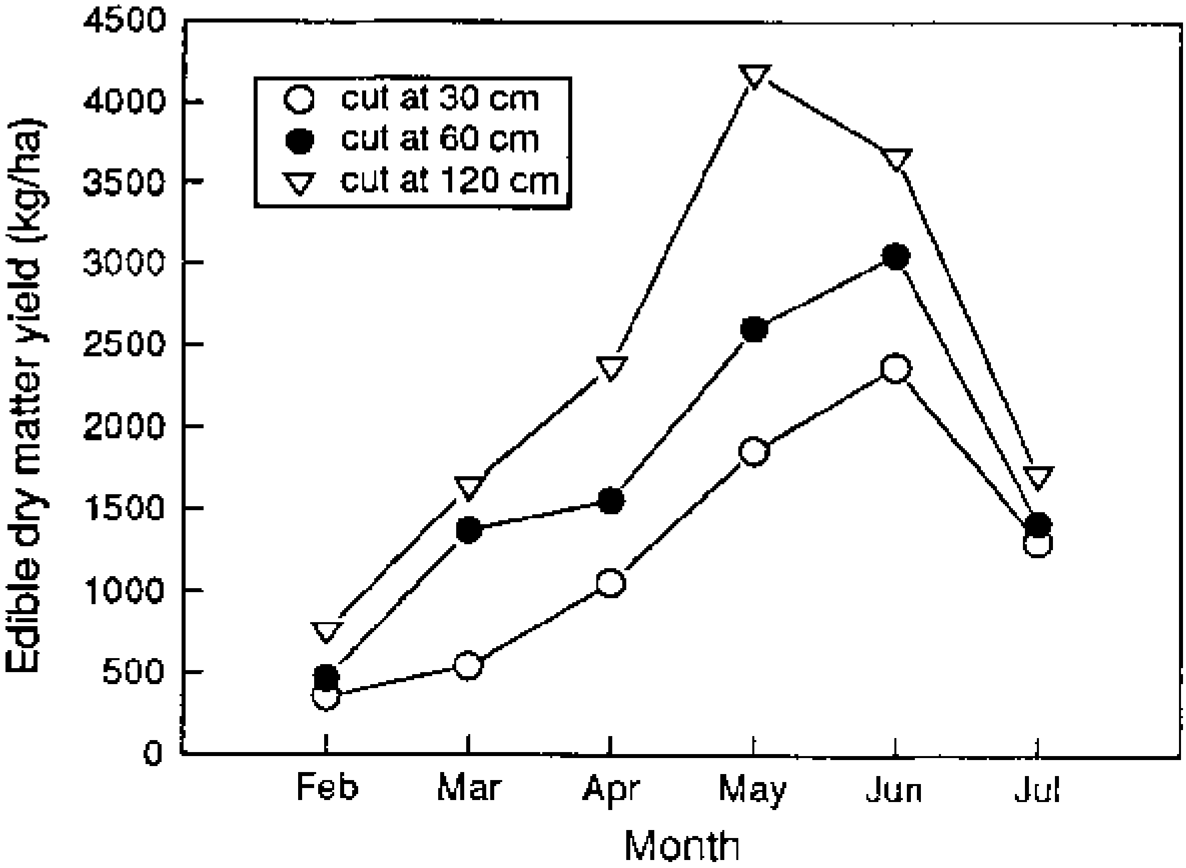
Table 3.2.3. Effect of varying temperature regime on the dry weights of tree legume species expressed as a percentage of their maximum weights after 16 weeks of growth (Swasdiphanich 1993).

	Temperature regimes (day/night ℃)			
Species	**20/17**	**25/21**	**30/27**	**34/32**
	(% of maximum value within species)			
Acacia villosa	1	4	61	100
Albizia chinensis	1	3	63	100
Calliandra calothyrsus	10	19	100	93
Gliricidia sepium	5	20	69	100
Leucaena diversifolia	2	22	76	100
Leucaena leucocephala	6	11	46	100
Sesbania grandiflora	4	13	75	100
Sesbania sesban	36	67	88	100
Stylosanthes scabra cv. Seca	1	9	100	83

Identification of new germplasm which has both cold and frost tolerance should receive priority in research programmes especially within highly nutritious species such as leucaena. The presently used cultivars of leucaena provide little cool season growth and shed their leaves, the most palatable and nutritious part of the plant, even after light frosts (Figure 3.2.1). High quality leaf material is therefore unavailable for grazing ruminants during the period of the year when it is most needed. Work at the Universities of Hawaii and Queensland has shown that hybrids of *L. leucocephala* with *L. pallida* (4n) and *L. diversifolia* (4n) (designated KX2 and KX3 respectively) have better cool tolerance than *L. leucocephala.*

The tree legume *Gliricidia sepium* loses all its leaf in southeast Queensland when temperatures drop to 15℃ and needs to be grazed in late summer and autumn before leaf shedding commences (Whiteman *et al.* 1986). In contrast, *Faidherbia albida* sheds its leaf during the moist growing season making it an excellent agroforestry species.

Fig. 3.2.1. Seasonal production *of Leucaena leucocephala* in southeast Queensland (Isarasenee *et al.* 1984). Frosts occurred in June.



Moisture

The generally accepted rainfall tolerances of tree legumes are shown in Table 3.2.1. A characteristic of tree legumes is that they may be found growing in a very wide range of rainfall environments. For instance, *Faidherbia albida can* be found growing in regions receiving as little as 300 mm and as much as 3,000 mm rainfall p.a. The accepted rainfall range for *L. leucocephala* (650-3,000 mm p.a.) is also very wide. Other species such as *S. sesban* and *Flemingia macrophylla* are less well adapted to drier environments. The lower drought tolerance of *C. calothyrsus* and *Gliricidia sepium* may be partly related to their shallow root systems but also to their inability to survive moisture stress. Swasdiphanich (1993) found that these species, when severely drought stressed, did not have the capacity to endure low leaf relative water contents, were less able to extract moisture from the soil profile and responded to drought stress with a higher proportion of fallen leaf. Species such as *L. leucocephala* and *Stylosanthes scabra* (Table 3.2.4) were more drought tolerant.

The *Sesbania* species may tolerate low precipitation levels provided they are planted in poorly drained 'run-on' areas subjected to periodic waterlogging.

Light

Tree legumes are often planted in the shade of taller plantation crops usually to provide physical support for cash crops such as vanilla and pepper. Leucaena and gliricidia are commonly used in this way. Increasingly, forage tree legumes will be incorporated into plantation systems to improve feed supply to ruminants and therefore an ability to grow at reduced light intensities will be a desirable characteristic. The work of Benjamin *et al.* (1991) demonstrated that gliricidia is the most shade tolerant of the principal tree legume species (Table 3.2.5). This was confirmed by the work of Liyange and Jayasundera (1989) who also demonstrated potential to select provenances of gliricidia which are specially well adapted to shaded environments. *Flemingia macrophylla* is also reported to be tolerant of light shade (Anon. 1989).

Table 3.2.4. Drought tolerance indices of some tree legumes after severe water stress (Swasdiphanich 1993).

Species	Av. weekly WUE prior to stress (g/kg)	Drought tolerance parameters after severe stress		
		Soil moisture (%)	RWC of young leaf (%)	Fallen leaf (%)
Calliandra calothyrsus	1.6	13.0	49.5	90
Gliricidia sepium	4.2	12.1	43.3	55
Leucaena leucocephala cv. Cunningham	2.6	12.0	33.0	25
Sesbania sesban	1.6	12.5	38.2	55
Stylosanthes scabra cv. Seca	0.6	11.9	22.8	2

WUE = water use efficiency
RWC = relative water content

Edaphic Adaptation

Soil fertility

Forage tree legumes can be found on a wide variety of soil types, including moderately infertile soils, although best production is obtained on fertile soil. For instance, Cooksley *et al.* (1988) found that highest yields of *L. leucocephala* were obtained on deep alluvial and colluvial soils rather than on shallow basaltic and andesitic soils even though frosts were more frequent on the former soil types.

One of the advantages of tree legumes is their deep root systems, a characteristic which confers persistence even on infertile soils. By contrast, many herbaceous legumes usually will not persist without the addition of inorganic fertilisers to correct nutrient deficiencies.

Much less work has been done on the nutrient requirements of tree legumes than on the herbaceous legumes. The most detailed study is that of Ruaysoongnern *et al.* (1989) who report the critical concentrations and external rates of application required by leucaena for a range of nutrients (Table 3.2.6). Many of these data are comparable to those required by other forage legumes; however, the critical concentration of potassium in index leaves (2.0%) and the external requirements of nodulated leucaena plants for phosphorus (225 kg P/ha) and calcium (230 kg Ca/ha) are relatively high, indicating greater requirements for these elements. A detailed review of the establishment requirements of leucaena to ensure effective nodulation is provided in Section 3.3.

Table 3.2.5. Shade tolerance of some tree legume species (Benjamin *et al.* 1991).

Species	Yield at high light (g/pot)	Yield at low light (g/pot)	Proportional reduction (%)
Acacia villosa	45.0	13.5	70
Albizia chinensis	42.2	25.9	39
Calliandra calothyrsus	38.6	23.2	40
Gliricidia sepium	32.2	24.6	23
Leucaena leucocephala	28.6	12.6	56
Sesbania grandiflora	26.5	16.4	38

Table 3.2.6. Estimated critical concentrations in index leaves and rates of application to achieve 90% maximum yield of leucaena for deficiency of the nutrients N, P, K, Ca, S and for toxicity of Mn (Ruaysoongnern *et al.* 1989).

Nutrient applied	**Special conditions**	**Critical conc'n**	**Rate of application for 90% max. yield (kg/ha)**	
			(dry matter)	**(nodule weight)**
N	N-supplied	4.1%	645	>90 and <175
P	(a) Inoculated	0.25%	225	no plateau reached
	(b) N-supplied	0.21%	250	no plateau reached
K	(a) N-supplied with $Ca(H_2PO_4)_2$	2.0%	35	no nodules formed
	(b) N-supplied with NaH_2PO_4	2.0%	180	no nodules formed
Ca	(a) Inoculated	0.49%	230	2550
	(b) N-supplied with $CaSO_4$	0.38%	175	no nodules formed
	(c) N-supplied with $CaCO_3$	0.38%	140	no nodules formed
S	N-supplied	0.24%	40	no nodules formed
Mn	(a) Inoculated	325 mg/kg	35	136
	(b) N-supplied	325 mg/kg	55	no nodules formed

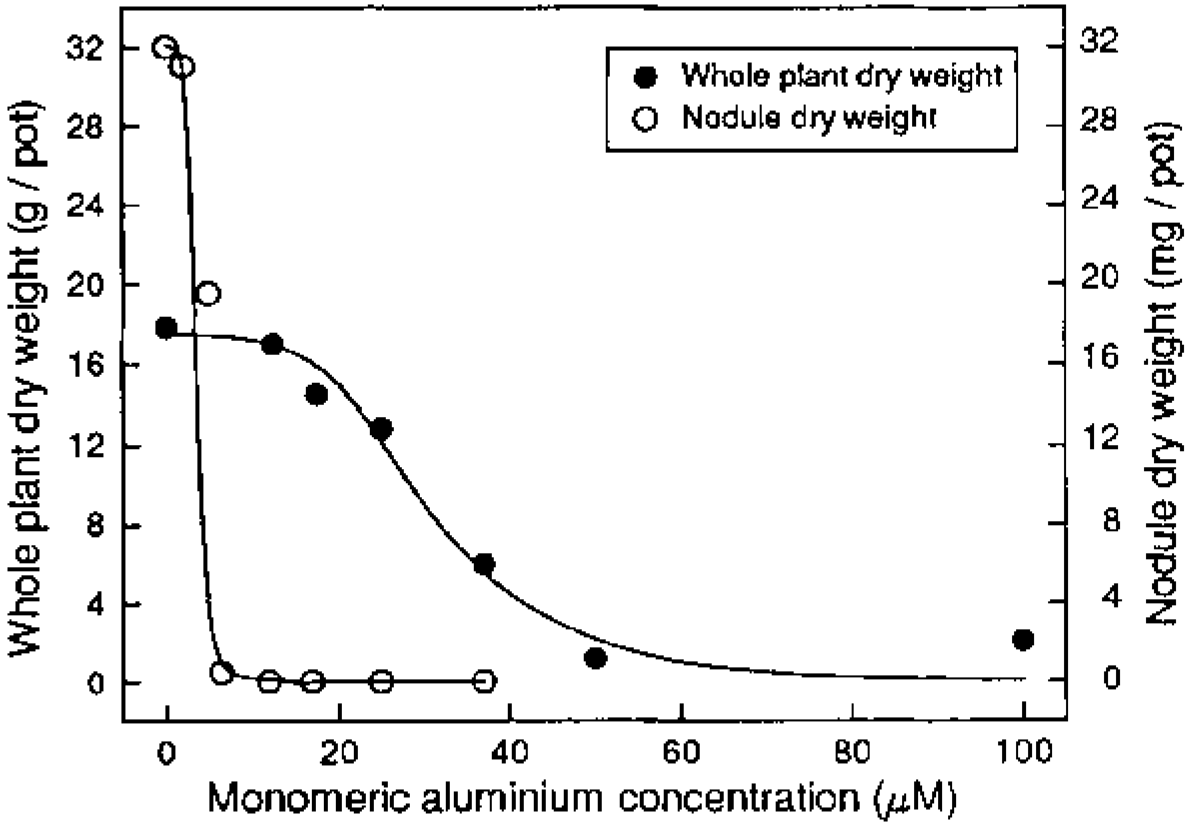
Acidity

Adaptation to acidity varies quite markedly among the tree legume species. Some species such as *Flemingia* (Budelman 1989) and *Gliricidia* (Hughes 1987) have been reported to be extremely well adapted to acidic soils as low as pH 4.5. In general, most species tolerate mildly acid soils (> pH 5.5) while some such as *L. leucocephala, G. sepium* and *Desmanthus virgatus* can tolerate highly alkaline soils.

Leucaena leucocephala is native to alkaline Mexican soils and is commonly regarded as being intolerant of soil acidity. However, studies at the University of Queensland have shown that growth of leucaena is not significantly reduced until pH falls below approximately 5.2 (1:5 in H_2O) or 4.2 (1:5 $CaCl_2$). This was confirmed by field trials in which significant responses to lime were obtained only at the lowest pH of 4.2 (1:5 $CaCl_2$). The nodulation process in legumes is often more sensitive to the effects of low pH than plant growth *per se.* Work of Ruaysoongnern *et al.* (1989) showed that nodulation was severely affected at concentrations of 5 μ M monomeric aluminium in solution culture whilst substantial reductions in plant weight did not occur until concentrations exceeded 20 μ M (Figure 3.2.2).

Trials in Hawaii have indicated that varieties such as Cunningham, K29, K132 and K420 may tolerate acidity better than others (Brewbaker *et al.* 1985). However, there are no varieties for the very acid oxisols of tropical South America.

Fig. 3.2.2 The influence of solution concentrations of monomeric aluminium on nodule and whole plant dry weight of *Leucaena leucocephala* cv. Cunningham (Ruaysoongnern 1990).



Poor drainage

Soils vary in their drainage characteristics and those which are either flat or have subsurface impermeable clay layers are vulnerable to intermittent waterlogging regardless of annual precipitation levels. Waterlogging may result in a number of effects which are injurious to plant growth. These include:

- reduced O_2 content and rate of diffusion in the soil,
- reduced redox potential which will lead to reduction of stable Mn and Fe forms in the soil to more available and toxic ionic species, and
- an increase in concentrations of CO_2, ethylene and some organic compounds which may be harmful.

Tree legumes which are tolerant of these effects are needed for both occasional and regularly waterlogged sites. The *Sesbania* species are particularly noted for their tolerance of waterlogging. A glasshouse study at the University of Queensland in a soil high in manganese showed *S. sesban* to be the most tolerant of the species tested. *Acacia villosa* also showed good tolerance while *L. leucocephala, C. calothyrsus* and *A. chinensis* were relatively intolerant (Table 3.2.7)*. Codariocalyx gyroides* is also reported to be tolerant of waterlogged soils (Skerman 1977).

Leucaena is widely reputed to be intolerant of poorly drained sites (Jones *et al.* 1982) and growth studies at the University of Queensland have confirmed this view (Figure 3.2.3). However, we have found that whilst leucaena seedlings are indeed vulnerable, well established plants are able to transpire excess soil water very quickly are therefore much less susceptible to waterlogging. In the seedling phase, *L. leucocephala* is susceptible to manganese toxicity and has a toxicity threshold of around 325 mg/kg (Table 3.2.6). Unlike aluminium, manganese appears to be more detrimental to plant growth than to *Rhizobium* and nodulation processes (Ruaysoongnern *et al.* 1989).

Table 3.2.7. Waterlogging tolerance of eight leguminous shrubs and trees (**M.C.**

Galang, unpublished data).

Waterlogging tolerance group	**Species**	**% Reduction in yield as moisture increased from 90 to 140% FC**
Excellent tolerance	*Sesbania sesban*	1
Good tolerance	*Acacia villosa*	14
Moderate tolerance	*Sesbania grandiflora*	25
	Aeschynomene americana	29
	Gliricidia sepium	31
Moderate intolerance	*Leucaena leucocephala*	47
	Calliandra calothyrsus	47
Intolerant	*Albizia chinensis*	75

FC = held capacity

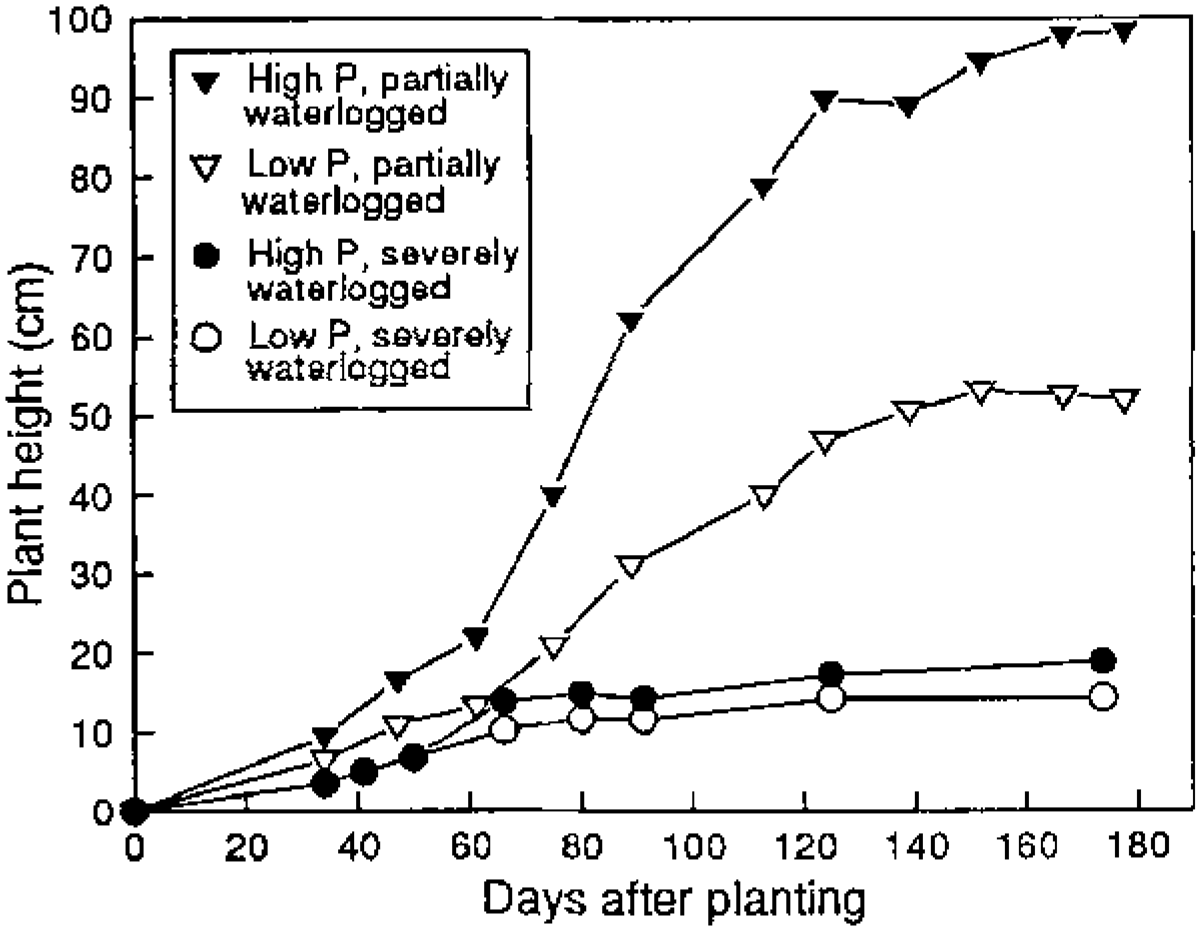
Other species reported to exhibit some tolerance of poorly drained soils are *Flemingia macrophylla* (Budelman 1989) and *Faidherbia albida* (Hocking 1987).

Salinity and alkalinity

Tolerance of salinity and alkalinity are important attributes sought in tree legumes. Species which tolerate these stresses can be used to make productive use of naturally alkaline sites, such as the uplifted coral line terraces frequently found around shore-lines of Pacific islands, or to rehabilitate areas salinised as a result of man's activities. Vast areas in India (Abrol and Bhumbla 1971) and Australia, for instance, have become salinised and more productive agriculture and forestry use could be made of these areas if suitable salt tolerant tree legumes were available.

Sesbania species are particularly tolerant of both salinity and alkalinity. Ghai *et al.* (1985) showed that seed of *S. aegyptica* (pseudonym *S. sesban*) was able to germinate without reduction at electrical conductivity levels up to 11 mmho/cm while *S. grandiflora* and *S. glabra* showed reductions in germination percentage of 23 and 37% respectively. However, the germination process is more sensitive to salinity than subsequent plant growth and other studies have shown that both *S. sesban* and *S. grandiflora* exhibit good tolerance of NaCl up to concentrations of 100 mM (Hansen and Munns 1985). *Acacia ampliceps* is one of the most salt tolerant of the Australian acacias. It is prominent close to tidal zones and in and around inland salt lakes (Turnbull 1986). It appears to be a useful forage and is often heavily grazed by cattle.

Fig. 3.2.3. The response of *Leucaena leucocephala* to waterlogging at nil and high rates of phosphorus application (N. Brandon, unpublished data).



Conclusions

A wide range of climatic and edaphic adaptations is exhibited by tree legumes. Although their seedling phase can be relatively more sensitive to various stresses, mature plants can be surprisingly tolerant. These attributes may permit the use of tree legumes on marginal soils and in rehabilitation situations, where herbaceous species would not survive, with minimal use of costly soil amendment practices.

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3.3 Establishment of Forage Tree Legumes

H.M. Shelton

Introduction

Some of the great advantages of many tree legumes, once established, are their longevity, vigorous growth and apparent immunity against competition from lower-growing herbaceous species. The tall stature and deep-rooted habit of tree legumes effectively insulate them from the most serious effects of competition. Consequently, in pasture systems, management of tree legumes to maintain grass/legume balance is simpler than with herbaceous legumes.

However, most tree legumes exhibit very slow growth as seedlings and at this stage of growth are vulnerable to competition from weeds (Maasdorp and Gutteridge 1986) and predation from wildlife. Long-lived species are often particularly slow as seedlings as much of their early growth is directed to establishing a strong root system. The poor establishment record of *Leucaena leucocephala* in subhumid Queensland is currently the major impediment to its more rapid adoption. This often results in an extended period before first grazing can occur and in a high rate of establishment failure (Lesleighter and Shelton 1986).

Methods for establishment of tree legumes are required which are quick and more reliable. Slow and/or unreliable establishment increases the time and level of risk before economic returns are feasible, and farmers are much less likely to adopt new technology when establishments risks are significant.

This section summarises what is known about establishment of tree legume species for utilisation in agricultural systems.

Root Systems of Tree Legumes

The poor establishment characteristics of tree legumes can be partly related to their rooting characteristics. Trees have evolved for long-term survival rather than quick early productivity. Their root systems have a high component of permanent structural roots as well as a system of fine roots responsible for nutrient and water uptake. A greater proportion of assimilates is translocated to non-productive structural development in tree roots.

Trees also have a much lower root length density than grasses (Bowen 1985). Atkinson (1980) reported root length densities ranging from 0.8 to 69 cm/cm^3 for horticultural trees compared with 1004,000 cm/cm^3 for grasses. Swasdiphanich (1993) measured root length densities in the surface 50 cm of soil of 0.5 cm/cm^3 for *L. leucocephala* and 2 cm/cm^3 for *Calliandra calothyrsus.* Low root densities make it difficult for roots to access poorly mobile nutrients ($H_2PO_4^-$, K^+ and NH_4^+) or immobile nutrients (Cu_2^+ and Zn_2^+) in the soil (Bowen 1985). Since the major concentration of tree roots occurs in the surface 15-30 cm of soil (Bowen 1985) it is clear that grasses will have a competitive advantage over trees especially in the seedling stage. Weeds, and particularly grass weeds, must be carefully controlled during the seedling phase of tree legumes. *Eucalyptus* species, which have adapted to grow in low nutrient soils, have quite fine roots (Bowen 1980) and this may make *Eucalyptus* seedlings more competitive with grasses.

There are a number of factors which can be manipulated to improve seedling growth rates and these are now considered.

Factors Affecting Seedling Growth Rates

Seed treatment

Scarification

The hard or waxy coats on the seed of many tree legumes inhibits the absorption of water and prevents uniform germination. The seed coat must be broken or scarified before germination will occur. Without scarification, the germination percentage may be <10%. Withington (1986) provides a summary of scarification methods for a range of tree legumes (Table 3.3.1). The most common method is hot water treatment, but sulphuric acid or mechanical scarification methods are also used.

Rhizobium inoculation

Forage tree legume plants which are not effectively nodulated will be pale in colour and will not grow vigorously due to inadequate nitrogen fixation leading to nitrogen deficiency. In preliminary evaluation trials it is possible to confuse this problem with poor adaptation to the environment.

Quite a number of tree legume species have specific *Rhizobium* requirements for effective nodulation and nitrogen fixation (Moloney *et al.* 1986). However, in many cases, the specificity of the species is not known, and the most effective *Rhizobium* strain has yet to be identified (Section 3.4)

Table 3.3.1. Pre-germination treatment for some nitrogen fixing trees (Anon. 1989).

Species	**Treatment.**	**Seeds/kg**
Acacia acuminate	C, D	60,000-80,000
Acacia aneura	A, C	75,000-95,000
Acacia angustissima	A, C	90,000-100,000
Acacia auriculiformis	A for 30 s, B for 15 min. C	30,000-90,000
Acacia crassicarpa	A for 30 8, C	40,000-60,000
Acacia holosericea	A for 1 min. C	70,000-80,000
Acacia mangium	A for 30 s, C	80,000-100,000
Acacia mearnsii	A, C	48,000-85,000
Acacia melanoxylon	A, B for 15 min. C	60,000-100,000
Acacia nilotica	A, C, D	7,000-11,000
Acacia polyacantha	D	10,000-25,000
Acacia saligna	A, C	14,000-25,000
Acacia senegal	C, D	10,000-30,000
Acacia tortilis	A, C, D	12,000-18,000
Albizia lebbeck	A, C, D	6,000-16,000

Albizia procera	A	20,000-24,000
Albizia saman (syn. *Samanea saman*)	A, C	6,000-8,000
Alnus species	no treatment needed	200,000-2,000,000
Cajanus cajan	no treatment needed	5,000-12,000
Calliandra calothyrsus	A, C, D	18,000-20,000
Casuarina species	no treatment needed	150,000-1,500,000
Chamaecytisus palmensis	A for 4 min	38,000-42,000
Dalbergia spp.	D	10,000-30,000
Enterolobium cyclocarpum	C, D	800-2,000
Erythrina poeppigiana	D	3,000-5,000
Faidherbia albida (syn. *Acacia albida*)	A, B for 20 min. C, D	20,000-40,000
Flemingia macrophylla	no treatment needed	50,000-80,000
Gliricidia sepium	no treatment needed	7,000-12,000
Leucaena spp.	A, B for 5-10 min. C	22,000-35,000
Mimosa scabrella	C, D	60,000-90,000
Paraserianthes falcataria (syn. *Albizia falcataria*)	A, B for 10 min. C	40,000-50,000
Pithocellobium dulce	no treatment needed	9,000-25,000
Prosopis spp.	A, C	20,000-50,000
Pterocarpus indicus	no treatment needed	1,500-2,000
Robinia pseudoacacia	A, B for 20-60 min. C	35,000-50,000
Sesbania grandiflora	C, D	20,000-30,000
Sesbania sesban	C, D	85,000-100,000
Tipuana tipu	no treatment needed	1,600-2,500

* Treatments:

> A. Pour boiling water over seeds, about 1 litre water per 250 9 of seeds or about five times as much water as seed, stir gently, pour off after 2 min (or as specified), replace with tap water and soak overnight.
>
> B. Cover seeds with concentrated sulphuric acid, stir gently for recommended soaking time, pour off acid and rinse well in water.
>
> C. Scratch or nick the round end of each seed with a file, knife or nail clipper. Do not cut the cotyledon.
>
> D. Soak in cold/tepid water for 24 h.

The *Rhizobium* requirements of leucaena are now well known and it is possible to obtain peat cultures of effective *Rhizobium* from seed suppliers, when ordering seed. This is not the case with most other species.

Gliricidia sepium (Mzoma 1989) and *Sesbania sesban* are known to require specific *Rhizobium.* In the latter species, there is a host-strain interaction and different accessions of *S. sesban* require different strains of bacteria (M. Masafu, unpublished data).

Until more is known about host plant - bacterial strain specificity, care should be exercised when evaluating new varieties of tree legumes. In some cases, it may be wise to apply nitrogen fertiliser, or to use soil from around the roots of well-grown nodulated trees.

Effective strains of *Rhizobium* for many tree legume species are available from NIFTAL at 1010 Holomua Road, Paia, Maui, Hawaii 96779, USA.

Site selection

Successful establishment of tree legume species will only be achieved if the characteristics of the proposed planting site are matched against the climatic and edaphic requirements of the species. If the establishment requirements are not fully met, growth of seedlings will be poor unless the soil is amended or an alternative site is found. Table 3.2.1 in Section 3.2 shows the environmental requirements of the main species of tree legumes.

Inherent vigour of seedlings

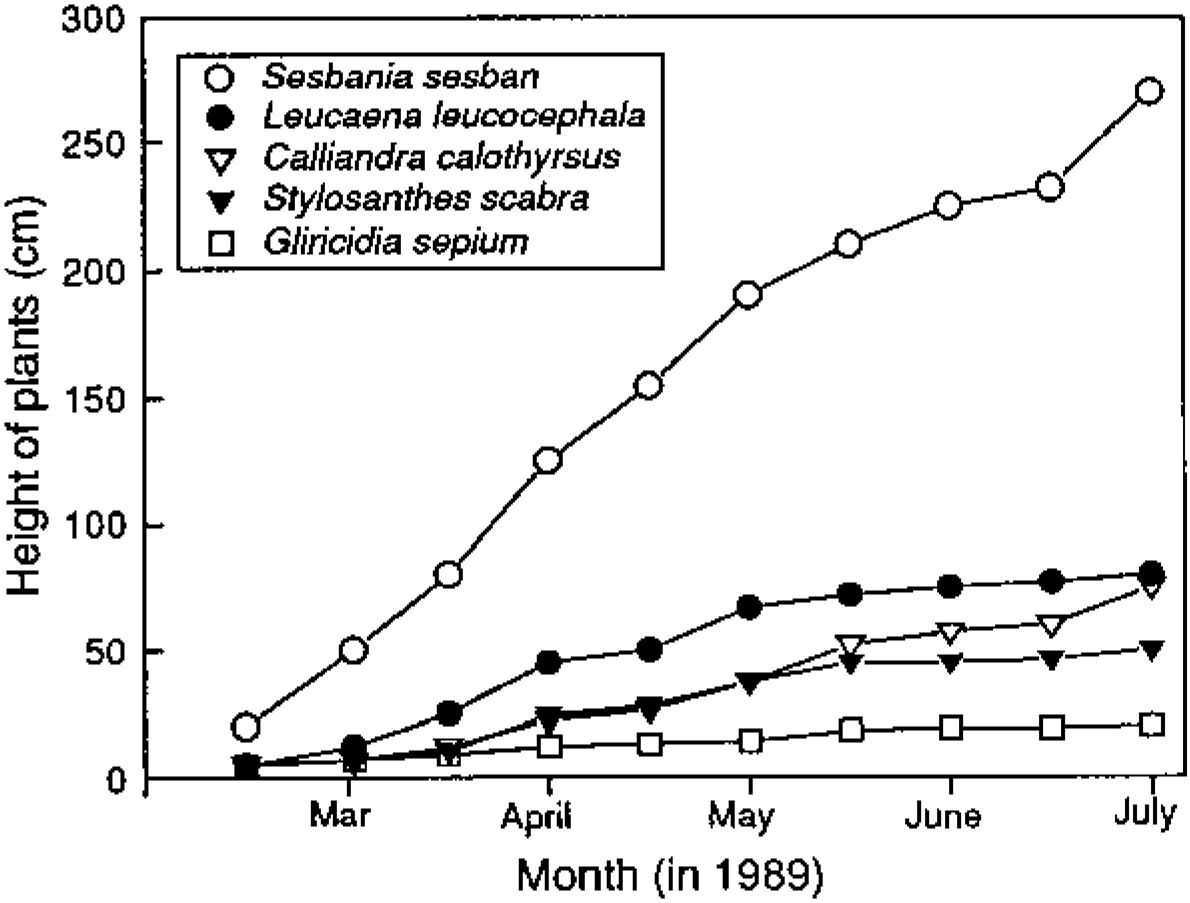
The vigour of young seedlings is largely determined by genetic growth potential, the environmental characteristics of the site chosen and the level of amendment of the soil. The vigour of young leucaena seedlings varies greatly depending on site characteristics, and there are genetic differences within the *Leucaena* genus. *Leucaena pallida* and its hybrids show superior vigour to *L. leucocephala* cv. Cunningham (Sorensson *et al.* 1993).

There are also differences among other species of tree legumes in seedling vigour. For instance, *S. sesban* consistently shows superior seedling vigour compared with other species (Figure 3.3.1). This can be related to the lower mycorrhizal dependency of *S. sesban,* higher root mass, higher root density, higher root surface area, higher root length, smaller root diameter and higher root hair incidence in *S. sesban* relative to other species such as *L. leucocephala* (Manjunath and Habte 1991).

Fertiliser application

The responsiveness of the tree legumes to applications of fertiliser depends on their external nutrient requirements for maximum growth, and the fertility of the soil being fertilised. There are many experiments in the literature providing information on the response of tree species to fertiliser application but these tend to be site specific (Bray *et al.* 1987) and therefore of limited value for predicting fertiliser requirements elsewhere. However, Moloney *et al.* (1986) and Ruaysoongnern *et al.* (1989) have reported data on the generalised external and internal nutrient requirements of some tree legumes; the latter work provided estimates of critical concentrations in index leaves as well as potential fertiliser requirements for a range of nutrients for *L. leucocephala* (Table 3.2.6). These indicate that nodulated leucaena plants have quite a high requirement for phosphorus and calcium. More work is required to elucidate the nutrient requirements of the other commonly used species.

Fig. 3.3.1. Seedling growth rates of five tree legume species at Redland Bay in southeast Queensland (Swasdiphanich 1993).



Vesicular arbuscular mycorrhizae

Most tree legume species form symbiotic associations with naturally occurring soil fungi called vesicular arbuscular mycorrhizae (VAM). This association assists the roots to exploit more fully the soil volume and to gain improved access to available nutrients especially phosphorus. Nutrient ions are transferred to the roots via the hyphae. VAM therefore compensate for the low root length densities of trees. VAM can produce 80 cm of hyphae per cm of fine root infected (Sanders and Tinker 1973) with a length/weight ratio of 500 times that of fine roots. Mycorrhizal infection is therefore an important strategy complementary to, and sometimes replacing, fine root production (Bowen 1985).

Both *Calliandra calothyrsus* and *L. leucocephala* are known to form mycorrhizal associations. Young leucaena seedlings are very dependent on rapid early mycorrhizal infection of the roots for adequate phosphorus supply. Ruaysoongnern (1989) showed that the growth of *L. leucocephala* without VAM infection was only 5% of that obtained in unsterilised soil; phosphorus concentration in young leaves was reduced from 0.31 to 0.07% and nodulation was reduced from 297 to 0 mg/plant.

Brandon and Shelton (1993) reported that leucaena plants growing in a soil inherently low in VAM activity (Mt Cotton soil) suffered a period of P deficiency until VAM infection increased to effective levels. This was not observed in a soil which had a higher inherent VAM activity (Theodore soil). Very high levels of phosphorus fertilisation (1,200 kg P/ha) negated the effect (Figure 3.4.2) while competition from grasses exacerbated the effect. Soils vary in natural VAM activity according to cropping and cultivation history. VAM levels are high under most tropical grass pastures but are reduced by long periods of cultivation or intermittent waterlogging and may be low in virgin sites under Australian native vegetation.

Weeds

The slow seedling growth of many tree legumes makes them susceptible to competition from fast growing weeds which may slow or completely dominate their growth. It is therefore vital that young seedlings be protected from weed competition until they are well established. This can be performed by hand, using hand-held or tractor drawn machinery, or by the use of herbicides.

Chemical weed control with leucaena is now well understood. Pre-emergence control of weeds can be obtained with Trifluralin (0.5 kg a.i./ha) and Alachlor (3 kg a.i./ha) when incorporated, or with 2,4-D amine (6 kg a.i./ha), Dacthal (8-10 kg a.i./ha) and Oryzalin (3 kg a.i./ha) when surface sprayed (Brewbaker *et al.* 1985). The post-emergence herbicides Fluazifop (2 kg a.i./ha) and Bentazone (2 kg a.i./ha) are effective against grass and broadleafed weeds respectively without being excessively phytotoxic to leucaena.

Little is known about herbicides for use with other tree legumes although Glover (1986) reported that Glyphosate (1 kg a.i./ha) and Simazine (1 kg a.i./ha) were effective and non-phytotoxic pre-emergent herbicides for control of grass and broadleafed weeds in *Gliricidia sepium.*

Wildlife

Damage by wildlife can be a serious hazard to establishment. In Australia, marsupials, hares, cockatoos and ducks all seek out young leucaena seedlings and can chew plants to ground level making them more susceptible to domination by weeds. Economical control methods are not available. The planting of larger areas tends to reduce the percentage of the total crop damaged. New varieties with improved seedling vigour will also reduce this problem.

Planting Methods

Direct seeding

Planting of tree legumes by seed to form hedgerows is the most common method for broad-acre sowings. Appropriate row spacings for leucaena in pasture sowings vary from 3 to 10 m with wider spacings used in drier environments. The current recommendation in central Queensland is single or double rows 1 m apart with approximately 4-5 m between centres. If plant spacing within rows is 30-50 cm, this gives a population of 13,000-33,000 plants/ha, vastly less than the 75,000-140,000 plants/ha reported to be necessary to achieve peak forage yield (Brewbaker *et al.* 1985). Smaller plant populations, in wider rows, may provide better rationing of limited water supply and an opportunity to intercrop the rows with grass.

In Australia, tree legumes (primarily leucaena are normally directly seeded using a seed drill, into fully prepared and clean cultivated seedbed. The technical aspects of direct seeding of *L. leucocephala Sesbania* spp. and *G. sepium* are provided in Brewbaker *et al.* (1985), Evans and Macklin (1990) and Glover (1989) respectively and will not be repeated here.

Planting seedlings

Most tree legumes are readily established from transplanted seedlings. Seedlings are first grown in greenhouse nurseries in polythene bags or in small plastic dibble tubes until they reach a height of 30-50 cm. After a short period of 'hardening' in the open air, seedlings are directly transplanted into the field into moist soil. Weeds need to have been previously controlled either mechanically or chemically. Watering and protection of seedlings from predators will be necessary until trees become well established.

Some nitrogen fixing trees can be planted from stump cuttings which are easier to transport into the field. The NFTA *Establishment Guide* (Anon. 1989) reports that *Albizia lebbeck, Calliandra calothyrsus, Dalbergia sissoo, Enterolobium cyclocarpum,* *Gliricidia sepium, Leucaena* spp., *Paraserianthes falcataria* and *Pterocarpus indicus* can be planted in this way.

Stump cuttings can be made from seedlings which reach 60-90 cm in height and 10-20 mm in diameter in nursery seedbeds. They are first carefully removed when the seedbed is thoroughly wet and stems and roots cut 15-20 cm above and below the crown. Gliricidia stump cuttings can survive several weeks if kept moist although survival is best when transplanted promptly.

A recent comparison of planting methods shows the superiority of transplanted seedlings over direct seeding methods especially when weed growth is not adequately controlled (Figure 3.3.2) (B. Woodhead, unpublished data). Survival of transplanted seedlings was also higher than that of plants from direct seeding methods.

Vegetative propagation

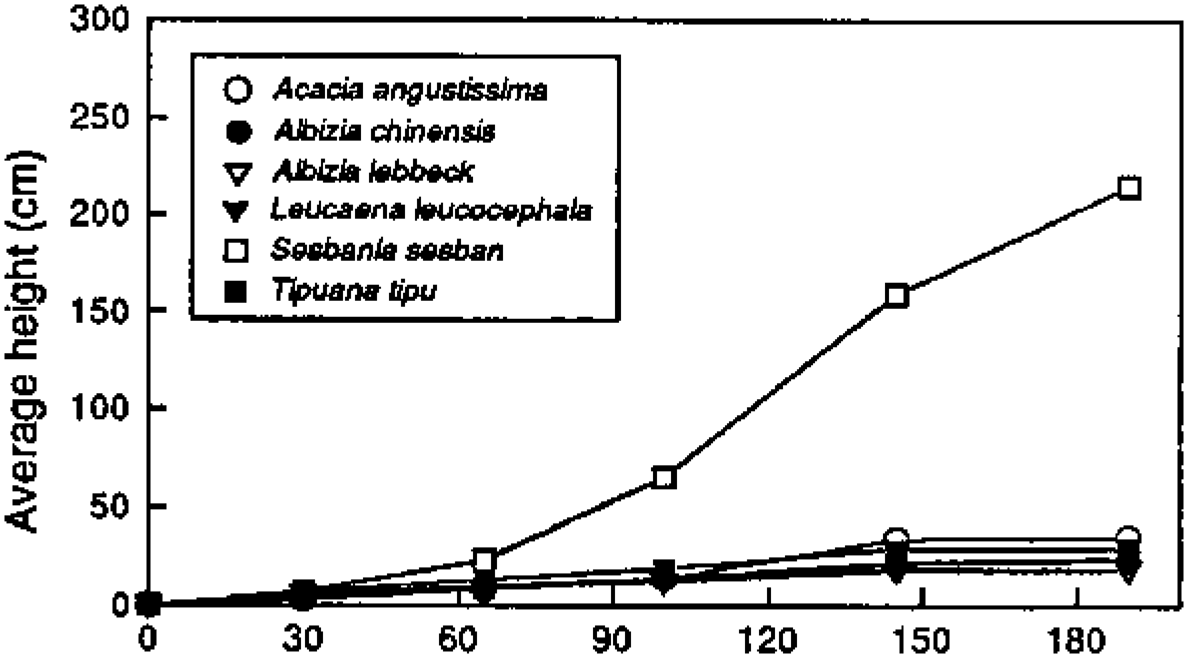
Vegetative propagation of tree legumes is commonly practised with some species. Its advantage is more rapid establishment of new stands which are genetically identical to the parent lines without the need for seed collection. Disadvantages are that it requires more hand labour and the root development of cuttings may be shallow and devoid of a strong taproot compared with seedling grown trees. Shallow rooted trees are more susceptible to drought and wind damage.

Gliricidia sepium is commonly planted vegetatively and a full description of propagation methods is given in Glover (1989). Gliricidia establishes readily from cuttings or 'quick sticks' and is ideal for shade trees, support trees or 'living fences'. Cuttings should be mature branches >7 cm in diameter which are brownish-green in bark colour. The cutting is normally cut obliquely at both ends, discarding the younger tips, and the base inserted 20-50 cm into the soil depending on the length of the cutting. Cuttings for living fences may be up to 200 cm long whilst those for hedgerows may be 30-50 cm in length. In Indonesia, cuttings are sometimes planted as close as 10 cm apart with alternate cuttings bent sideways at 45° and plaited onto upright cuttings. This makes a surprisingly strong fence. In other areas, barbed wire is strained along the line of rooted cuttings and anchored on supported comer posts to make an equally strong fence. The fences can be periodically pruned to provide fodder, green manure, fuelwood or stakes for new fences. Frequency of pruning depends on the environmental conditions for growth and the end use of prunings. Living fences around agricultural fields need to be pruned regularly to reduce shading.

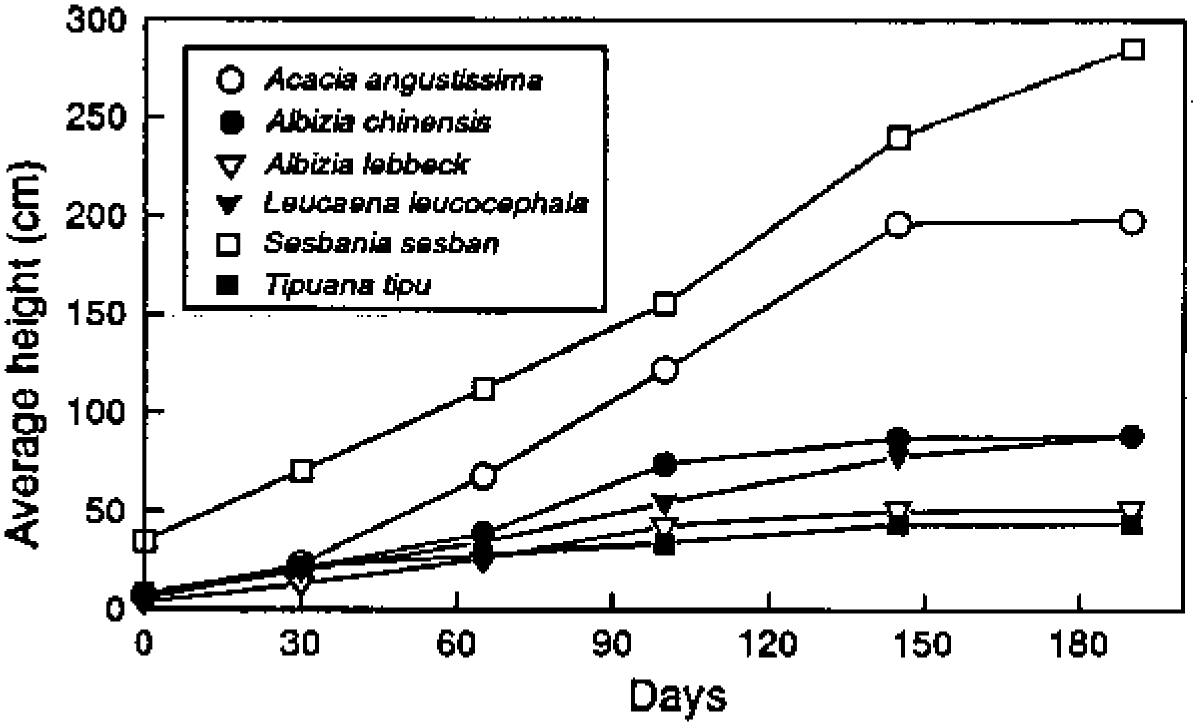
The *Sesbania* species seed prolifically and are normally planted from seed, although research suggests that some sesbanias can be established from cuttings (Evans and Macklin 1990). *Sesbania* species can also be propagated using *in vitro* methods (Harris and Puddephat 1989, Harris *et al.* 1989).

Fig. 3.3.2. Growth rates of six tree legumes established by planting seed or transplanted seedlings at Mt Cotton in southeast Queensland. Vertical bars represent LSD (P < 0.05) at days 30, 100 and 190. (B. Woodhead, unpublished data).

(a) Cultivation



(b) Seedling



Leucaena leucocephala is difficult to propagate vegetatively (Litzow and Shelton 1992) although Duguma (1988) and Bristow (1983) have reported successful establishment from cuttings. Both the University of Queensland at Brisbane and NFTA staff in Hawaii have recently reported success with grafting techniques onto suitable root stocks.

Similar techniques may be used for other species of tree legumes.

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3.4 Microbial Symbioses of Tree and Shrub Legumes

P.J. Dart

Introduction

Many forest trees are legumes which nodulate with the bacterium *Rhizobium* (fast growing) or *Bradyrhizobium* (slow growing) and fix gaseous nitrogen thereby utilising some of the 84,000 tonnes of nitrogen gas in the air above each hectare of land. There are more than 18,000 species of legumes of which about 7,200 species are woody. Only about 18% of these woody species have been examined for nodulation and of these 92-94% of the mimosoids and papilionoids nodulated, but only about 34% of the caesalpinoids (Allen and Allen 1981, Brewbaker *et al.* 1982, Dobereiner 1984). It is not easy to determine if tree legumes nodulate as nodules are both difficult to find in forest soils and difficult to assign to a particular tree. Hence, observations on young plants are helpful to assess the nodulation status of the plant.

Besides legumes, the humid tropical forest genus *Parasponia* (family Ulmaceae, order Urticales) also nodulates and fixes much nitrogen with a specific group of *Bradyrhizobium* bacteria (Trinick and Hadobas 1988). However, the closely related *Trema* spp., *Celtis* spp., *Ulmus parviflora* and *Gironniera subequalis* do not appear to nodulate.

Nodulated plants also occur in six other families; about 160 species are involved. The nodule forming endophyte is an actinomycete bacterium known as *Frankia* which can now be grown in pure culture and used as an inoculum. The best known of these species in tropical situations are *Casuarina equisetifolia, C. junghuhniana, C. cunninghamiana, Alnus nepalense* and *Eleagnus philippensis.*

Non-symbiotic Nitrogen Fixation

Biological nitrogen fixation also occurs through non-symbiotic bacteria growing on roots and in degrading litter; blue-green algae or cyanobacteria on soil and plant surfaces; and associations of cyanobacteria with fungi and lichens, or with higher plants such as liverworts, mosses, cycads and the angiosperm *Gunnera.* Most of the nitrogen in forest ecosystems is derived from biological nitrogen fixation. These systems are very efficient in recycling nitrogen leached to lower depths in the soil through uptake by deep roots, and through leaf fall, concentrating this nitrogen in the litter and upper soil horizons.

Disturbing this natural cycle which conserves scarce nutrients so effectively can lead to rapid loss of soil fertility. Maintenance of the litter layer as a soil mulch to reduce erosion as well as to conserve nutrients is a very important aspect of maintaining soil fertility around trees and shrubs.

Symbiotic Nitrogen Fixation

Inoculant strain selection

There are varying degrees of specificity in the requirement of tree species for effective rhizobium strains. There are even differences among provenances in the effectiveness of particular strains. Soils contain several types of rhizobium, and in some soils, populations of appropriate strains may be absent or too small for nodulation to occur. It is in these situations where a response to nodulation inoculation with rhizobium might be expected. Strains for use as inoculants therefore need to be selected for a particular legume accession (Table 3.4.1). This process usually starts with the assembly of a collection of strains by isolation from nodules, usually obtained from the legume under consideration. This is followed by an assessment of their ability to fix nitrogen in a strain trial in pots using a rooting medium which does not contain rhizobia.

Tree legumes are nodulated by two kinds of rhizobia. One type now known as *Bradyrhizobium* is slow growing on laboratory media, but is the prevalent kind of rhizobium in most tropical soils, nodulating many tropical plants effectively. All three legume families are nodulated by *Bradyrhizobium.* Another group is the fast growing *Rhizobium* type which produces more gum and larger, more distinctive colonies than *Bradyrhizobium* strains. Colonies of such fast-growing strains appear on agar about three days after inoculation compared with seven or more days for the slow growers. Fast growing *Rhizobium* strains have been isolated from *Mimosa caesalpiniaefolia, Mimosa invisa, Mimosa pudica, Leucaena leucocephala, Acacia farnesiana* and species of *Sesbania,* and form a distinctive preferred host group (Campelo and Dobereiner 1969, Trinick 1980). Both fast and slow growing rhizobia nodulate several *Acacia* species, but some are specific for either fast or slow growers (Dreyfus and Dommergues 1981, Roughley 1987). The non-legume *Parasponia* seems to be nodulated by a distinctive group of *Bradyrhizobium* strains (Trinick and Hadobas 1988).

Table 3.4.1. Total dry matter yield of five lines of *Sesbania sesban* inoculated with two strains of *Rhizobium* or fertilised with inorganic nitrogen (M. Masafu, unpublished data).

***S. sesban* line**	**Rhizobium strain**		**Nitrogen treatment**		
	PMA-295/2	**CB-3023**	**+N***	**-N**	**Mean**
9266	8.6	8.8	19.9	7.4	11.2
10895	9.7	6.4	19.2	6.6	10.2
15022	7.0	8.4	18.6	6.6	10.2
15036	9.2	7.4	18.9	6.7	10.6
30071	14.0	6.8	18.5	6.5	11.5
Mean	9.7	7.6	19.0	6.6	

LSD ($P < 0.06$) *Rhizobium* and nitrogen means = 1.0 g; line means = 1.1 g; interaction 2.1 g.
* +N = 42.5 kg N/ha

Nodules that are nitrogen-fixing contain haemoglobin very similar to the pigment in muscles. This haemoglobin is concerned with maintaining an adequate oxygen supply to the bacteria at low oxygen tension to maintain the nitrogen fixing process which is sensitive to oxygen. The colour of a sliced nodule is thus a useful indicator of its nitrogen fixing activity. Brown, green or white nodules are probably non-fixing while red or pink nodules are usually formed by strains effective in nitrogen fixation. The more red the colour of a legume nodule, usually the more active it is.

Sometimes soils contain strains which nodulate but which are not very effective in fixing nitrogen. In these situations, inoculating plants with a superior strain may supplant the indigenous soil population in forming the nodules. This is not easy because only a small number of bacteria can be added in the inoculum relative to the large soil population of rhizobia. To overcome competition from the indigenous population, the inoculum strain needs to have an intrinsic competitive ability to form nodules and to be able to colonise root systems readily, so that the strain is present in the zone of the root susceptible to nodulation.

Legumes are often grouped into species which reciprocally nodulate with a 'homologous' group of rhizobium strains isolated from those species (the cross inoculation group). 'Heterologous' strains isolated from outside this group usually do not initiate infections within this group.

Rhizobium infection and nodule development

Root infection and nodule development involves colonisation of the rhizosphere by rhizobia, their attachment to the root at the site of infection, and uptake of plant flavonoids by rhizobium that modify gene expression to initiate production of specific factors enabling infection and nodulation to occur. Rhizobia induce specific changes in plant cell wall development at this stage that enable the bacteria to cross the cell wall barrier.

In the first pattern of infection, rhizobia invade the small emerging root hairs by causing them to curl during growth and enclose a rhizobium microcolony. This then induces production of an infection thread within the root hair cell. The infection thread grows into the root cortical cells carrying the rhizobia.

The second method of infection occurs through cortical cells or the epidermal cells, which do not form root hairs, usually at the break in the cortex integrity caused by the emergence of a lateral root. The rhizobia invade the root growing in the intercellular spaces, a microcolony causes the cortical cell wall to thin and grow around the bacteria, depositing cell wall materials on the internal wall surface, and the bacteria appear to grow through this barrier. Once released, the rhizobia induce host cell division and divide along with the chromosomes in the process. All the invaded cells are then produced by continued host cell division. Nodules produced in this way usually have a round appearance. *Parasponia* nodules seem to be formed in this way.

Most tree nodules appear to develop from infection threads, and are also characterised by a terminal meristem which continues to form cells for nodule growth. Behind the meristem the expanding cells are invaded by infection threads which release the rhizobia. The rhizobia then divide and multiply, at the same time remaining enclosed within a plant derived membrane. This membrane may contain one or several bacteroids which may be rod shaped but for some associations they may be very enlarged and pleomorphic. Only a small proportion of the nodule cortical cells in some tree nodules is invaded. Little is known about the effect this has on nodule performance. Because of continued growth, perennial nodules can be very large (more than 3 cm long), often with several meristems developed from the original one, giving the nodule a coralloid appearance.

Control of nodule number and nodule senescence

The development of a root nodule involves a complex and continuing exchange of signals between host plant and bacterium. It is a finely tuned interaction and the process may abort at any stage. Nodulation is under the genetic control of both partners but little is known of the way in which one symbiont modifies the expression of genes in the other partner.

The existing nodules on a root seem to influence the formation of other nodules. For soybean this appears to be through a shoot factor which translocates to the root to control further nodulation. For some tree species, the level of this control varies from plant to plant and between species. Thus nodule number on *Acacia mangium* may vary from about 200 per 8 month old plant to several thousand nodules on older plants. Nodulation on plants with many nodules seems to be more robust in the face of stresses than on plants with fewer nodules.

For some species there is a cyclical growth of nodules in the rainy season followed by senescence and decay in the dry season, the senescence starting at the base of the nodule in the oldest formed cells which turn green or brown due to chemical changes in the haemoglobin (Homchan *et al.* 1989). The degeneration continues to the meristem, and the nodule then dries out leaving an empty shell which sloughs off the root, releasing rhizobia back into the soil. Nodules will only form again when new roots develop. Little is known about the factors resulting in nodule senescence or the perenniality of other nodules. The pattern of nodulation is influenced to a certain extent by the rhizobium strain; some less effective strains form nodules which senesce earlier, but the process seems to be host plant determined.

Many tree legume nodules are characterised by a thick protective husk layer containing a peripheral sheet of suberised and thickened cells. The husk cells also contain much tannin. Both characteristics are presumably protective adaptations against desiccation and pest attack. Both NH_4^+ and NO_3^- at high concentrations in soil solution inhibit nodulation of many legume species including some tree species such as *Leucaena* and *Albizia.* However, small amounts of combined nitrogen can be synergistic with nodulation in providing for the nitrogen requirements of plants. Very little is known of the tolerance of tree species to soil nitrogen levels, although nodulation of *L. leucocephala* is stimulated by small amounts of nitrogen fertiliser and inhibited by large amounts (see Figure 2.1.2). Adding small amounts of nitrogen fertiliser (30-50 kg N/ha) may boost seedling growth and produce a more extensive nodulation. In an experiment with 20 *Acacia* species grown in an acidic soil (pH 4.5 in water), nitrogen fertiliser applied at 100 kg N/ha produced more rapid growth than plants which were unfertilised, relying on nodulation for their nitrogen supply. This was partly a reflection of the long time taken to form nodules on tree seedlings so that the N supply from nodules was only available over about half the 5 month growth period (N. Ashwath, P.J. Dart and D.G. Edwards, unpublished data).

Response to inoculation

In recent experiments in northeast Thailand, inoculation of *L. leucocephala* at six sites with the highly effective *Rhizobium* strain TAL 1145 resulted in most of the nodules being formed by the inoculant strain over the first 72 weeks (Homchan *et al.* 1989). Virtually no nodules were formed in the uninoculated plots in the first 20 weeks. At 20 weeks, inoculated plants were between 66 and 280% larger, depending on the site. The strain TAL 1145 proved to be very effective in nitrogen fixation and well adapted to the soils in six of the eight sites tested, moving to uninoculated plots and forming nodules. At 72 weeks, there was no apparent effect of inoculation on plant dry matter production and height (Homchan *et al.* 1989). However, the increased vigour in the establishment phase would justify the effort and small cost of inoculating plants. By 64 weeks at some sites, some indigenous populations of rhizobia had developed sufficiently to nodulate the *Leucaena* as well as the inoculant strain.

In a similar trial in peninsular Malaysia on four acid soils, the inoculated plants were also much better nodulated in the early stages of growth up to about 200 days after planting when plants became too large for further meaningful sampling. The response to inoculation resulted in a substantial increase in plant growth and nitrogen uptake at two of the four sites over the first 300 days (Chee *et al.* 1989).

Several important trees and shrubs are nodulated by specific strains of *Rhizobium*

Sesbania sesban lines differed in their response to two strains of *Rhizobium* with a marked strain x line interaction (M. Masafu, unpublished data) (Table 3.4.1). Thus it may be necessary to select specific strains to effectively nodulate lines or cultivars within a species. *Acacia* species appear to be nodulated by a diverse range of rhizobia which may be fast growing *Rhizobium* or slow growing *Bradyrhizobium* species. Only a restricted range of rhizobia will nodulate some species (e.g. *A. holosericea, A. cincinnata, A. polystachya*). Other species such as *A. auriculiformis* are more promiscuous in their nodulation habits, nodulating with a range of *Rhizobium* and *Bradyrhizobium* strains present in many tropical soils. Strains that infect and nodulate a particular *Acacia* species often vary a great deal in their effectiveness in fixing nitrogen.

Forty-eight strains of rhizobia were isolated from *Acacia* species from different countries and were tested for their effectiveness in nodulating and fixing nitrogen with *A. auriculiformis* and *A. mangium* in sand culture. Strain PMA 311/1 from northern Australia was outstandingly effective on both, and is now a recommended inoculant strain (Dart *et al.* 1991).

Acacia mangium is much more specific in its *Rhizobium* affinities than *A. auriculiformis*

Habish and Khairi (1970) found that of ten *Acacia* spp. occurring in Sudan, some were nodulated by *Bradyrhizobium* and others by *Rhizobium* spp. Some species nodulated freely with rhizobia isolated from other species, while others only nodulated with a very restricted range of isolates. Dreyfus and Dommergues (1981) extended these observations showing that some Africian species nodulated effectively only with slow growing *Bradyrhizobium* strains (e.g. *Faidherbia albida*), whereas others nodulated only with fast growing *Rhizobium* strains (e.g. *A. nilotica, A. raddiana* and *A. Senegal*). *Acacia seyal* was effectively nodulated by both types of rhizobia. Similar patterns of specificity were obtained for introduced *Acacia* spp. of Australian origin.

Roughley (1987) showed that a great deal of host species x strain specificity existed among Australian acacias, with some species being very specific, nodulating with a few strains isolated from those species, while others nodulated freely with strains isolated from a wide range of *Acacia* spp. nodules.

The large degree of interaction between soils, strains and host species indicates that selection of rhizobium strains will be best done on a species by species basis and then tested for provenance interactions.

Moisture, acidity and salinity effects on nodulation

Rhizobia move through the soil with a wetting front after rain. Soil moisture levels affect the ability of rhizobia to move along the root system and to colonise young roots with emerging, infectable root hairs. Thus nodulation is limited in dry soils.

Nodulation of *A. auriculiformis* and *A. ampliceps* was much affected by the soil moisture tension in a pot experiment. Pots were watered to weight twice daily to maintain levels of 0.008 MPa moisture deficit (near to field capacity), 0.08 MPa or 0.8 MPa. Virtually no nodules were formed at 0.8 MPa and nodule number at 0.08 MPa was about half that in the moist soil at 0.008 MPa (N. Aswathappa, P.J. Dart, D.G. Edwards and P.K. Kanna, unpublished data).

Trees such as *Acacia* spp. are often grown in adverse soil conditions and methods of selecting rhizobium and host provenances tolerant of acidity and salinity are currently being investigated.

In a field trial in Malaysia, *L. leucocephala* strain TAL 1145, selected for acid tolerance, was less competitive in forming nodules than strain CB81. The latter strain was isolated from an alkaline soil and was less acid tolerant in growth *in vitro.* However, a Malaysian isolate was the most persistent and competitive strain. This suggests that it may be beneficial to select strains for adaptation to particular soils as well as for ability to fix nitrogen. The ability of inoculant strains to form nodules in competition with indigenous populations is an important criterion for strain selection.

There are differences between rhizobium strains nodulating *Acacia* species in their tolerance of salinity. Strains isolated from nodules grown in saline soil were more tolerant on agar and in broth of higher salt levels than other strains. Some strains could grow in the presence of 2% salt.

Inoculation of *Acacia ampliceps,* a salt tolerant species, with a salt tolerant strain, resulted in a large increase in nitrogen fixation in the presence of 200 mg salt compared with a non-tolerant strain (N. Zou, P.J. Dart, N. Marcar and C.J.. Asher, unpublished data).

Rhizobium populations are usually small or absent in saline soils, and salinity tolerant strains survive better than intolerant strains when added to such soils.

Rhizobium inoculation techniques

At present, limited seed availability restricts most reforestation and some agroforestry activity to nursery reared plants. This makes it easy to inoculate the plants by dipping the seed before sowing in a slurry of peat carrier plus rhizobium inoculum plus a glue such as 1.5% (w/v) carboxymethylcellulose. Since rhizobia are killed by UV light, the seed should be dried in the shade after inoculation, and planted as soon as possible. Another method is to suspend the peat carrier plus rhizobium in water and sprinkle this mixture over the seedlings.

Since rhizobia are killed by most fungicides and many insecticides it is good practice not to inoculate treated seed using the seed coating method.

At present there is no commercial production of inoculants for forest tree species. Commercial inoculants are available for *Leucaena.*

Nitrogen fixation

The amount of nitrogen fixed by trees can be estimated in several ways (Peoples *et al.* 1991, Danso *et al.* 1992, Ladha *et al.* 1993). The simplest method is a relative measure based on plant dry matter accumulation. The nitrogen balance method uses the Kjeldahl digestion process to measure N contents of soil and plant material at the beginning and end of the growth period. Alternatively nitrogen fixation is estimated as the difference in N uptake by a nodulated and a non-nodulated control plant. This method is suitable for plants in pots or small plants in the field, but obviously has limited use for larger trees. Variability in soil N content spatially is difficult to handle, requiring many samples to provide an accurate estimate of the overall N level.

The isotope ^{15}N which occurs at an abundance of about 0.366% in air can be used to measure nitrogen fixation in several ways by isotope dilution. These include measurement of ^{15}N uptake by plants grown in an atmosphere containing ^{15}N; comparison of the uptake by fixing and non-fixing plants of ^{15}N containing fertiliser added to soil; and the natural abundance method.

In the natural abundance method, a very sensitive mass spectrometer is required to measure the small differences in ^{15}N and ^{14}N content of fixing and non-fixing plants when no external N is supplied. The method relies on the different ratio of ^{15}N in nitrate and ammonium in the soil and in N_2 in the atmosphere. Nitrogen fixing plants will take up more atmospheric N and hence will end up with a different ^{15}N:^{14}N ratio than the non-fixing plants.

Ladha *et al.* (1993) used this technique to measure nitrogen fixation by *Gliricidia sepium* in an alley cropping or hedgerow system in the Philippines. About 50% of the nitrogen in the plants was derived from nitrogen fixation except in the dry season when this fell to 30%. *Acacia auriculiformis* and *Paraserianthes falcataria* fixed about 55% of their nitrogen uptake. In northern Australia, *Desmodium rensonii* fixed about 70%, and *Gliricidia sepium* 26-75%. In Indonesia, *Sesbania sesban* fixed about 80% (Peoples *et al.* 1991).

In a glasshouse experiment, nitrogen fixation by *L. leucocephala* amounted to about 65% of N uptake whereas *Faidherbia albida* derived about 20% from the atmosphere. Provenances within these species varied a great deal in the proportion and amount of nitrogen fixation (Sanginga *et al.* 1990). Extrapolation from nitrogen balance experiments and cutting trials in the field suggest that *Leucaena* can fix up to 300 kg N/ha/year, a very large amount indeed.

Mycorrhizae

Mycorrhizae are beneficial, symbiotic fungal associations with plant roots which benefit plant growth by increasing the effective absorbing zone of the root through the hyphae which explore the soil away from the root surface.

Mycorrhiza benefit growth through uptake of 'immobile' nutrients such as P, Zn, Cu and NH_4 usually present in soil in low concentrations in soluble form. The nutrients travel inside the hyphae via cytoplasmic streaming to the root cells where uptake by the plant occurs. In return, the plant supplies carbohydrates and amino acids for the fungal growth. There are two major forms of mycorrhizal development in higher plants - ectomycorrhizal and vesicular arbuscular mycorrhizae (VAM).

Vesicular arbuscular mycorrhizal hyphae found in the top 5 cm of the soil around subterranean clover roots were up to 30 m in length for every centimetre of root length (Abbott and Robson 1985). Ectomycorrhizae can form between 20 and 39% of the weight of tree roots.

Ectomycorrhizae do not penetrate the root cells but form a 'Hartig net' of fungal mycelium round the root, often distorting root growth by increasing lateral number and stunting and thickening the roots. These roots proliferate at the soil surface beneath the litter layer and play an important role in recycling nutrients from the litter back into the trees. Ectomycorrhizae develop on woody plants and are particularly important in establishment of pines commercially.

They are formed by higher fungi, mainly Basidiomycetes and Ascomycetes, and produce above ground fruiting bodies such as truffles. There are about 2,000 species of fungi associated with Douglas fir tree roots many of which are potential ectomycorrhizal fungi. There is some host species fungal species specificity in the effectiveness of the association. Nurseries propagating trees often adopt practices which ensure development of the ectomycorrhizae by using a fungal spore inoculum or mixing forest soil in the root medium in which the tree seedlings are grown.

VAM are much more widespread and can form associations with most herbaceous and many woody species. They are called vesicular arbuscular because they invade the plant root and form characteristic, large, thick-walled vesicles in the roots and invade the cortical cells to form arbuscules or tree-like growths which are the surface for interchange of metabolites between fungus and host plant. VAM form spores, often in specialised sporophyte structures in the soil, and these germinate to form hyphae attracted chemotactically to the root surface, which they then penetrate. The hyphae colonise the root, form arbuscules and develop more hyphae which penetrate the soil. Some groups of plants, such as the Cruciferae, are poorly infected. VAM infections start 2-3 weeks after germination of seedlings.

There are more than 100 species of VAM now recognised in soil. Because the fungi cannot be cultured *in vitro,* species are classified on the basis of morphological characters such as spore size, wall thickness and form, spore contents, form of the hyphal connection to the spore, vegetative hyphal thickness and form. VAM survive in soils as spores and perhaps hyphae. Strains within species can be distinguished by differences in their effects on plant growth. Soils usually contain up to six spores per gram of soil. Spores vary in size but are usually in the range 50-150 μ m in diameter.

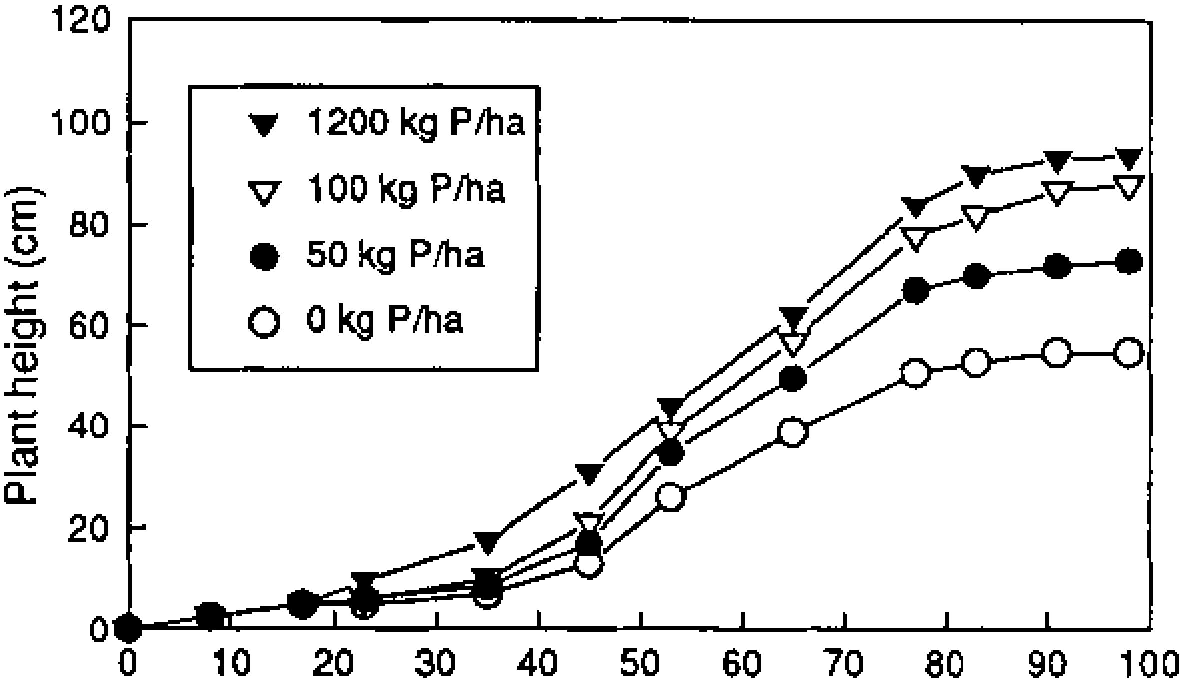
Mycorrhizal strains and host species interact to determine the amount of infection and the level of colonisation. Strains giving good growth responses with one plant species are generally effective with others, but strains differ in their tolerance of acid soil related stresses. At CIAT in Colombia, scientists have selected inoculant strains which are effective on both their pasture legume and grass selections, are adapted to low pH soils and give plant growth responses even with increasing levels of rock phosphate addition to the soil.

Because most soils contain some mycorrhizal propagules already, competition between indigenous strains and introduced strains is a key factor in the response to inoculation. Very little is known of the competitive ability of strains because they are so hard to identify since they cannot be grown in culture. At the moment, competitive strains are selected empirically on the basis of plant growth response to inoculation in non-sterile soil. If the plant responds the strain is considered more competitive than the native strains in forming mycorrhizae.

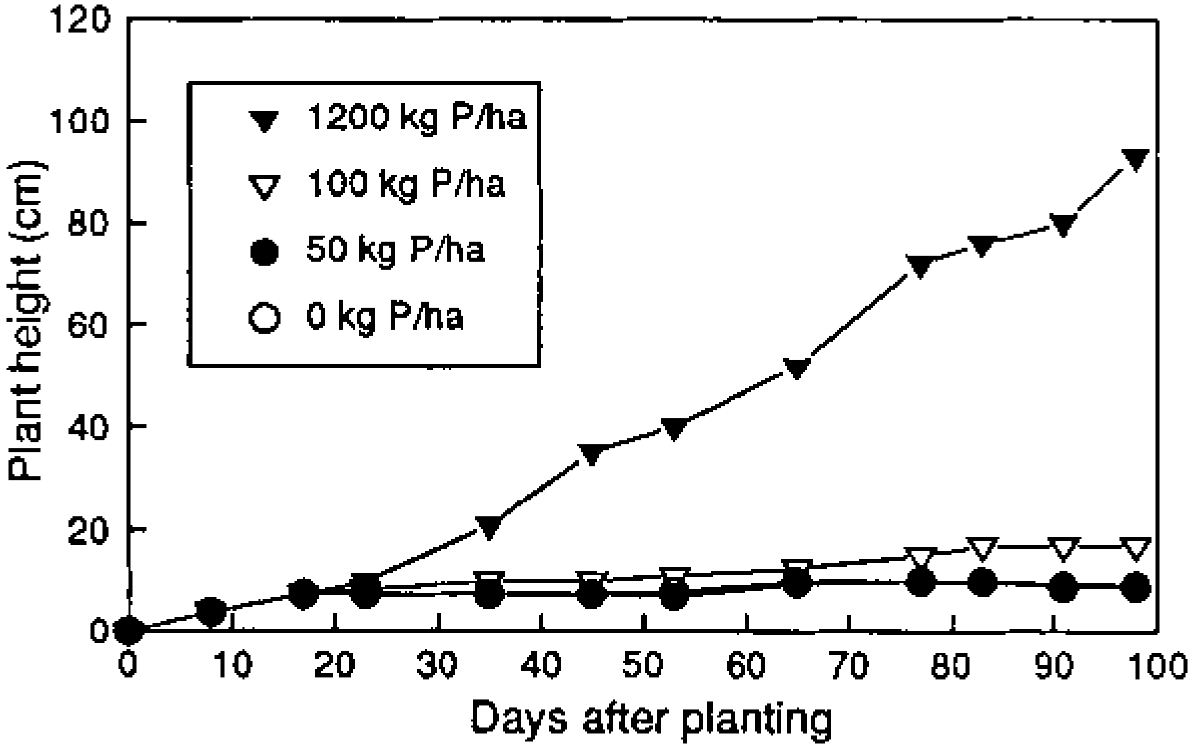
Work at the University of Queensland has demonstrated the importance of VAM to the phosphorus nutrition of *Leucaena leucocephala.* In sterilised soil, growth of Leucaena was poor without the benefit of the VAM symbiosis, but could be restored to normal levels by very high applications of phosphorus fertiliser (Figure 3.4.1). Examination of phosphorus concentrations in whole tops of Leucaena seedlings growing in unsterilised soil showed that seedlings experienced a period of P deficit prior to effective VAM infection which may limit early growth. This was avoided by application of very high rates of phosphorus (Figure 3.4.2). Brandon (1993) argued that the slow seedling growth of leucaena observed in many soils could be partially attributed to this period of P starvation during early establishment.

Fig. 3.4.1. Plant height of Leucaena grown at four phosphorus rates in (a) unsterilised and (b) sterilised soil from Mt Cotton in southeast Queensland (Brandon 1993).

(a) Unsterilised



(b) Sterilised



Brandon (1993) also showed that soils of southeast Queensland vary in their mycorrhizal activity as estimated by a bioassay which measured infection levels on the roots of leucaena (Figure 3.4.3). He concluded that soils low in mycorrhizal activity were likely to have been continuously cultivated, regularly waterlogged or to have come from areas supporting native eucalypt forest.

Fig. 3.4.2 Phosphorus concentration in whole tops of leucaena grown at four phosphorus rates in unsterilised soil from Mt Cotton in southeast Queensland (Brandon 1993).

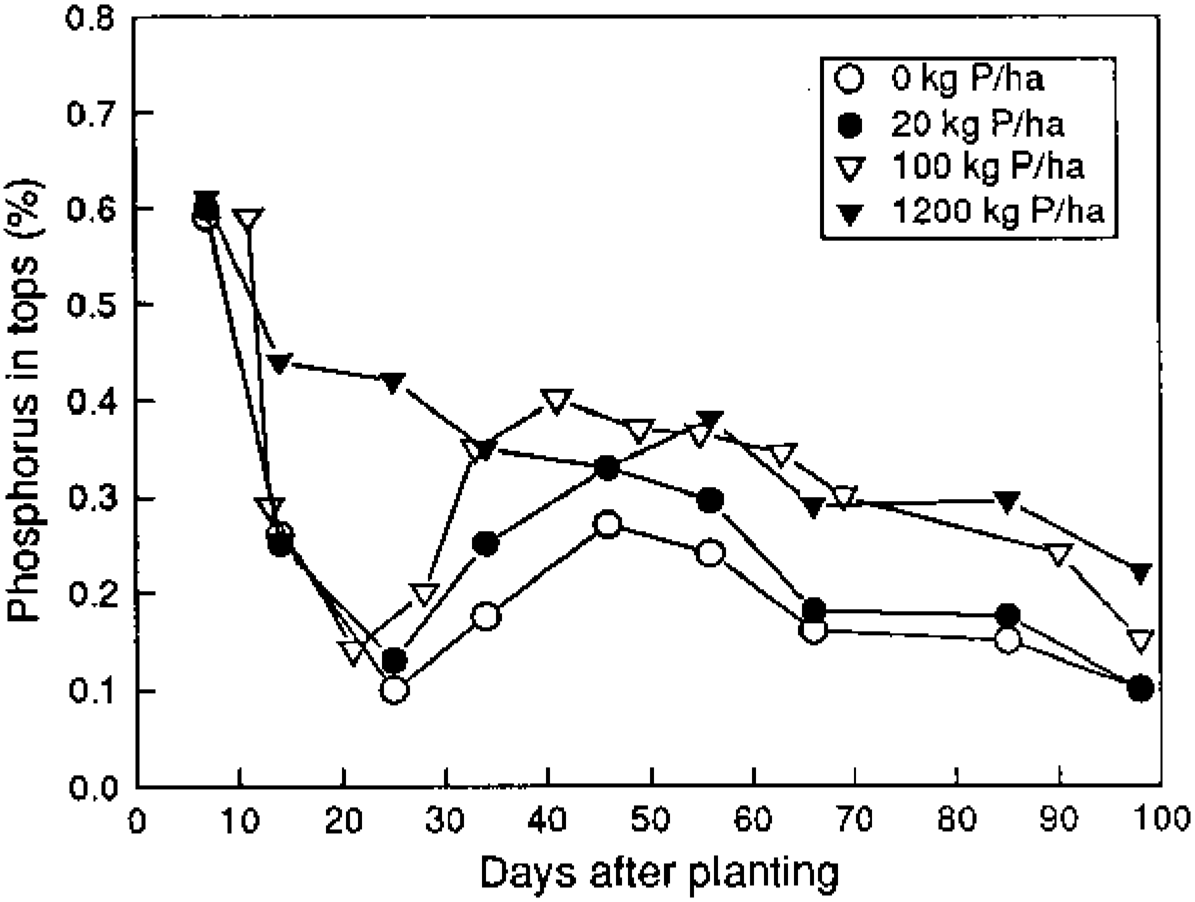
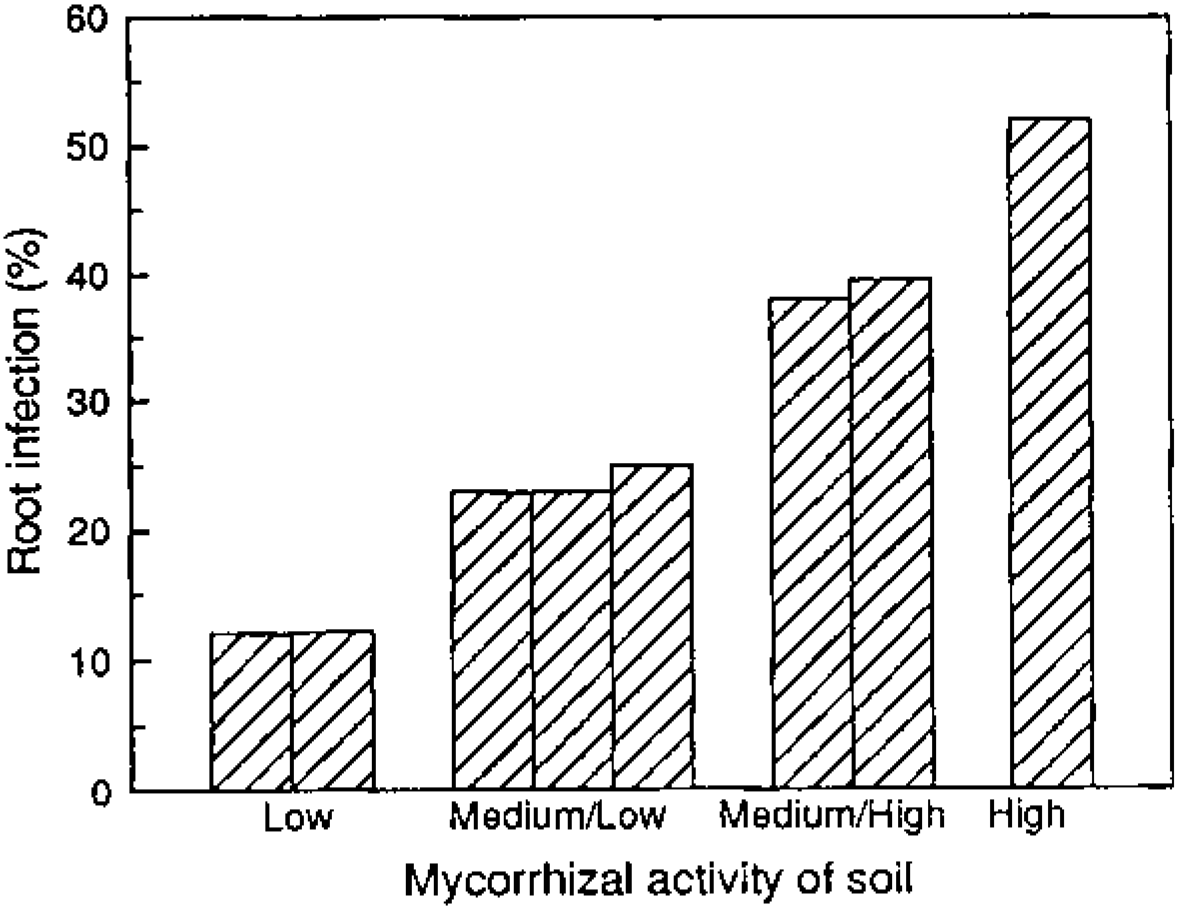


Fig. 3.4.3. Mycorrhizal infection level of leucaena after 7 weeks' growth in eight soils from southeast Queensland dilated in a sterilised sandy loam soil.



Other work (Ruaysoongnern 1989) has shown that nodulation and therefore N nutrition of leucaena may also be dependent on the VAM symbiosis. No nodulation of rhizobium-inoculated leucaena occurred in sterilised soil, and even at high phosphorus levels, nodulation was lower in sterilised than in unsterilised soil (Table 3.4.2).

Inoculants

VAM fungi must be multiplied for use as inoculants by growing on plant roots in pots or in nursery beds on plants such as the grasses *Cenchrus ciliaris* (buffer grass), *Paspalum notatum* (Bahia grass), *Panicum maximum* (green panic), or maize. Inoculants are prepared by chopping up the roots and adding a mixture of roots, spores and hyphae to the seed or cutting to be inoculated using a glue as 'sticker'. In selecting inoculant strains for effectiveness, experiments are usually conducted by growing plants in sterilised rooting medium, with and without inoculation, with and without P addition. Effective strains are then tested in field experiments and have been shown to increase P, Zn and water uptake and dry matter yield of a range of crops.

Inoculation can enhance plant growth in the presence of relatively insoluble fertilisers such as rock phosphate and help produce a large residual effect of the fertiliser on plant growth in subsequent years after the fertiliser addition. VAM inoculation is practised commercially with citrus plantings into irrigated desert sands in California, where soils are sterilised by fumigation, and in rehabilitation of disturbed soils such as mine sites. Large responses have been obtained with *Acacia auriculiformis* planted in degraded hilly soils in the Philippines (Dart *et al.* 1991).

While inoculation of nursery plantings or transplanted materials is feasible, inoculants for broadacre crops have not yet been commercialised. Finding a suitable inoculant form is a major problem and the logistics of preparing inoculants for thousands of hectares is daunting! Some progress has been made in growing VAM in sterile conditions using plant cells in a tissue culture system to foster fungal growth. A few ectomycorrhizal strains can be grown in culture and this can serve as an inoculant. Methods to use mycorrhizae in tree production systems are being investigated in two research projects at the University of Queensland.

Mycorrhizal inoculation of nurseries should be considered as a routine practice to ensure good establishment of these beneficial associations.

Acacia species can form both ecto- and endo-mycorrhizal associations (Redder and Warren 1987). The ectomycorrhizal fungus *Thelephora* spp. forms a beneficial association in promoting growth of *A. auriculiformis. Glomus etunicatum* followed by *G. macrocarpum* and *Gigaspora margarita* were the most effective VAM isolates for *A. auriculiformis* and *A. mangium.* For *A. mangium,* the response to inoculation with *G. etunicatum* in the nursery persisted in the field for 2 years after planting at Pantabangan in the Philippines while all uninoculated trees died (R. de la Cruz, personal communication).

Table 3.4.2. Effect of VAM inoculation and phosphorus application on VAM infection of roots, concentration of P in youngest fully expanded leaves (YFEL) and nodulation of leucaena seedlings growing in a podzolic soil.

Parameter	**Rate of phosphorus application (kg/ha)**			
	150		**450**	
	-VAM	**+VAM**	**-VAM**	**+VAM**
Dry wt. (g/pot)	1.5	28.1	86.7	81.1
Nodules (mg/pot)	0	297	1,334	2,029
% Root infection	0	77	0	98

Y. P in YFEL	0.07	0.31	0.17	0.23

Conclusion

Forage tree legumes form major symbiotic associations with two groups of microorganisms, namely, rhizobia and mycorrhizae. These associations play crucial roles in providing for the nitrogen and phosphorus nutrition of host plants. There is evidence that the two symbioses interact and that effective development of one symbiosis will enhance the development of the other. Much more needs to be known about the organisms, their ecology and their host x strain interactions to ensure that growth of tree legumes is maximised.

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3.5 Defoliation Management of Forage Tree Legumes

W.W. Stür, H.M. Shelton and R.C. Gutteridge

Introduction

The use of tree legumes for forage, fuelwood, mulch or green manure requires regular cutting or grazing of the trees. A sound understanding of the effects of defoliation management on tree regrowth is important in determining optimum production strategies. In general, regrowth of forage plants depends on:

- a the availability of active meristematic tissue (buds),
- a the amount and photosynthetic capacity of residual leaf area, and
- a the mobilisation of available carbohydrate and other reserves from plant material which remains after defoliation.

The rate of regrowth is also influenced by environmental conditions (e.g. availability of moisture) after cutting and the developmental stage of the plant (Humphreys 1981).

While there have been numerous experiments comparing different cutting heights and cutting intervals of tree species, there are few studies which have investigated the principles underlying the defoliation response of tree legumes (i.e. the relative importance of residual leaf area and carbohydrate reserves, or the role of meristematic tissue). The results of the various cutting trials are difficult to interpret because of the different conditions under which the trials were carried out, but major trends are apparent and these will be discussed.

This section will provide a framework for considering the effects of different management strategies on productivity of tree legumes, and for developing management practices appropriate to sustainable farming systems.

Inherent Tolerance to Repeated Defoliation

There are differences among forage tree legume species in their ability to cope with repeated cutting. *Sesbania grandiflora,* for example, does not tolerate repeated cutting of the main stem above a certain height (Home *et al. 1986,* Ella *et al.* 1989). Other tree legumes with a poor tolerance to regular cutting of main stems include *Paraserianthes falcataria* and *Acacia cunninghamii* (Gutteridge 1990). There have been no investigations into the reasons for the inability of some tree legume species to coppice satisfactorily. In herbaceous pasture species, poor branching close to the ground and a lack of lateral buds have been identified as causes for the poor persistence of regularly defoliated erect ecotypes of *Stylosanthes guianensis* (Grof *et al.* 1970). From practical observations, the same reasons may apply in the case of *Sesbania grandiflora.* It has little or no branching close to the ground and, when cut back, does not coppice profusely. This indicates a lack of buds on the main stem. Farmers in eastern Indonesia have developed a management strategy appropriate for this tree species, which they grow on paddy walls for wood and forage. They lop only side branches and leave the main stem of the tree uncut. The tree can cope with this type of defoliation which results in a tall tree with a small crown on top.

This example highlights the need to understand the effects of defoliation on forage tree legumes and to develop management strategies appropriate for each species. Research on tree legumes is still relatively new and, with the exception of *Leucaena leucocephala,* we only have a very limited knowledge of defoliation responses of individual species.

Defoliation and Growth

Defoliation can be broadly divided into cutting and grazing. Cutting of tree legumes is practised extensively in southeast Asia where tree legume leaves are used to supplement low quality, naturally occurring grasses and crop residues. On the other hand, grazing of tree legumes is common practice in large-scale cattle production systems such as in northern Australia.

Defoliation can be described in terms of frequency and intensity. Frequency is how often the trees are cut or grazed, while intensity describes the amount of leaf and stem remaining after defoliation. The latter can range from removal of all plant material above a certain cutting height (as is often used in experiments) to very lenient defoliation such as lopping of only some branches of trees. Grazing is often less severe than cutting in intensity, as animals remove mainly leaf while cutting removes whole branches. Defoliation intensity and frequency interact, with more severe defoliation intensity requiring longer intervals between defoliations to allow the trees to recover. Conversely, under lenient defoliation systems, trees can be harvested more frequently.

Forage trees require a number of attributes to survive and coppice under regular defoliation. The woody stem and branches of grazed trees need to have elasticity to withstand bending by the grazing animals. Brittle trees may break too easily and expose the tree to fungal attack. This happens in *Sesbania sesban* when grazed.

Figure 3.5.1 illustrates a regrowth curve for biomass production above cutting height for *Calliandra calothyrsus* (*W.W.* Stür and H.M. Shelton, unpublished data). Similar responses are expected for other medium sized forage trees such as Leucaena or gliricidia. Smaller trees or shrubs such as *Desmodium rensonii* or *Codariocalyx gyroides* may be expected to have a lower overall yield per tree and may reach their maximum leaf yield earlier.

The effect of defoliation on yield can be delineated into three distinct phases. The first is a commonly observed lag phase after cutting (weeks 0-4) when regrowth is slow due to low leaf area. This is followed by a period of maximum productivity (weeks 4-10) when leaf production increases markedly. The sigmoidal curve then plateaus as full light interception is approached and older leaves begin to senesce (weeks 10-24). Guevarra *et al.* (1978) reported that leucaena did not reach full light interception until 3 months after planting. This period may be shorter when cutting well established trees or very dense plantings. Wood growth is slow initially, but wood accumulation continues to occur over a much longer period than leaf. During the third stage, the trees increase in height and woody biomass increases, while leaf yield remains steady or increases only slightly.

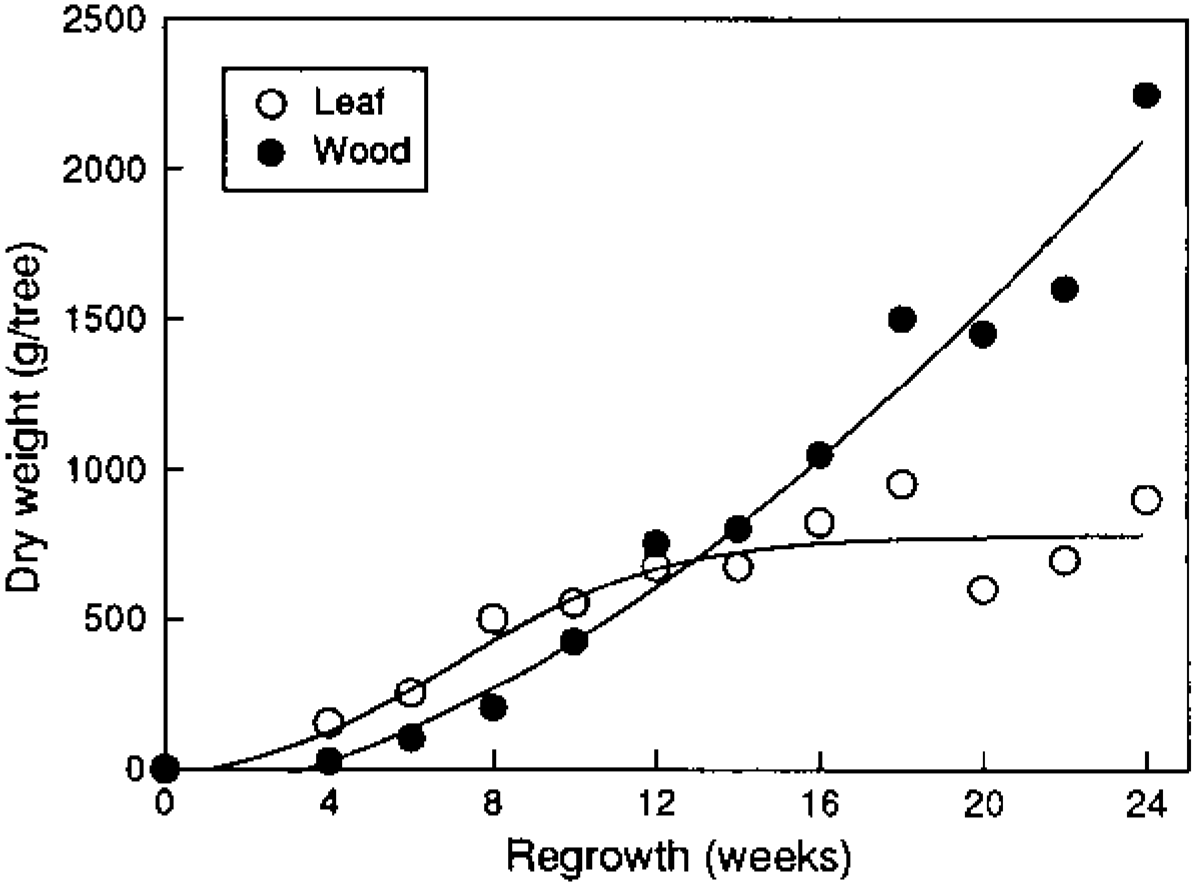
In general, cutting interval has a more dominant influence on total yield than cutting height.

Cutting interval

Figure 3.5.1 illustrates the finding of many studies that, while total biomass yield continues to increase with longer cutting intervals, the additional yield beyond a certain interval consists mainly of woody stem (Guevarra *et al.* 1978, Ella *et al.* 1989).

By comparing change in weekly growth rates with change in mean weekly growth rate, it is possible to determine the best interval to cut, or graze, regrowth to maximise yield of edible forage (Figure 3.5.2). In this example, maximum mean growth rate occurred just after the point of maximum growth rate and was a flat peak, in contrast to weekly growth rate which showed a steeper response. This meant that maximum edible yield could be achieved by cutting at any time during a 3 week period from approximately 8.5 to 11.5 weeks after commencement of regrowth. This period coincided with an edible forage fraction of 50-60% of total regrowth biomass. These calculations, together with other data and general observations, indicate that leafiness may be used as an indicator of optimum cutting interval. Cutting at the time when the proportion of edible material falls to 50% maximises yield of edible forage. Longer intervals, with lower forage fraction, are recommended when higher wood yields are desired.

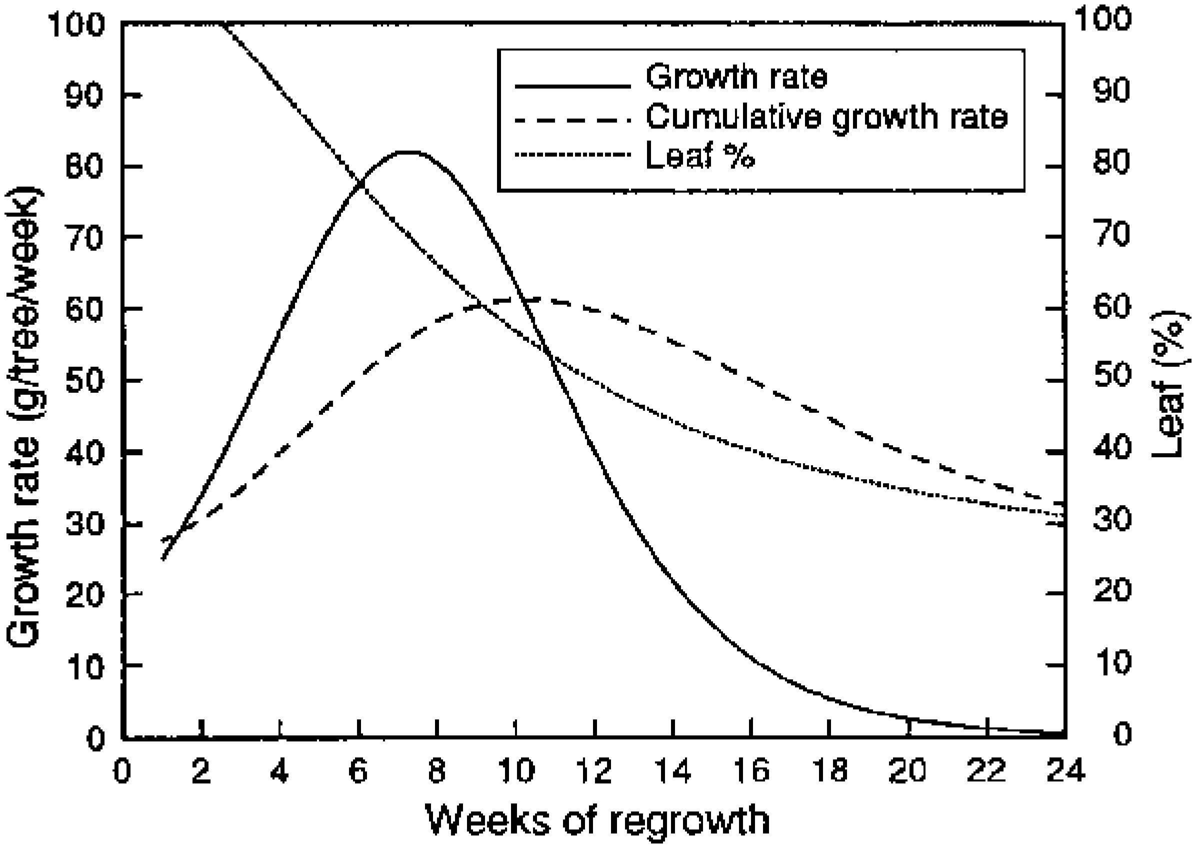
Fig. 3.5.1. Leaf (including edible stem to 5 mm diameter) and stem (wood) dry matter production (g/tree) of *Calliandra calothyrsus* after cutting (W.W. Stür and H.M. Shelton, unpublishe data).



Some experimental results reported in the literature are summarised in Table 3.5.1. Gliricidia had a lower proportion of wood than Leucaena and calliandra in the experiment of Ella *et al.* (1989), while the maximum edible yield of the shrub *Codariocalyx gyroides* occurred at short cutting intervals (Lazier 1981).

Cutting frequency also affects shoot number and size. Pathak *et al.* (1980) found that branch number was negatively related to length of cutting interval in leucaena plants cut every 6, 9 or 17 weeks. This agrees with our field observations that short cutting intervals result in a higher number of shoots or branches in Leucaena However, in the study of Guevarra *et al.* (1978), although branch size was larger at long cutting intervals, branch number was unaffected.

Fig. 3.5.2. Weekly growth rate, man weekly growth rate and proportion of edible forage of *Calliandra calothyrsus* during a 24 week regrowth period (W.W. Stür and H.M. Shelton, unpublished data).



In summary, the range of defoliation intervals for maximising leaf production from forage trees such as Leucaena or calliandra appears to be around 24 months in the humid tropics, but may be longer in drier areas or the cooler subtropics (Gutteridge and MacArthur 1988). It is probably shorter for smaller trees and shrubs. If wood is a desired by-product of forage tree legume production, then a longer cutting interval should be selected.

Defoliation intensity

Experimentally, forage trees are usually cut to a certain height. This often results in very severe defoliation with little or no leaf remaining. In such cases, the lag phase before high growth rates are again achieved is long as new leaf growth has to be supported initially by stored carbohydrate reserves and it takes some time before leaf area has recovered to support maximum growth. More lenient defoliation systems which leave some leaf area after defoliation, can be expected to have a shorter lag phase as growth is supported by the current photosynthesis from the remaining leaf area. Unfortunately, no critical studies have been published which compare the relative importance of available bud meristem, carbohydrate and other plant reserves, and residual leaf area after defoliation of forage trees.

Table 3.5.1. Examples of the effect of cutting interval on edible fraction and stem yield of various forage tree legumes.

Cutting interval (weeks)	Species	Edible	Wood	Edible	Reference*

		(t/ha)	**(t/ha)**	**(%)**	
6	Leucaena *leucocephala*	8.6	2.0	81	1
12	Leucaena *leucocephala*	10.5	9.2	63	1
11	Leucaena *leucocephala*	9.4	2.6	78	2
14	Leucaena *leucocephala*	11.5	6.4	68	2
18	Leucaena *leucocephala*	12.0	8.8	68	2
8	Leucaena *leucocephala*	9.2	7.8	64	3
16	Leucaena *leucocephala*	10.3	18.6	36	3
6	*Calliandra calothyrsus*	7.2	1.6	82	1
12	*Calliandra calothyrsus*	10.3	5.1	67	1
6	*Gliricidia sepium*	7.7	1.0	89	1
12	*Gliricidia sepium*	8.2	1.7	83	1
2	*Codariocalyx gyroides*	1.6	0.4	80	4
6	*Codariocalyx gyroides*	2.1	1.1	66	4
8	*Codariocalyx gyroides*	*1.9*	1.2	61	4
4	*Sesbania sesban*	2.7	0.3	90	5
6	*Sesbania sesban*	2.8	1.1	72	5
8	*Sesbania sesban*	2.7	1.8	60	5

* References: 1. Ella *et al.* (1989); 2. Guevarra *et al.* (1978); 3. Ferraris (1979); 4. Lazier (1981); 5. Galang *et al.* (1990)

Some researchers have found that higher cutting heights produced higher yields (e.g. Krishna Murthy and Munegowda (1982) with leucaena). Isarasenee *et al.* (1984) reported enhanced growth of leucaena cut at 120 cm compared with 60 or 30 cm. They further suggested that early regrowth was supported by movement of carbohydrate reserves from stem rather than from current photosynthesis. A low cutting height of 5 cm was detrimental to both yield and persistence of *Codariocalyx gyroides* (Lazier 1981). On the other hand, Ferraris (1979) found no difference in the yields of leucaena cut at 10 or 30 cm. Similarly, Pathak *et al.* (1980) found little difference in Leucaena yields when cut at 10, 20 or 30 cm. A wider range of cutting heights (30, 60 and 90 cm) for Leucaena also did not affect yield in an experiment conducted by Jama and Nair (1989). Cutting height was, however, positively related to shoot number per plant and this was also observed in the trial by Pathak *et al.* (1980).

In the absence of detailed studies on defoliation intensity on subsequent regrowth, only speculative comments can be made. Poor regrowth at low cutting heights may be related to a lack of regrowth sites (buds) and this can be expected to vary with species. If sufficient buds are available, initial regrowth must depend on the mobilisation of carbohydrate and other nutrient reserves. Increasing cutting height may result in greater available reserves and residual leaf on the stump and this may lead to a shorter lag phase.

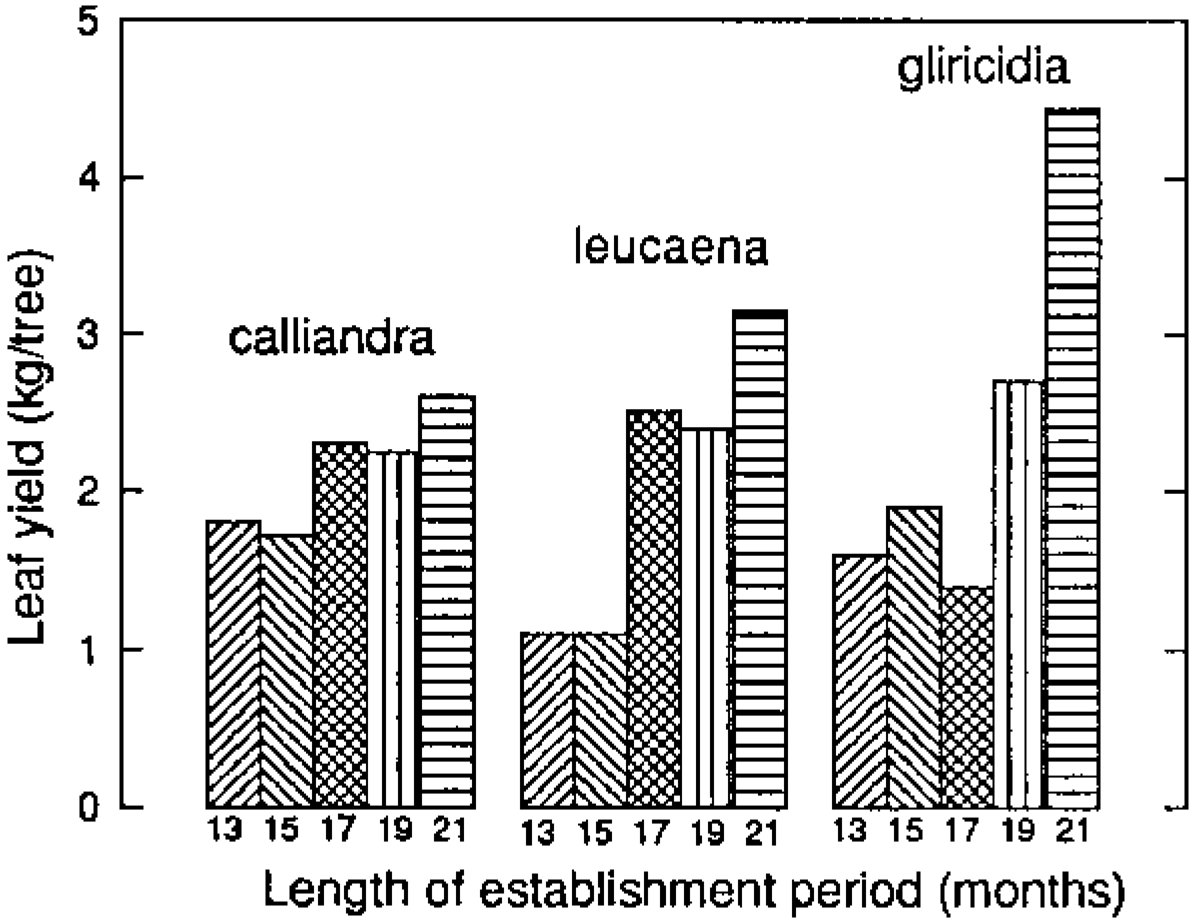
Tree Size and Timing of Defoliation

Other factors which influence regrowth after defoliation are tree size and timing of defoliation.

It is general practice to leave forage trees uncut until they reach a height of at least 1-1.5 m. This establishment period can be greater than one year in many cases. The benefit of a long establishment period before first defoliation was demonstrated by Ella *et al.* (1991). They showed that the age of trees at the first harvest was positively related to yield at subsequent harvests (Figure 3.5.3). The positive effect of a long establishment period was more pronounced for Leucaena and gliricidia than for calliandra. 'Older' trees were larger than 'younger' trees at the first cut, and the increased growth may have been related to there being more reserves in the larger stumps and presumably to the larger root system (not measured) on the 'older' trees.

Cutting forage trees at different seasons of the year (dry vs. wet season) and at different stages of development (flowering vs. vegetative) may also influence subsequent regrowth. However, little has been published on these topics. It may be speculated that cutting at the beginning of a dry season or during the dry season could result in the exhaustion of reserves as growth and replenishment of reserves may be restricted by moisture availability. On the other hand, tree legumes are usually deep-rooted and therefore have access to moisture in the deeper soil layers. They may also be expected to have a large amount of reserves in stems and root system, which may not easily be exhausted. Guevarra *et al.* (1978) mentioned that a more pronounced lag phase during regrowth of leucaena was observed when trees were cut at the long interval of 18 weeks as compared with shorter cutting intervals. They attributed this to a 'sink' effect of flowering and pod development which may have restricted carbohydrate accumulation in roots and stems and vegetative growth.

Fig. 3.5.3. Effect of length of establishment period of tree legumes before first cutting on subsequent leaf yield (cumulative dry matter yield kg/tree over four 3-monthly harvests) (after Ella *et al.* 1991).



Future Research

There is a need for critical studies on the effect of defoliation on regrowth of forage tree legumes. Basic research is required on the role of residual meristem (buds), residual leaf area, and energy and nutrient reserves for regrowth. Such experiments could contribute significantly to our practical understanding of defoliation responses by investigating the appropriate defoliation management for the various forage trees.

Comparing different forage trees within an experiment is difficult. Many experiments have used a common cutting height and frequency for all species. As the optimum defoliation management will vary with species with contrasting growth habit, a common management system may advantage some species while disadvantaging others. Results from such experiments are difficult to interpret.

This problem can be partially overcome by harvesting each species individually at an appropriate interval or plant height to take into account seasonal variability. Criteria for cutting intensity may be specified levels of residual stem and leaf area after defoliation rather than a fixed cutting height. Until the optimum defoliation management for individual species is known, management decisions will be based on intuition or inflexible schedules rather than on physiological principles.

Conclusions

In summary, forage tree legumes differ in their ability to withstand repeated defoliation. It is suspected that this is related to the availability of bud meristem, but no work has so far been undertaken to confirm this aspect.

Regrowth after defoliation has to be supported from residual leaf area and stem and root reserves, and the relative importance of these two factors needs to be investigated. Leaving as much residual leaf area as possible can be expected to reduce the length of the lag phase after defoliation.

Cutting frequency has a major effect on the proportion of edible forage and wood production. Longer intervals are appropriate if wood is the preferred by-product, while shorter intervals are required to optimise leaf production. Common cutting intervals are in the range 24 months.

Cutting intensity affects the amount of leaf and stem remaining after defoliation. Although very low cutting heights may have a detrimental effect on subsequent regrowth of some species, the effect of cutting height on subsequent productivity is often neutral and sometimes positive.

Leaving forage trees uncut for a long period before the first cutting has been shown to have a beneficial effect on productivity.

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3.6 Seed Production of Forage Tree Legumes

R.C. Gutteridge and W.W. Stür

Introduction

Apart from *Leucaena leucocephala* very little definitive information is available on the seed production of forage tree legumes. *Leucaena leucocephala* is the only species for which seed has been produced in commercial quantities but production is declining in the wake of the psyllid problem. Small quantities of seed of species such as *Gliricidia sepium, Calliandra calothyrsus* and *Sesbania sesban* are available from various institutions and organisations mainly for research purposes but reliable sources of larger amounts of seed are virtually nonexistent.

Little detailed research on seed production of forage tree legumes has been carried out and this section relies on principles applicable to other plants as well as on observations.

Principles of Reproductive Development

Although tree legumes are generally long-lived, most are dependent on seed production for long-term survival and each species has had to evolve a reliable system of seed production.

Climate has a major influence on the evolution of seed production characteristics since the timing of flowering, pollination and seed development is crucial for successful seed production.

Reproductive development can be divided into several phases. These include a period of obligate vegetative growth (juvenility), floral initiation, anthesis, pollination and seed development.

Juvenility

Plants first pass through a juvenile phase before they are able to move into a reproductive phase. The length of the juvenile phase varies from species to species and can be as long as several years. It appears to be related to the length of the life cycle of the species and the climate in which the plant has evolved. For example, seedlings of annual grasses from arid environments, where the growing season is short, can initiate floral development within days of emergence (Humphreys 1981). Once plants have passed through their juvenile phase, floral initiation can occur whenever conditions are favourable.

In Java, *Calliandra calothyrsus* has been reported to flower 4-6 months after planting (NAS 1983). In Brisbane, Australia, *Sesbania sesban* flowered 3 months after emergence (Sedi and Humphreys 1992).

Floral initiation

Floral initiation is usually controlled by environmental factors such as daylength, temperature and water and nutrient availability. The timing of floral initiation is related to the climate in which the species has evolved. For example, *Gliricidia sepium* originates from Mexico and Central America (latitude 7-25°N) in a sub-humid climate with 5 months' dry season from December to April (Hughes 1987). In this environment, trees are deciduous, losing their leaves early in the dry season in December/January, and flower (without leaves) between January and March. Seeds mature 40-55 days after flowering before the onset of the first rains in May. Hughes (1987) stated that gliricidia produces a good seed crop in most years and that the timing of seed production is highly predictable in its areas of natural distribution. Floral initiation may therefore be related to:

- short days (shortest day is approximately 11 h at latitude 15°N),
- dry season moisture stress, or
- deciduousness, which in turn is often related to photoperiod.

Although temperature varies little near sea level at latitude 15°N, flowering is delayed by low temperatures experienced at higher altitudes. Hughes (1987) reported that in Guatemala, seed of gliricidia matures in February at sea level but 2 months later at a nearby high altitude (950 m) site. It is likely that all four factors interact in determining the time of floral initiation in gliricidia.

When grown at other similar locations around the world, flowering and seed production follow a similar pattern. In Timor, Indonesia (latitude 10°S), gliricidia sheds its leaves at the beginning of the dry season in July and flowers in August (= shortest days, dry season and deciduousness) (J. Nulik, personal communication). At latitude 10°N in the Philippines, gliricidia sheds its leaves at the beginning of the dry season in November and flowers in December (= shortest days, dry season and deciduousness) (A. Castillo, personal communication). In Brisbane, Australia (latitude 27°S), gliricidia drops its leaves in July (shortest days and low temperatures) and flowering is delayed until October (Gutteridge and MacArthur 1988). If grown at locations where the environmental conditions are markedly different gliricidia will not produce a high seed yield. For example, Glover (1989) reported that in some parts of Asia and the south Pacific, gliricidia flowers in the wet season and seed production is poor.

In general, floral initiation of temperate and subtropical species is strongly related to photoperiod (varied somewhat by temperature), while this factor is generally only weakly expressed (quantitatively rather than qualitatively) in tropical species. Tropical species are usually able to initiate floral development throughout the year and sometimes reproductive development is enhanced by a change from wet to dry conditions. Some species, with a short day requirement, do not or only sparsely flower near the equator, but can be induced to flower more profusely by low temperatures (high altitude) or by moisture stress (Humphreys and Riveros 1986).

In leucaena, flowering can occur at any time during the year whenever growing conditions are favourable but will increase under moisture stress and also with the onset of shorter days in the subtropics. Calliandra produces most seed in the June to September dry season in Java; however, it is capable of flowering throughout the year (NAS 1983).

Anthesis, pollination and seed development

The mode of reproduction or breeding system of tree legume species varies from largely self-fertilised and self-compatible as in *Leucaena leucocephala* (Hutton and Gray 1959) to largely outcrossing. Examples of outcrossing species are gliricidia (Aken'Ova and Sumberg 1986), *Erythrina* spp. (Neill 1988) and *Prosopis* spp. (Arroyo 1981).

In leucaena, anthesis occurs early in the morning and pollen falls directly on to the stigmas; this results in a high degree of self-pollination, although cross-pollination can occur (Hutton and Gray 1959). Other species of the genus *Leucaena* such as the diploid form of *L. diversifolia* and *L. pallida* are self-incompatible and thus highly cross-pollinated (Brewbaker 1983).

In cross-pollinated species, the success of pollination depends on the presence of suitable pollinators and favourable weather during anthesis. Carpenter bees (*Xylocopa* sp.) have been observed visiting gliricidia flowers both in its native range and in areas where it is cultivated, and Janzen (1983) suggested that these bees are the primary pollinators. *Calliandra* is pollinated in its native range by bats of the genus *Glossophaga* and by large hawkmoths. *Sesbania* spp. are pollinated by bees, except for large-flowered species such as *S. grandiflora* which appear to be pollinated by birds (Brewbaker 1990).

Seed development from pollination to seed maturity takes 40-55 days in gliricidia (Hughes 1987), approximately 60 days in calliandra (NAS 1983) and 40 days in *Sesbania cannabina* in good growing conditions (Sedi and Humphreys 1992).

Once seeds are mature, the pods containing the seed shatter and seeds are dispersed. This dispersal mechanism has implications for harvesting, since pods on a tree ripen unevenly and hence have to be harvested individually.

Seed pods and seeds vary greatly in size and shape between species. Seed size ranges from 55,000 to 80,000 seeds per kg in *Sesbania sesban* to 21,000 to 28,000 seeds per kg in leucaena, 14,000 seeds per kg in calliandra and 4,70011,000 seeds per kg in gliricidia.

Practical Aspects of Seed Production

Site selection

Selecting the 'right' site for seed production is of utmost importance. Apart from providing good growing conditions for the tree legume species, the timing of floral initiation, anthesis and seed development is crucial if maximum seed yields are to be obtained. Adverse climatic conditions during pollination or seed development can result in very low seed set and yield. For example, Atta-Krah (1987) reported that early rains during flowering led to heavy flower drop and low seed set in gliricidia. Seed production problems in calliandra have been widely reported in Africa, particularly Kenya (D.J. Boland, unpublished data). The reason for this is unclear but it may be related to the lack of suitable pollinators or climatic incompatibility with heavy rains preventing pollen movement during flowering.

Areas with reliable and distinct wet and dry seasons, where the tree legume produces seed during the dry season, are ideal for seed production because of the favourable warm, dry conditions during flowering, pollination and seed development. A fertile, well drained soil will favour good seed production.

Seed crops of largely outcrossing, insect-pollinated species such as gliricidia need to be isolated from other trees of the same or related species to prevent cross-pollination. Such species need to be planted in blocks containing at least 30 trees and isolated by at least 200 m. A border row should be established around the block and seed should not be collected from this row. Largely self-fertilised species such as Leucaena need only be separated from related species by a few metres to prevent contamination.

Management and harvesting

To obtain maximum seed yields, trees need to have a good framework to maximise potential floral sites. Cutting gliricidia to 0.5 m after a seed harvest reduced flowering and seed yield in the following 2 years relative to an uncut control (Atta-Krah 1987). Similarly, Mohatkar and Relwani (1985) reported that seed yield of leucaena was higher when cut at a height of 1.2 m rather than 0.6 m and that seed yield decreased with higher tree density. While this demonstrated a positive relationship between tree size and seed yield for individual trees, practical considerations for harvest of large trees need to be taken into account. Low seed yield per tree may be compensated by a higher planting density. Hare (1985) suggested that leucaena seed crops should be sown in rows 2 m apart with 0.2 m between plants in the row. The trees should be cut back to 0.5 m height at the start of each wet season to encourage branching and facilitate hand harvesting.

The potential seed yield of tree legume species is very high. For example, seed yields of up to 3,000 kg/ha were recorded for leucaena from a small seed production orchard in Hawaii (NFTA 1985). However, the actual harvested yield is much lower due to harvesting problems; pods are often at an inaccessible height and pods ripen unevenly which means that only a small fraction of the potential seed yield is harvestable at any one time. Repeated hand harvesting can overcome this problem to some extent. In Australia, mechanical harvesting of Leucaena has been achieved using overhead booms or arms supported on a frame which knocks the ripe pods into a trailer. A mobile thresher and cleaner can be attached to take the seed from the collecting trailer (J. Wildin, personal communication). In 1986/87, over 5 t of *L. leucocephala* seed were produced for commercial sale in Queensland (QDPI statistical records), but this declined to less than 3 t in 1987/88 following the arrival of the psyllid insect and consequent reduction in demand for seed.

Gliricidia regularly yielded over 25 kg/ha of seed per year in a 5 ha plantation near Pen Fui airfield in Timor, Indonesia (J. Nulik, personal communication). In West Africa, Sumberg (1985) reported seed yields of gliricidia up to 89 g per tree per year, equivalent to approximately 37 kg/ha at the spacing used. Seed yield was closely related to the number of set racemes per tree. Seed collection from most of the perennial sesbanias is easy and large quantities of seed can be rapidly hand harvested and processed. In Hawaii, Evans and Rotar (1987) obtained seed yields of approximately 1.5 t/ha from *S. sesban,* although R.C. Gutteridge (unpublished data) obtained lower yields of approximately 250 kg/ha from a small area of *S. sesban* var. Nubica at Mt Cotton, southeast Queensland. Harvested seed needs to be dried in the shade to a moisture content below 10% for safe storage. Fast sun-drying may damage seeds and reduce germination percentage and storage life.

Seed storage

In general, the seed of tree legumes with a hard seed coat (e.g. *Leucaena* spp. and most *Sesbania* spp.) can be stored for reasonably long periods without special treatment. Lulandala (1981) obtained 100% germination percentage of leucaena seed after 11 months' storage at 25℃. Cobbina *et al.* (1990) reported that the germination of Leucaena seed stored at either room temperature, in a deep freeze or in dry soil in a glasshouse for 12 months was not significantly different from that at the start of the storage period.

However, seed of species without a hard seed coat such as gliricidia, *S. grandiflora* and to a lesser extent calliandra requires specialised storage conditions if seed viability is to be maintained. Ideally seed of these species should be stored in sealed containers at a moisture content of less than 10% and at a temperature of 4℃ or less. Calliandra seed retained viability when stored in a refrigerator (4℃) for 2.5 years but viability was reduced by 15% when seed was stored at room temperature for one year (NAS 1983).

Thomson and Evans (1990) suggested that seed storage life will be prolonged

by:

- ensuring that the seed collected is fully mature, thoroughly dried (<10% moisture) and clean,
- dusting with insecticides to kill insects,
- storing in airtight containers in an atmosphere of CO_2, and
- storing at low temperatures (< 4℃) and low humidi ty.

Conclusions

Although seed production of forage tree legumes has not been widely studied, it appears that it should not be unduly difficult to produce reasonable quantities of good quality seed provided suitable locations are selected.

There is scope for the selection or breeding of varieties of tree legumes with higher seed yields with improved synchronisation of seed set, reduced pod shattering on drying and resistance to pod pest infestation. However, higher seed yields should not be achieved at the expense of vegetative yield and the ultimate aim of all improvement programmes must be higher yields of edible forage.

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4.1 The Nutritive Value of Tree Legumes

B.W. Norton

Introduction

Tree leaves and pods form a natural part of the diet of many ruminant species and have been used traditionally as sources of forage for domesticated livestock in Asia, Africa and the Pacific (Skerman 1977, NAS 1979, Le Houerou 1980a). Although not all forage trees are legumes, more than 200 species of leguminous trees are reported to be used for forage, with most species being tropical or subtropical in origin. The most commonly used species come from the genera *Acacia, Albizia, Calliandra, Desmanthus, Desmodium, Gliricidia, Leucaena, Prosopis* and *Sesbania* (Brewbaker 1986). Compared with herbaceous legumes, tree and shrub legumes have received relatively little attention in the search for productive and persistent forage sources for the tropics (NAS 1979). In Australia, most research has centred on native tree species which are generally of low nutritive value (Wilson and Harrington 1980). The recent success with Leucaena as a new high quality forage species for northern Australia (Jones 1979) has prompted a search for other legume tree and shrub species suitable for introduction to other Australian grazing systems.

Tree legumes must have both desirable agronomic characteristics and high nutritive value to be useful as forages. The nutritive value of a feed is determined by its ability to provide the nutrients required by an animal for its maintenance, growth and reproduction. Tree legumes have been mostly used as feeds for ruminants, although there are some reports of their inclusion in the diets of non-ruminants (pigs and poultry). The leaves, stems and fruits may be used either as a complete feed or as a supplement to other feeds. In some species, a major limitation to the use of one or more of these components is the presence of toxic and/or anti-nutritive factors.

This section reviews the nutritive value of forage trees when used as a single feed. Later sections examine the use of tree legume foliage as a supplementary feed and the effects of anti-nutritive factors found in tree leaves on their nutritive value.

A Definition of Nutritive Value

Nutritive value is a function of the feed intake (FI) and the efficiency of extraction of nutrients from the feed during digestion (digestibility). Feeds of high nutritive value promote high levels of production (liveweight gain). Feed intake in ruminants consuming fibrous forages is primarily determined by the level of rumen fill, which in turn, is directly related to the rate of digestion and passage of fibrous particles from the rumen. Voluntary consumption of feed may also be modified by animal preference, some feeds being eaten in smaller or larger amounts than predicted by digestibility (D) (Egan *et al.* 1986). The acceptance or edibility (palatability) of a feed has been related to both physical characteristics (hairiness and bulk density) and the presence of compounds which may affect taste and appetite (volatile oils, tannins and soluble carbohydrates).

The productivity of ruminants is closely associated with the capacity of a feed to promote effective microbial fermentation in the rumen and to supply the quantities and balances of nutrients required by the animal tissues for different productive states.

There is no simple predictor of the quality of tree legume foliage. Chemical composition alone is an inadequate indicator of nutritive value since the availability of nutrients from forages is variable. Digestible dry matter (or energy) intake (FI x D) may also be a poor predictor of potential productivity since the composition of nutrients absorbed is not described. Modern concepts of feed evaluation require that quality be assessed in terms of the capacity of a feed to supply nutrients in proportions balanced to meet particular productive functions (Leng 1986). The nutritive value of feeds should be ranked on the following characteristics:

- voluntary consumption potential,
- potential digestibility and ability to support high rates of fermentative digestion,
- high rates of microbial protein synthesis in the rumen relative to volatile fatty acids (VFA) produced (fermentation protein/energy (P/E) ratio),
- high rates of propionic acid synthesis (glucogenic) relative to total VFA synthesis (fermentation glucogenic/energy (G/E) ratio), and
- ability to provide bypass nutrients (protein, starch and lipid) for absorption from the small intestine (absorbed P/E and G/E ratios).

This information is available for some temperate and tropical grasses and legumes but there are few comparable data for browse trees and shrubs.

Chemical Composition of Forage Tree Legumes

Much of the considerable information now available on the chemical composition of tree foliage (Gohl 1981, Le Houerou 1980a) is from proximate analysis (total N. ether extract, crude fibre, nitrogen free extractives) and is of limited value as a predictor of nutritive value. Analyses based on detergent extraction are more useful since plant dry matter is separated into a completely digestible fraction (neutral detergent solubles (NDS)) representing cell contents, and a partially digestible fraction (neutral detergent fibre (NDF)) representing plant cell walls.

Element (N, P, S, etc.) composition provides values which can be compared with animal requirements. However, whilst values less than predicted requirements are indicative of deficiency, values greater than prescribed are not necessarily indicative of sufficiency. Not all elements are fully available for use by the microbial population in the rumen or for absorption in the intestines. Some examples of this will be presented. Table 4.1.1 shows that the chemical composition of a selected range of tree legume species varies with soil type (location), plant part (leaf, stem, pods), age of leaf and season. Further variability in composition is introduced when subjective selection of the 'edible' fractions of tree foliage is made. Edible fractions tend to contain higher stem contents and to be of lower nutritive value than leaves alone.

Proteins and tannins

The protein content of forage tree legume leaves (12-30%) is usually high compared with that of mature grasses (3-10%). The proteins are digested in the rumen to provide ammonia and amino acids for microbial protein synthesis. Microbial cells then pass to the small intestine, providing the major source of absorbed amino acids for the ruminant. In some cases, feed proteins may escape digestion (bypass proteins) in the rumen and provide additional protein for absorption in the small intestine. The microbial population in the rumen requires a minimum level of ammonia (70 mg N/l) to support optimum activity; lower values are associated with decreased microbial activity (digestion) and are indicative of nitrogen deficiency. Feeds containing less than 1.3% N (8% crude protein) are considered deficient as they cannot provide the minimum ammonia levels required. All forage tree legumes have N contents higher than this value, and may be judged adequate in protein. However, tannins found in some tree legume leaves form complexes with plant proteins which decrease their rate of digestion (degradability) in the rumen, thereby decreasing rumen ammonia concentrations and increasing the amount of plant protein bypassing the rumen. Where the tannin-protein complexes are dissociated in the low pH of the abomasum, an additional source of protein is made available for absorption by the animal. In other cases, the tannins protect the proteins from digestion even in the small intestine.

Table 4.1.1. The chemical composition (g/kg dry matter) of foliage from a selected range of tree legume species.

*

NDF = neutral detergent fibre
ADF = acid detergent fibre
ND = none detected

** References: 1. Ahn *et al.* (1989); 2. Norton *et al.* (1972); 3. McMeniman (1976); 4. Leche *et al.* (1982); 5. Goodchild (1990); 6. Le Houerou (1980b); 7. Gohl (1981); 8. Robertson (1988); 9. Ash (1990); 10. Ahn (1990); 11. Brewbaker (1986); 12. Bamualim *et al.* (1980); 13. Borens & Poppi (1990) 14. Chadhokar (1982); 15. Carew (1983); 16. van Eys *et al.* (1986); 17. Soedomo *et al.* (1986); 18. Singh *et al.* (1980); 19. Lamprey *et al.* (1980)

Tannins may therefore have a beneficial effect (increasing bypass protein or decreasing ammonia loss) or a detrimental effect (depressing palatability, decreasing rumen ammonia, decreasing post-ruminal protein absorption) on protein availability. It is clear that the interpretation of the nutritional value of protein in forage trees requires information on the nature and action of tannins. The proteins in the leaves of species which do not have tannins (*Albizia lebbeck, Enterlobium cyclocarpum, Albizia saman* and *Sesbania* spp.) will be rapidly degraded in the rumen, providing high levels of rumen ammonia, much of which will ultimately be wasted by excretion as urinary urea. Such feeds provide N in a similar way to urea. Species which contain some tannins will therefore provide both degradable and undegraded rumen N and will be more effective sources of supplemental N for ruminants. Nevertheless, the significance of tannins in tree legume forage is poorly understood, with low concentrations being beneficial and high concentrations detrimental. It is also likely that not all tannins act similarly; this area requires further study.

Macro and trace element content

Table 4.1.2 shows some values for the concentrations of elements in a range of forage trees. There is little information available on the trace elements (Cu. Mn, Zn, Co, I) and only fragmentary data on the macro-elements. Sulphur (S) in plant material is mainly found in the form of sulphur amino acids and is required, together with N. for microbial protein synthesis in the rumen. Concentrations greater than 1.5 g/kg dry matter or N:S ratios less than 15:1 are considered adequate. However, where protein digestion in the rumen is limited by complexing with tannins, S rather than N may become the limiting factor in microbial protein synthesis. From the data available, most species appear to meet the S requirements of ruminants, with the possible exception of the *Acacia* spp.

Table 4.1.2. The concentration of minerals (g/kg dry matter) in the edible foliage of some forage tree legumes.

* References: 1. Ahn *et al.* (1989); 2. Le Houerou (1980b); 3. Entwistle and Baird (1976); 4. Gohl (1981); 5. Robertson (1988); 6. Brewbaker (1986); 7. Bamualim *et al.* (1980); 8. Borens and Poppi (1990);9. McGowan *et al.* (1988); 10. Chadhokar(1982); 11. Carew (1983) 12. Lamprey *et al.* (1980)

The minimum requirement of ruminants for phosphorus (P) varies from 1.2 to 2.4 g/kg feed dry matter depending on physiological function. Forage tree leaves generally have high P concentrations. Mulga (*Acacia aneura*) is an exception with low P contents and responses of sheep to P (+ molasses) supplementation have been reported (McMeniman and Little 1974). Calcium (Ca) is closely associated with P metabolism in the formation of bone, and a Ca:P ratio of 2:1 is usually recommended for ruminant diets. Ca is rarely limiting in forage diets and the same is true for forage trees (Table 4.1.2). However, high concentrations of oxalic acid in leaves may decrease the availability of Ca during digestion. Gartner and Hurwood (1976) have suggested that high oxalate levels in mulga affect Ca metabolism in sheep. Magnesium (Mg) and potassium (K) are found in excess of requirements in tree leaves and are seldom a limiting dietary factor in ruminants.

Although sodium (Na) deficiency has been recorded in cattle grazing tropical pastures, short term deficiencies are rare. Ruminants effectively conserve tissue Na by recycling it through the rumen. The recommended requirement for Na in ruminant diets is 0.7 g/kg dry matter. Some tree species appear to be marginal in Na, but deficiencies are probably not common as forage tree leaves usually form only part of a ruminant's diet. Deficiencies of minerals other than S and P appear to be unlikely, although leucaena is reported to be low in both Na and I.

Voluntary Intake and Digestibility of Tree Legume Foliage

When compared with information on chemical composition, there is less known about the feeding value of tree foliage for stock. The digestibility of plant material in the rumen is related to the proportion and lignification of plant cell walls (NDF). Tree forages with a low NDF content (20-35%) are usually of high digestibility and species with high lignin contents are often of low digestibility. Bamualim *et al.* (1980) showed that the lignin content of tree foliage was negatively correlated (r = -0.92) with feed digestibility in nylon bags. Stems have higher lignin contents than leaves, and are less digestible. It may therefore be predicted, from their high NDF and lignin contents (Table 4.1.1), that *Acacia* spp. and *Albizia chinensis* will be of low digestibility. More information on the NDF, ADF, lignin and tannin content of tree foliages is needed if a comprehensive assessment of their nutritive value is to be made.

In vitro digestion techniques (Tilley and Terry 1963, McLeod and Minson 1978) provide comparative estimates of dry matter digestibility between feeds. These values may be used to rank the quality of feeds but usually underestimate measured *in vivo* digestibility. New techniques which measure the rates of feed digestion in nylon bags suspended in the rumen (*in sacco*) (Mehrez and Orskov 1977, Ffoulkes 1986) can also be used to rank feeds. This technique has the advantage that the rates of digestion of different feed components (protein and starch) may also be calculated. *In sacco* digestibility usually overestimates *in vivo* digestibility. Table 4.1.3 shows values for *in vitro, in sacco* and in vivo estimates of tree legume digestibility, and for the intake of foliage by different ruminant species. These data were collected under a range of conditions, and only general conclusions can be drawn about the comparative value of the different species.

In vitro (IVD) and *in sacco* (ISD) estimates of feed digestibility generally ranked feeds in the same order, but these values were not useful predictors of either *in vivo* digestibility (DMD) or voluntary feed intake (VFI). For this reason, these techniques provide only qualitative data on feed nutritive value. The usefulness of IVD and ISD, as estimates of quality, is to predict DMD, which is closely related to VFI for tropical grasses (Minson 1982). Data in Table 4.1.3 suggest that the same predictions cannot be made for forage trees. For example, similar values (66-68%) were found for the IVD of tagasaste (*Chamaecytisus palmensis*) and gliricidia, whereas *in vivo* digestibilities were found to be 76 and 55% respectively. Intake values were similar. Similarly, DMD was not a guide to intake of *Albizia lebbeck,* where sheep consumed significantly more fallen leaf (DMD 43%) than fresh leaf (DMD 64%). Conversely, goats appeared to consume similar amounts of Leucaena (35.6 g/kg/liveweight (LW)) and gliricidia (32.6 g/kg LW) despite large differences in digestibility (68.0 and 56.3% respectively).

These results suggest that factors other than the rate of digestion in the rumen determine the voluntary intake of tree foliage by ruminants. Low intakes associated with high feed digestibilities may be related to the presence of compounds which are appetite depressants (tannins, alkaloids, etc.). High feed intakes and low feed digestibilities may be related to rapid rates of passage of feed through the rumen, such as when the small leaflets of pinnate leaves are being consumed. Since there are no known techniques which predict palatability and intake, the nutritive value (VFI x DMD) of forage tree species can only be accurately determined by feeding trials. Feeding trials have the added advantage of also providing information on animal health and productivity (liveweight gain).

The screening of forage trees for nutritive value by qualitative methods may therefore lead to some erroneous conclusions if not supported by feeding trials. Tree legumes of low digestibility and high palatability would be rejected. The form in which the leaves are fed (fresh, wilted or dry) is also known to affect both intake and digestibility in some species (Palmer and Schlink 1992). As will be discussed later, the problems of low digestibility (and intake) may be partially overcome by supplementary feeding or by combination with other feeds.

Table 4.1.3. Some values for *in vitro, in sacco* and *in vivo* digestibility and voluntary feed intakes of ruminants given forage tree legume species. All values are for fresh foliage unless stated otherwise.

While all species contained high concentrations of proteins (Table 4.1.1), the N degradability of protein, as estimated by *in sacco* methods, varied considerably. High degradability (>78%) was found in all species which did not contain tannins, while most tannin-containing species were of low degradability (<39%). Exceptions were *Codariocalyx gyroides,* gliricidia and Leucaena which showed moderate degradability (64-84%) yet contained 3-7% tannins. The high intakes of the latter two species suggest that tannins, in these examples, did not reduce palatability. There is little known about the nature and chemistry of tannins in forage trees. It seems that not all tannins decrease protein degradability in the rumen.

Ahn *et al.* (1989) have shown that the drying of tree legume leaf decreases tannin content and, in the case of gliricidia and *Tipuana tipu,* removes all tannin. In most species, drying decreased tannin content and increased N degradability. Drying may be a practical means of manipulating protein availability from forage tree legumes. In contrast, the decreased tannin content after drying was associated with a decreased *in sacco* N digestibility for *T. tipu* while there was no significant effect on the degradability of gliricidia. Our understanding of these effects is incomplete.

Limitations to Nutritive Value of Forage Trees as a Sole Feed

Some tree legumes contain anti-nutritive factors which adversely affect nutritive value. For this reason, depending on the species, tree legume foliage may be of lower nutritive value as a sole feed than as a supplement to other feeds. The significance of secondary plant compounds becomes more evident when tree foliage is the only feed consumed.

Acacia species are generally of low nutritive value, and as a sole feed are little better than a maintenance feed for stock. Mulga (*Acacia aneura*) has received considerable research attention in Australia. Its nutritive value may be greatly increased by the provision of specific supplements. McMeniman and Little (1974) first demonstrated that supplementation of mulga with P in molasses increased wool growth in sheep. McMeniman (1976) also showed that sheep on mulga responded to the addition of urea to their diet, even though the diet contained more than the minimum level of crude protein. It was subsequently shown that sheep on these diets were also responding to the additional S in molasses (Hoey *et al.* 1976, Gartner and Niven 1978). Digestibility was only slightly increased by the supplements but voluntary consumption of mulga was increased by 150%.

Pritchard *et al.* (1988) showed that the feeding of polyethylene glycol (PEG) to sheep fed mulga markedly increased feed intake, weight gain and wool growth. The low quality of mulga is therefore related to its high content of condensed tannins and their capacity to bind feed proteins. These proteins are poorly digested in the rumen and appear also to be indigestible in the intestines. Consequently, sheep consuming mulga have low rumen ammonia and S levels, which can be corrected by S supplementation. The addition of PEG preferentially binds the tannins thereby making plant proteins more available for digestion. The increased digestion rate stimulates feed intake and changes mulga from a maintenance ration to one on which sheep can grow. Sulphur supplements to the drinking water are sufficient to produce this response. These findings are relevant to other *Acacia* species of low nutritive value.

Research with leucaena has resulted in the discovery of rumen bacteria capable of degrading 3 hydroxy-4(1H)-pyridone (DHP). Inoculation of cattle with the bacteria (see Section 4.5) increases the intake and productivity of cattle grazing this tree legume in Australia. There are prospects for isolating other bacteria with beneficial functions from the rumen which may be used as an inoculum to animals to offset the detrimental effects of tannins and other secondary plant compounds.

New problems will arise with each new species that shows agronomic promise, and careful evaluation of the nutritive value of each introduction needs to be made.

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4.2 Tree Legumes as Dietary Supplements for Ruminants

B.W. Norton

Introduction

Leguminous tree leaves have traditionally been fed as supplements to housed and tethered animals in Asia, Africa and the Pacific islands. Species such as *Leucaena leucocephala* (leucaena) have also been grown with grasses in fodder banks to provide a source of high quality forage for ruminants raised in cut-and-carry systems. Legume tree leaves maintain higher protein and mineral contents during growth than do grasses, which decline rapidly in quality with progress to maturity. Legume tree foliage is therefore useful as a protein supplement. There is increasing interest in the use of these trees as sources of high quality feed for grazing ruminants and as supplements to improve the productivity of ruminants given low quality feeds. The use of forage tree legumes in grazing systems for cattle will be discussed later in this volume (Section 4.5).

This section reviews the use of leguminous trees as supplements to ruminants on low quality diets. The response of the different ruminant species (cattle, sheep and goats) and the comparative advantages of different tree foliage species as supplements are discussed.

What is a Supplement?

The microbial population in the ruminant fore-stomach is responsible for the digestion of both the fibrous and soluble fraction of plant material consumed. This fermentation results in the production of volatile fatty acids (VFA) which are the major source of energy for ruminants. Microbial cells and undigested plant proteins are the main sources of protein. Maximum fermentation rates are attained when all factors required by the ruminal microorganisms are available, namely - a source of energy (sugars, cellulose), nitrogen (N), sulphur (S) and minerals. As described earlier, when the rate of fermentation is restricted, feed intake decreases and nutrient availability to the animal is limited. Low quality diets (straws and mature grasses) are characterised by low animal productivity as shortage of one or more of the essential nutrients limits microbial activity. Supplements are required to correct these deficiencies, thereby increasing basal feed intake and hence animal production. The amount of leguminous tree foliage needed to provide effective supplementation will vary with the quality of the basal diet, the quality of the supplement and the level of animal production expected (maintenance or growth). Any evaluation of forage trees as supplements should therefore investigate the effects of increasing levels of supplement on animal performance so that minimum quantity-maximum effect responses can be determined.

Leguminous Trees as Supplements to Low Quality Forage

There is an extensive and diverse literature on the effects of leguminous tree supplementation on the productivity of cattle, sheep and goats. Forage tree leaves, particularly Leucaena and *Gliricidia sepium* (gliricidia), have been used as supplements to a wide range of forages and agricultural by-products. They have been incorporated into concentrate rations as substitutes for more expensive processed protein sources, used as supplements to sisal waste in Mexico and as the major protein source for cattle fed molasses diets. Table 4.2.1 provides information on the response of cattle, sheep and goats to supplements of tree foliage to low quality hay diets. The levels of supplementation ranged from 10 to 33% of dry matter intake, or from 0.3 to 1.1% liveweight.

Since basal feed intake usually increases with supplementation, practical recommendations for levels of supplement to be offered are better expressed in relation to liveweight of the animal than as a percentage of a diet. The studies of Bamualim *et al.* (1984a,b) with goats and sheep given leucaena as a supplement to spear grass (*Heteropogon contortus*) illustrate the common response to supplementation. These authors observed an increase in hay intake and an overall improvement in diet digestibility with supplementation. Although weight changes were not measured in these experiments, the increase in digestible dry matter intake is predictive of improved weight gain. Leucaena supplementation increased rumen ammonia concentrations, stimulated microbial protein synthesis in the rumen (from 1.6 to 2.9 g/day) and increased the amount of plant protein available for absorption. The degradability of Leucaena protein in the rumen was estimated to be 66% for fresh Leucaena and 40% for dried Leucaena The increased protein absorption from the small intestine stimulated an increased voluntary consumption of low quality straw. Other experiments generally demonstrate similar responses, although supplementation of rice straw with leucaena generally did not increase basal intake but did increase digestible nutrient intake (Table 4.2.1).

Leucaena supplements at a rate of 0.6% liveweight (16% in dry matter) were effective in converting a weight loss to a significant weight gain in both sheep and cattle. Higher levels of gliricidia (1.1% liveweight) were needed to convert a substantial weight loss in cattle to maintenance. It is not possible to decide from the information available whether gliricidia is less effective than leucaena as a supplement, since there are no comparable studies where the weight changes of cattle given leucaena and rice straw were recorded.

Table 4.2.1. The effects of supplementation with tree legume foliage on the intake of low quality forages and productivity of cattle, sheep and goats.

Browse	Animal	Basal diet	Voluntary intake (g/kg/d)		Dietary DMD (%)	Liveweight gain (g/day)	Ref.*
			Tree leaves	Basal diet			
Leucaena	goats	spear	-	10.8	47.3		1
		grass	4.3F	15.3	55.5		
	goats	maize	-	10.3	46.0		2
		stover	5.5D	10.3	51.0		
	sheep	spear	-	12.2	50.5		3

leucocephala		grass	3.2F	12.3	49.3		
	sheep	sorghum	-	24.6	41.7	-44	4
		stover	5.9D	32.8	46.7	85	
	cattle	rice	-	18.3	37.6		5
		straw	6.8D	15.9	40.3		
	cattle	natural	-	20.2	42.0	-20	6
		grass	5.2D	26.1	44.0	290	
	buffalo	rice	-	18.4	36.6		5
		straw	7.4	17.1	38.6		
Gliricidia sepium	goats	-	34.6F	-		I	7
	sheep	-	33.9F	-		39	
	goats	-	32.6F	-	56.3	60-75	8
	sheep	barley	6.8F	13.1	42.3		9
		straw	6.8D	22.6	60.5		
	cattle	rice	-	27.0	47.0	-113	10
		straw	11.0D	22.0	55.0	10	
Calliandra calothyrsus	sheep	barley	6.8F	145	36.3		9
		straw	6.8D	22.9	59.0		

D = dried F = fresh
DMD = dry matter digestibility

* References: 1. Bamualim *et al.* (1984b); 2. Banda and Ayoade (1986); 3. Bamualin *et al.* (1984a); 4. Goodchild (1990), 5. Moran *et al.* (1983); 6. Wahyuni *et al.* (1982) 7. Carew (1983); 8. Murugan *et al.* (1985); 9. Ahn (1990); 10. Doyle *et al.* (1986)

The form in which the browse is fed appears to be an important determinant of the response obtained. Ahn (1990) found significant increases in intake and digestibility of barley straw fed to sheep when dried gliricidia and *Calliandra calothyrsus* (calliandra) were offered as supplements. For both legumes, drying decreased feed N degradability (calliandra 62-47%, gliricidia 89-71%), increased protein absorbed and increased N retention. The high degradability of both fresh and dried gliricidia in this study suggests that the poor responses of cattle fed rice straw may be due to the insignificant amount of bypass protein. In the ideal tree supplement, sufficient protein should be degraded in the rumen to provide ammonia for the basal activities of the microbes yet there should be significant amounts of bypass protein for absorption in the small intestine. A plant protein degradability of 30% would meet this ideal requirement.

The Comparative Value of Forage Tree Legumes

Table 4.2.2 shows the results of experiments in which various species of forage tree legumes were evaluated as supplements for goats. The basal diet of Napier grass (*Pennisetum purpureum*) used by van Eys *et al.* (1986) was sufficient for maintenance, and all three fodder tree species increased weight gain to the same extent. However, weight gains were further increased when a source of bypass protein (formaldehyde treated soybean meal) was provided, suggesting that the growth of goats was limited by insufficient protein available for absorption in the small intestine. High levels of foliage supplements are indicated here. The effects of drying of tree foliage on response to supplementation is clearly shown in the studies of Robertson (1988). Dried foliage promoted higher weight gains than fresh foliage for all species, with no species being superior. The poor performance of goats fed leucaena is possibly due to acute (DHP) toxicity, although some of this effect was removed by drying.

It is possible that drying may have a number of different effects. It may increase the amount of protein bypassing the rumen and decrease the content of anti-nutritive factors. Drying has been reported to improve palatability in some species. Robertson (1988) found that all leaf supplements were avidly consumed, so differential palatability was not the cause. The experiment was conducted over 5 weeks, and it is possible that over a longer period, goats may have adapted to the fresh supplements. The experiment of Ash (1990) was short-term, and no weight change results were reported. However, the low levels of supplementation suggested that growth responses would have been be minimal.

Table 4.2.3 shows some comparisons of the nutritive value of forage tree legume supplements for sheep. From the limited data available, levels of supplementation greater than 0.3% liveweight (12% dry matter) are needed to maintain the body weight of sheep given rice straw. *Leucaena leucocephala* cultivars promoted lower weight gains in grazing sheep than calliandra and gliricidia. *Paraserianthes falcataria* was superior to other species tested, and seems worthy of further study. No comparable data are available for cattle.

Table 4.2.2. Some comparisons of the nutritive value of forage tree legumes as supplements for goats.

Browse species	**Voluntary intake (g/kg DM/d)**		**Dietary DMD (%)**	**Liveweight change (g/day)**	**Ref.****
	Tree foliage supplement	**Basal diet**			
(a) Basal diet of Napier grass					
Napier grass	-	33.4	58.1	-1	1
Gliricidia sepium	4.1D*	29.4	57.3	20	
Leucaena leucocephala	4.2D	29.1	62.0	22	
L. leucocephala + 2.7 g/kg F-SBM*	3.9D	26.1		45	
Sesbania grandiflora	4.1D	30.2	55.9	20	
S. grandiflora + 2.7 g/kg F-SBM	3.8D	33.6		52	
(**b**) **Basal diet of rice straw**					
Albizia chinensis	7.5F*	18.5	51.0	0	2
	7.5D	16.5	44.0	54	
Calliandra calothyrsus	7.5F	18.5	47.3	24	

	7.5D	18.5	43.6	48	
Gliricidia sepium	7.5F	18.5	56.0	12	
	7.5D	15.5	46.9	42	
Leucaena leucocephala	7.5F	15.5	48.6	-18	
	7.5D	18.5	47.2	0	
Sesbania sesban	7.5F	14.5	53.7	0	
	7.5D	17.5	52.2	54	
© Basal diet of Guinea grass					
Guinea grass	-	19.5	51.6		3
Albizia chinensis	3.8F	17.3	53.0		
Gliricidia sepium	3.9F	19.5	52.5		
Sesbania grandiflora	3.8F	20.8	55.9		

* F-SBM = formaldehyde treated soybean meal. D = dried, F = fresh
** References: 1. van Eys *et al.* (1986); 2. Robertson (1988); 3. Ash (1990)

Table 4.2.3. Some comparisons of the nutritive value of forage tree legumes for sheep.

Fodder tree legumes	**Voluntary intake (g/kg/d)**		**Dietary DMD (%)**	**Liveweight change (g/day)**	**Reference**
	Tree leaves	**Basal diet**			
Leucaena leucocephala	2.9D*	22.0	58.0	-13	1
Gliricidia sepium	2.4D	20.5	51.0	-16	
Leucaena leucocephala cv. Salvador	Sheep grazing native pasture and given concentrate supplements			12	2
Leucaena leucocephala cv. Cunningham				15	
Calliandra calothyrsus				33	
Gliricidia sepium				34	
Paraserianthes falcataria				57	

* D = dried DMD = dry matter digestibility
* References: 1. Vearasilp (1981) (rice straw); 2. Ibrahim *et al.* (1988)

Effects of Forage Tree Legumes on Animal Performance

Experiments investigating the effects of increasing levels of supplementation of Leucaena and gliricidia for cattle, sheep and goats are summarised in Table 4.2.4. There are no comparable data available for other species. This information is needed if new species are to be recommended. Two supplementation strategies are indicated, viz. supplementation to prevent weight loss and supplementation which maximises liveweight gains. The first strategy provides a conservative use of tree foliage and the second a production oriented approach. The level of supplement required will depend on the quality of the basal feed. For example, high levels of forage tree supplementation (1.1% LWt or 33% DM) of rice straw are required to just maintain cattle (e.g. gliricidia (Doyle *et al.* 1986), leucaena (Moran *et al.* 1983)). Where basal diet quality is higher, lower levels (0.5% LWt or 15% DM) are probably sufficient for weight maintenance. Maximum gains are achieved when supplements are provided at 1.0-1.5% LWt (40-60% DM). Higher levels often decrease performance.

There is a need to develop standard methods for evaluating forage tree legumes both as a minimum supplement (prevention of weight loss) and as a production feed (optimising weight gain). It is recommended that four treatments be tested, viz. the basal diet fed *ad libitum,* tree foliage supplement provided at a rate of 0.5 and 1.5% liveweight and *ad libitum.* In this way, information may be gained on the supplemental value for production and the possible toxicities that might arise when animals consume the herbage as a sole feed. The feeding period should be for at least 10 weeks, and weight change and diet digestibility measured. This experimental format is presently being used to evaluate new tree legume feeds at the University of Queensland.

Table 4.2.4. The effect of increasing levels of forage tree legume supplementation on productivity of cattle, sheep and goats.

Browse species	**Animal species**	**Basal diet**	**Supplemental level (%DM)**	**Voluntary intake (g/kg/day)**	**Dietary DMD %**	**Weight change (g/day)**	**Reference***
L. leucocephala	cattle	natural	0	20.2	42.0	-20	1
	grass		20	26.1	44.0	290	
			40	28.8	46.0	540	
			60	28.8	44.0	590	
			100	22.0	51.0	310	
L. leucocephala	sheep	poor	0			-9	2
		hay	15			15	
			27			37	
			45			53	
			59			65	
L. leucocephala	goats	maize	0	10.3	46.0		3
		stover	35	15 8	51.0		
			51	20.8	48.0		
			59	21.5	54.0		
L. leucocephala	goats	barley	0^+	17.9	48.4	51	4
		straw	33	29.5	60.5	71	
			65	30.9	57.2	66	
			100	27.0	62.1	46	
Gliricidia	came rice	0	27.0	47.0	-113	5	

		straw	10	31.0	46.0	-54	
			20	31.0	49.0	-94	
			33	33.0	55.0	10	
G. sepium	sheep	*Brachiaria*	0	weight gains of ewes		-7	6
		milliformis	25	from joining to lambing		5	
			47	at (40 weeks)		9	
			72			8	
G. sepium	goats	poor	0	21.8	45.0		7
		hay	22	25.9	45.0		
			36	29.5	51.0		
			46	30.0	55.0		
Albizia chinensis	goats	barley	0^+	18.9	45.9		4
		straw	27	27.8	56.4		
			61	27.4	48.8		
			100	24.6	48.0		
Sesbania sesban	goats	barley	0^+	17.7	48.3	41	4
		straw	33	28.7	60.9	47	
			66	31.7	64.1	63	
			100	27.8	63.9	9	

DM = dry manor
DMD = dry matter digestibility
0^+ Supplemented with 70 g molasses + 30 g urea

* References: 1. Wahyuni *et al.* (1982) (Indonesia); 2. ILCA (1987) (Ethiopia); 3. Banda and Ayoade (1986) (Malawi); 4. Norton *et al.* (1992) (Australia); 5. Doyle *et al.* (1986) (Thailand); 6. Chadhokar and Kantharaju (1980) (Sri Lanka); 7. Smith and van Houtert (1986) (Nigeria)

The Use of Forage Tree Legumes in Tropical Grass Silages

In many parts of the wet tropics, the conservation of grass for hay is a problem due to slow rates of drying which reduce the quality of the hay. In temperate areas, where slow rates of drying are experienced, silage is a common form of grass conservation. A major reason for poor quality silage is loss of protein which is degraded to ammonia during the anaerobic fermentation that produces lactic acid. Effective fermentation requires a source of soluble carbohydrate which is usually present in high quality temperate grasses.

In anticipation of low levels of soluble carbohydrate in tropical grasses, molasses is often added. However, with a high quality hay such as pangola grass (*Digitaria decumbens*), there was no advantage gained by adding molasses (Tjandraatmadja *et al.* 1993). Table 4.2.5 shows results from studies where tropical grasses and tree leaves were used to make silage for feeding to sheep. The inclusion of both gliricidia and leucaena produced highly palatable silages which promoted weight gain. When compared with sorghum silage, which is usually recommended for tropical areas, the tree-pangola grass silages were superior. When lower quality grasses were used (*Setaria sphacelata*) molasses was necessary to produce silages which promoted weight gain. In other studies with these silages, feed protein degradabilities were determined as 78% for pangola silage, 65% for leucaena + pangola silage and 75% for gliricidia + pangola silage. These values suggest that, unlike other silages, a significant component of the original bypass protein in the browse was retained after fermentation. As found previously, gliricidia protein was more degradable in the rumen than leucaena proteins. These studies suggest that tree legume leaves may be a useful protein addition to tropical silages.

Conclusions

This review suggests that forage tree legumes have considerable potential as supplements to low quality diets and that their use as supplements merits further investigation. However, whilst there is considerable information available on the supplementation value of leucaena and gliricidia, less is known about other forage tree legumes. Forage tree legumes are a costly resource to establish and their judicious use is required if maximum benefit is to be obtained from them. A knowledge of their comparative nutritive value and the levels of supplementation required for particular purposes is needed if these trees are to become an important part of the feed resources available to livestock producers.

Table 4.2.5. The use of leucaena and gliricidia leaves in silage for sheep (Tjandraatmadja 1989).

Grass	Forage tree	Molasses	Intake (g/kg/day)	DMD (%)	Weight change	Nitrogen balance (% intake)	Rumen ammonia (mg N/L)
Pangola hay	-	-	23.9	64.7	+	16.6	134
Pangola grass	-	+	16.1	60.6	-	6.8	100
	L. leucocephala	-	22.9	54.9	+	28.8	88
	L. leucocephala	+	22.7	56.4	+	33.6	77
	G. sepium	-	23.1	53.3	+	36.4	77
	G. sepium	+	25.4	55.8	+	40.3	88
Setaria hay	-	-	16.7	40.6	-	< 0	31
Setaria grass	-	+	19.0	56.5	-	6.7	54
	L. leucocephala	-	22.1	53.6	0	31.0	77
	L. leucocephala	+	21.1	57.4	+	35.5	105
	G. sepium	-	17.1	54.4	-	33.3	80
	G. sepium	+	21.8	60.4	+	36.2	114
Sorghum silage	-	-	15.9	57.1	-	< 0	46

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4.3 Anti-nutritive and Toxic Factors in Forage Tree Legumes

B.W. Norton

Introduction

Plants have co-evolved with predator populations of bacteria, insects, fungi and grazing animals, and have developed defence mechanisms which assist their survival. Leguminous trees and shrubs often have thorns, fibrous foliage and growth habits which protect the crown of the tree from defoliation. Many plants also produce chemicals which are not directly involved in the process of plant growth (secondary compounds), but act as deterrents to insect and fungal attack. These compounds also affect animals (including humans) and the nutritive value of forages. Mycotoxins (fungal metabolites) produced by saprophytic and endophytic fungi are also a potential source of toxins in forages.

The effects of both secondary metabolites and mycotoxins vary with animal species. Non-ruminants (e.g. pigs, poultry and horses) are usually more susceptible to toxicity than ruminants which have the capacity to denature potential toxins in the rumen. The nature and action of toxins in plants have been the subject of several reviews (Duke 1977, Rosenthal and Janzen 1979, Hegarty 1982, Seawright *et al.* 1985, Barry and Blaney 1987), in which attention was focused on pasture plants of commercial importance.

This section reviews the information available on the anti-nutritive and toxic compounds which have been found in forage tree legumes.

Screening Techniques for Plant Toxins

In plant introduction and range evaluation programmes, there is a need to rapidly screen large numbers of plants for nutritive value, palatability and potential toxicity. Since it is usually not feasible to collect sufficient herbage to feed ruminants, alternative techniques have been developed using laboratory animals (e.g. mice, rats, rabbits and guinea pigs) as test animals. Rats have been used to detect a wide range of plant toxins potentially harmful to man and other monogastric animals. Since the rat is more sensitive to plant toxins than ruminants, several workers have used a rat bioassay to test the presence of toxins in tropical pasture legumes (Bindon and Lamond 1966, Strickland *et al.* 1987). Although toxicity to rats is not necessarily indicative of similar problems in ruminants, the process allows rapid identification of potentially toxic species which can then be investigated further in feeding trials with ruminants. The results of these bioassays will be discussed in this section. With the increasing interest in tree legume species, there is a need to extend these trials to a wider range of species.

Secondary Plant Compounds in Forage Tree Legumes

Secondary plant compounds may produce toxic effects in ruminant animals (e.g. cyanide, nitrate and fluoroacetate), may depress intake and/or utilisation of feed components (mycotoxins, high tannins), or may enhance feed nutritive value (low tannins, anti-protozoa! activity). Table 4.3.1 provides a summary of the compounds which have been found in tree legume species which may affect animal productivity. The list of species and compounds is not exhaustive, and some compounds listed may not be toxic. Although mycotoxins in forages are known to cause some commercially important toxicoses in grazing stock (e.g. ryegrass staggers, lupinosis and facial eczema), no comparable reports can be found for stock consuming tree species.

The mode of action of some of the compounds (tannins, cyanogenic glycosides and saponins) has been described in detail by other reviewers and will not be attempted here. In the following section, the significance of these compounds to the nutritive value of the major tree legume species will be discussed.

Acacia

Mulga (*Acacia aneura*) is the most common *Acacia* species used for stock feeding in Australia. As mentioned in Section 4.2, mulga is of low nutritive value. Many acacias have high concentrations of phenolic compounds in their leaves, the major compounds being lignin and tannins. The tannins may be further categorised into hydrolysable tannins (polyesters of garlic acid and hexahydroxyphenic acid derivatives) and condensed tannins (proanthocyanidins). In ruminants, the ingestion of hydrolysable tannins can cause death, but these animals have a higher tolerance of condensed tannins. The condensed tannins in mulga inhibit plant protein degradation in the rumen and decrease rumen availability of sulphur, which then depresses the digestibility of plant cell walls. It is also possible that these tannins inhibit microbial enzymes in the rumen and decrease the availability of plant proteins for digestion in the intestines.

Table 4.3.1. A list of secondary compounds found in some forage tree legume species.

Species	Plant part	Compound	Reference
Acacia aneura	leaf	condensed tannins, oxalate	1
Acacia cambagei	leaf	cyanogenic glycoside (CG)	2
		CG hydrolase	
		oxalate	
	bark		
Acacia cana	leaf, stem	selenium	2
Acacia doratoxylon	leaf, stem	CG	2
Acacia georgina	leaf, stem	CG hydrolase (no CG)	2
		fluoroacetate	2
Acacia salicina	leaf, bark	tannins	3
	pods	saponins	4
Albizia chinensis	bark	echinocystic acid	5
		glycosides, oleanolic acid	
		sterols	
	leaf	condensed tannins	6

Albizia lebbeck	flowers	various sterols	7
	leaf	pipecolic add derivatives	8
	root	echinocystic acid	9
Calliandra calothyrsus	leaf	condensed tannins	6
Calliandra haematocephala	leaf	pipecolic acid derivative	10
Calliandra portoricensis	leaf	tannins, saponins, flavonoids,	11
		glycosides	
Gliricidia sepium	leaf	pinitol	12
	leaf	condensed tannins	6
	leaf	coumarins, melilotic add	13
	leaf	CG, nitrate	14
	seed	canavanine, heat stable toxin	9
Leucaena leucocephala	leaf	mimosine	15
	leaf	condensed tannins	6
	leaf	flavanol glycosides	16
Sesbania grandiflora	leaf, seed	condensed tannins, glycosides	17
	flowers	methyl oleanolate	18
Sesbania sesban	leaf	saponin (glucuronide-oleanolic acid)	19
	leaf	saponin, heat labile toxin	20
	seed	saponin (stigmasta galactopyranoside)	21

* References: 1. Gartner and Hurwood (1976); 2. Cunningham *et al.* (1981); 3. Everist (1969); 4. Hall *et al.* (1972); 5. Rawat *et al.* (1989); 6. Ahn *et al.* (1989); 7. Asif *et al.* (1986); 8. Romeo (1984); 9. Sotelo *et al.* (1986); 10. Marlier *et al.* (1979); 11. Aguwa and Lawal (1987); 12. Calle *et al.* (1987); 13. Griffiths (1962); 14. Manidool (1985); 15. Hegarty *et al.* (1964); 16. Lowry *et al.* (1984); 17. Andal and Sulochana (1986); 18. Kalyanaguranathan *et al.* (1985); 19. Dorsaz *et al.* (1988); 20. Shqueir *et al.* (1989); 21. Kholi (1988)

Tannins do not appear to be present in all *Acacia* species, and perhaps low tannin species could be selected for further study. Tannins may also be associated with the poor acceptability of young mulga leaves, although volatile oil content is also highest in young leaf (Melville 1947). There is recent evidence that some ruminal microorganisms are able to metabolise tannins, or able to remain active in a high tannin environment, and may be used as inoculants to overcome the detrimental effects of tannins in ruminants (Section 4.6).

Mulga also contains sufficient insoluble oxalate to affect the availability of calcium (Gartner and Hurwood 1976). Where oxalate concentrations are high, calcium oxalate crystals may be formed in the kidney leading to urolithiasis. However, given time to adapt, the microorganisms in the rumen can metabolise moderate amounts of oxalate, and there is little reason to suspect that oxalate poisoning is a serious problem when feeding mulga.

Cyanogenic glycosides (CG) occur in many *Acacia* species and, when ingested and hydrolysed to free hydrogen cynanide (HCN), cause cyanide toxicity. Cynanide combines with haemoglobin in blood and inhibits respiratory enzymes, ultimately causing death. The response of ruminants to CG ingestion varies. In the rumen, HCN is converted to thiocyanate using available sulphur and thiocyanate is absorbed and excreted. Thiocyanate is a goitrogen, inhibiting the activity of the thyroid gland, and often the effect of CG ingestion is seen as the development of goitre (thyroxine or iodine deficiency). Iodine supplementation overcomes this effect. The ruminal trapping of sulphur may also induce a sulphur deficiency which can be corrected by supplemental sulphur (Wheeler *et al.* 1975). The formation of HCN from this glycoside requires the presence of a specific hydrolytic enzyme in the plant tissue. Table 4.3.1 shows that both enzymes are not always present and, in the absence of the hydrolytic enzyme, CG are not toxic.

The seeds and pods of *Georgina gidyea* (*Acacia georgina*) contain fluoroacetic acid (FA), an organic acid found in a range of other plants (e.g. *Dichapetalum, Gastrolobium* and *Spondanthius*). This compound inhibits the Krebs cycle by formation of fluorocitrate and is used as a poison for rats and rabbits. FA and its derivatives are also used as insecticides. Fluorine is a cumulative poison, and its effects are often observed only after stock have been grazing plants containing these compounds for a significant time. When compared with other FA containing plants, *G. gidyea* has only low concentrations, and FA poisoning is only a problem when the plant is the sole source of food during a drought. It is of some interest that native Australian mammals (e.g. kangaroos and possums) normally consume the seeds of *G. gidyea* with impunity, suggesting that these species have developed a mechanism for tolerance of toxicity (Twigg *et al.* 1986).

Albizia

Albizia lebbeck or Indian siris has been more intensively studied than the faster growing *A. chinensis.* A major difference between the species is in tannin content. *Albizia chinensis* contains significant levels of condensed tannins and proanthocyanidins while *A. lebbeck* contains no extractable tannins (Ahn *et al.* 1989). Green leaf, fallen leaf and flowers of *A. lebbeck* have all been shown to be highly palatable and of high nutritive value for sheep (Lowry 1989). Less is known about *A. chinensis* although it is readily accepted (either fresh or dried) by young goats as a supplement to low quality straws (Robertson 1988, Ash 1990) and is eagerly browsed by does and their kids.

A variety of secondary compounds have been isolated from *Albizia* species, some having biological activity. A range of sterols (taxerol, cycloartemol, lupeol, campesterol and sitosterol) have been found in the flowers of *A. lebbeck* (Asif *et al.* 1986) and a saponin (echinocystic acid) was reported in root extracts (Shrivastava and Saxena 1988). Saponins are glycosides of steroid or triterpenoid compounds (e.g. ursane, oleanane and lupane) and, by their detergent action, have been implicated in the formation of bloat in cattle grazing white clover pastures. Triterpenic substances and glycosides of echinocystic acid (saponin) have been isolated from the bark of *A. chinensis,* and these bark extracts have been found to have molluscicidal (Ayoub and Yankov 1986), spermacidal (Rawat *et al.* 1989) and insecticidal (Tripathi and Rizvi 1985) properties. Rahman *et al.* (1986) also reported that alkaloids from the seeds of *A. lebbeck* are fungicidal and cytotoxic to selected lines of cancer cells growing *in vitro.* As the name suggests, the neutral non-protein amino acid albizzine was first isolated from *Albizia lebbeck,* but no toxic activity has been reported.

Whilst these compounds may provide some protection against plant predators, they do not appear to affect the palatability and intake of forage trees by ruminants. It has been observed that whilst goats will eat the bark of some browse trees, little bark damage is found when goats browse *A. chinensis.* The high content of saponins in bark may be deterring consumption. There appear to be no reports of saponins in *Albizia* leaf and the dried leaf is non-toxic when fed to rats (Ahn 1990). Although there is a paucity of information on the effects of *A. chinensis* fed to ruminants, it appears that *Albizia* species may prove to be a valuable new source of forage for ruminants.

Calliandra

All *Calliandra* species appear to contain condensed tannins, with high levels (>10%) in *C. calothyrsus.* When fed to rats (20% of diet), feed intake (palatability) was high but all rats lost weight (Ahn 1990). Tannins are known to have a direct effect on metabolism. Chickens fed high tannin sorghums develop leg abnormalities (Elkins *et al.* 1978). Barry *et al.* (1986) found that plasma growth hormone levels increased with increased intake of condensed tannins by sheep. Tannins react not only with dietary protein but also with enzymes of the gut wall and protein in saliva

Ruminants appear to be more tolerant of tannins than non-ruminants, although few studies have been conducted with forage tree legumes. Palmer and Schlink (1992) have reported that wilting (25℃ for 24 h) *Calliandra calothyrsus* (calliandra) depressed feed intake in sheep when given a sole diet over an 8 day period. Ahn *et al.* (1989) have shown that drying decreases extractable tannin content of tree legumes, including Calliandra. Table 4.3.2 shows the results from an experiment where frozen (fresh) and dried calliandra were fed as supplements to sheep given a low quality (barley straw) diet. The removal of tannins by polyethylene glycol (PEG) infusion resulted in an increased consumption of straw when frozen calliandra was fed. Drying alone increased straw intake and the digestibility of the cell walls (NDF). PEG infusion increased the digestibility of N. particularly in the rumen, which resulted in higher urinary N losses as ammonia. It was concluded from this study that the presence of both tannins and a heat labile compound in fresh calliandra depresses feed utilisation, and that drying removes a factor (not tannin) which is depressing the digestibility (and intake) of barley straw by these sheep. The nature of this factor is not known, and clearly deserves further study. At the level of feeding used in this study, drying effectively removed the detrimental effect of both tannins and the unknown heat labile factor. There is a need to confirm these effects at higher levels of forage intake, and to reconcile these positive effects of drying with the negative effects found by Palmer and Schlink (1992).

Although there are no reports of secondary compounds in *C. calothyrsus,* the leaves of *C. portoricensis* were found to contain saponins, flavonoids and glycosides (Aguwa and Lawal 1987). These extracts have bactericidal (Adensina and Akinwusi 1984, Aguwa and Lawal 1987) and helminthicidal properties in dogs (Adewuni and Akubue 1981). Pipecolic acid, a non-protein amino acid, and its derivatives have been isolated from the leaves of *C. haematocephala* (Marker *et al.* 1979) and these compounds were shown to have insecticidal properties (Romeo 1984). The effects of these compounds on sheep is not known, but it does seem possible that some may be useful as stock and human medicines.

Gliricidia

There is varying opinion about the nutritive value of *Gliricidia sepium* (gliricidia). It is generally agreed that it is a high quality forage, but of low palatability when first introduced to animals. Carew (1983) found that gliricidia in the diet of sheep and goats induced diarrhoea and depressed consumption of dried leaves during the first 3 weeks of feeding. Similar observations were made by Robertson (1988) where goats took 5 days to adapt to prescribed intakes of fresh and dried gliricidia leaves. The odour of the leaves has been implicated in this initial reluctance of animals to eat gliricidia (Brewbaker 1986). However, once adapted, there appear to be no long-term detrimental effects on sheep and cattle (Chadhokar 1982). The composition and quality of milk of dairy cows given 30% of their diet as fresh gliricidia leaves was not affected (Chadhokar 1982).

Table 4.3.2. The effects of drying *Calliandra calothyrsus* and infusion of polyethylene glycol (PEG) on dry matter and N utilisation in sheep given barley straw diets supplemented with *Calliandra* (adapted from Ahn 1990).

Component	Frozen		Oven-dried	
	-PEG	+PEG	-PEG	+PEG
Intake (g/day)				
Tannins	17.7a*	17.7a	14.6b	14.6b
Barley straw	624.0a	761.0b	721.0b	742.0b
Calliandra	180.0	180.0	189.0	189.0
Total	804.0a	941.0b	910.0b	931.0b
Digestibility (%)				
Dry matter	39.9	39.6	46.3	44.1
NDF	39.3a	40.6a	49.0b	46.5b
Nitrogen (N)	20.7a	39.2b	31.6c	43.4b
N utilisation (g/day)				
N intake	10.2	10.9	10.7	10.8
N in faeces	8.1a	6.6b	7.4c	6.1b
N in urine	4.0a	5.9b	3.9a	5.4b
N balance	-1.9	-1.6	-0.5	-1.1

* Values within a line with different subscripts differ significantly ($P < 0.06$)

The tannin content of gliricidia leaves does not appear to interfere with plant protein availability but may be one of the factors affecting palatability (Table 4.3.3). Ahn (1990) found that drying removed all extractable tannins from gliricidia increased straw intake, dry matter and N digestibility and N balance in sheep. However, it is not possible to decide whether these effects were due to the tannins or some other factor removed or inactivated during drying. Even though drying removed tannins and improved nutritive value, sheep still consumed gliricidia with reluctance, suggesting that the factor(s) associated with poor palatability were not removed by drying.

The factors affecting palatability of gliricidia in ruminants are probably the same as those that depress digestibility and growth in rabbits and chickens given gliricidia leaf meal diets (Raharjo and Cheeke 1985). Gliricidia and calliandra were the least palatable of the forages offered in this study. Ahn (1990) also found depressed intakes, weight loss and foetal deaths in rats offered a diet containing 20% dried gliricidia leaf. Gliricidia bark and seeds are reported to be used as a rat poison in some countries (Sotelo *et al.* 1986) suggesting that a toxic principle is present. Coumarins have been found in gliricidia leaf (Table 4.3.1); these compounds are precursors of phyto-oestrogens which have caused infertility and abortion in sheep grazing clover in Australia (Cox and Braden 1974). However, Chadhokar (1982) fed diets containing 75% gliricidia to pregnant sheep and found only beneficial effects of supplementation. Sotelo *et al.* (1986) have reported a thermostable toxin in gliricidia seeds which killed mice within l week of feeding. These authors isolated a non-protein amino acid, canavanine (2-amino-4-guanidooxy-butyric acid) from gliricidia seeds, and this compound may be associated with the toxicity of gliricidia in non-ruminants. However, many of these reports require confirmation by further experimentation. Nevertheless, despite the problem with palatability in ruminants, the undoubted value of gliricidia as a source of forage makes continued study of this species still worthwhile.

Leucaena

The value of *Leucaena leucocephala* (leucaena) as a feed for stock has been documented by many workers even though all parts of the plant contain the non-protein amino acid mimosine (β -[N-(3-hydroxy-4-oxopyridyl)]-α -aminopropionic acid) which is highly toxic to non-ruminants. Mimosine acts by interfering in cellular mitosis, and the symptoms of toxicity are alopecia, reduced appetite, reduced weight gain and often death. It is recommended that diets for pigs and poultry should contain less than 10% leucaena.

It is now known that in areas where leucaena is indigenous (Central America), and in parts of Asia, ruminants consuming leucaena appear able to degrade the ruminal metabolite of mimosine, 3-hydroxy-4(1H)-pyridone (DHP), to harmless end-products (Jones and Lowry 1984). This capacity is associated with a specific bacterial population in the rumen of these adapted animals. However, where leucaena has been introduced to ruminant populations without this adaptation, symptoms of toxicity such as alopecia, excessive salivation, lack of coordination of gait, enlarged thyroid glands (low serum thyroxine) and reduced fertility are often observed (Jones 1979). These symptoms have been reported in Papua New Guinea (Holmes *et al.* 1981) Australia (Hegarty *et al.* 1976) and can be expected in other areas of the tropics where leucaena has been newly introduced.

Toxicity in ruminants is caused by DHP, which is a potent goitrogen. The severity of toxicity is related to the level of leucaena consumed, and diets containing less than 30% are generally considered safe for ruminants. Alternatively, ruminal organisms capable of degrading DHP may be introduced into the rumen of stock grazing leucaena (Jones and Megarrity 1986), thereby removing this restraint to increased use of leucaena. The management strategies needed to maximise animal productivity from leucaena are reported in Section 4.5.

Table 4.3.3. The effects of drying supplemental *Gliricidia* and *Calliandra* leaf on the intake and utilisation of barley straw by sheep (adapted from Ahn 1990).

Component	***Gliricidia***		***Calliandra***	
	Fresh	**Dried**	**Fresh**	**Dried**
(a) Intake (g/day)				
Tannins	4.0	0.0	23.8	16.4
Barley straw	392.0a*	680.0b	436.0a	691.0b
Tree forage	200.0	200.0	204.0	200.0
Total	593.0a	880.0b	640.0a	891.0b
(b) Digestibility (%)				
Dry matter	42.3a	60.5b	36.3a	59.0b
Nitrogen	24.6a	47.4b	7.3c	39.9d
(c) N utilisation (g/day)				
N intake	8.3a	8.5a	9.2b	9.7b
N in faeces	6.3a	4.5b	8.6	5.8a
N in urine	2.9	2.6	2.4	1.4
N balance	-0.9a	1.4b	-1.7a	2.5b

* Values with a line with different subscripts differ significantly ($P < 0.06$)

Sesbania

Two species of *Sesbania* are potentially useful forage sources - the slower growing tree *S. grandiflora* and the rapidly growing short-lived species *S. sesban. Sesbania grandiflora* leaves and pods are reported to be palatable and non-toxic for cattle (NAS 1979). Some other reports suggest that the white flowering variety is non-toxic, while the purple flowering type is toxic (Hutagalung 1981). Dried leaves of *S. grandiflora* have been fed (20% of diet) to milking cows (Tendulkar *et al.* 1984) and goats (15% of diet) without detrimental effects (van Eys *et al.* 1985, Ash 1990). *Sesbania sesban* has also been successfully fed as a sole diet to goats (Singh *et al.* 1980) and as a supplement to low quality forage for young sheep (Reed and Soller 1987). In this latter study, *S. sesban* (50% dry matter) was fed for 91 days, during which time the sheep grew at a rate of 48 g/day.

A major difference between the species is that *S. grandiflora* contains condensed tannin precursors (cyanidins) in leaves, whilst no tannin can be detected in *S. sesban.* However, both species contain compounds potentially toxic to non-ruminants. The methyl ester of oleanolic acid has been isolated from the flowers of *S. grandiflora* and shown to have haemolytic effects on sheep and human erythrocytes (Kalyanaguranathan *et al.* 1985). Olvera *et al.* (1988) found poor growth and high mortality in *Tilapia fingerlings* at all levels of inclusion (10-35%) of *S. grandiflora* leaf meal in a fish meal diet. Similar results were obtained when leaf meal of *S. grandiflora* was substituted in starter rations for chickens (A. Ash, personal communication).

Oil from the seeds of *S. sesban* is accorded specie properties in Ayurvedic medicine, and is reported to have bactericidal, cardiac depressant and hypoglycaemic actions. The saponin, stigmasta-galactopyranoside has recently been isolated from *S. sesban* seeds (Kholi 1988). Dorsaz *et al.* (1988) have isolated glucuronide derivatives of oleanolic acid which has molluscicidal activity against *Biophalaria glabrata,* one of the known snail vectors of schistosomiasis. This saponin also showed spermicidal and haemolytic activity. Tripathi and Rizvi (1985) also found that *S. sesban* extracts had anti-feeding activity against moth larvae. Shqueir *et al.* (1989) found that the inclusion of *S. sesban* leaf meal in poultry diets (10% of diet) proved fate. to young chicks, and that the provision of either cholesterol or sitosterol with the diet significantly improved survival. The authors reported that the leaves contain a saponin-like toxin and a heat labile factor. It is clear from these studies that both *Sesbania* species contain a number of toxins with specific activity against a variety of organisms.

Although no reports of acute toxicity in ruminants were found, many of these trials were of limited duration. In grazing studies with goats in Australia, goats showed a high preference for the bark of *S. sesban,* even when sufficient leaf was available, killing many trees. No toxic effects were found in goats consuming this bark. It has been observed that the bark of *S. sesban* accessions may be either green or red, and goats readily consumed green bark. It is not known whether goats have the same preference for the red-barked variety, or whether the colour is indicative of compounds detrimental to ruminants. This aspect of grazing behaviour needs further study. In a year-long field grazing study at the University of Queensland, heifer cattle were initially reluctant to browse *S. sesban.* However, after 3 months they began to consume *Sesbania* selectively and their weight gains dramatically improved with no indication of toxicity (Gutteridge and Shelton 1991).

Conclusions

Although many different, and some potentially dangerous, compounds have been isolated from many of the potentially useful forage legume trees, little is known about the specific effects of these compounds on ruminant metabolism. The intense interest in leucaena has generated research which firstly identified the regional problem of mimosine and DHP toxicity, and then proceeded to provide a practical solution to the management of this problem. A newer set of forage trees is now available and is being agronomically evaluated. Their nutritive value needs to be intensively studied before they can be released for widespread use.

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4.4 Management of Anti-nutritive Factors - with Special Reference to Leucaena

R.J. Jones

Introduction

In addition to the proteins, carbohydrates, fats and other compounds essential to metabolism, plants also contain 'secondary' metabolites. These occur in a variety of chemical structures and vary from genus to genus and from species to species. They appear to be more widespread in tropical forages than in temperate forages, and are more prominent in woody genera than in herbaceous ones (Jones and Lowry 1990).

The role of the numerous secondary plant compounds in plants is not fully understood. However, it is generally accepted that they may enable a plant to deter or limit predation by herbivores (Culvenor 1970, Rosenthal and Janzen 1979). The compounds may be toxic, confer unpalatability or reduce the intake of grazing herbivores. Ruminants, however, may be less affected by such anti-nutritive substances because of the capacity of the rumen microorganisms and the liver to degrade these compounds and so render them less harmful to the animal.

The range of compounds known to have anti-nutritive qualities is large (Hegarty 1982) and is discussed in Section 4.3. It is very likely that some of these, and possibly new compounds, will be encountered in new species of forage trees that are now being considered for release to industry.

Strategies for Managing Anti-nutritive Factors

A number of approaches could be used to reduce the effects of known anti-nutritive factors remembering that more than one factor may be involved in any given plant.

Avoid using the plant

Clearly this strategy can be used if one has a choice either to plant a problem tree legume species or not. In some cases, however, the tree legume may be a component of the natural vegetation of the area and may have some useful attributes, e.g. mulga (*Acacia aneura*) in western Queensland.

Use supplements to overcome the anti-nutritive factor

High concentrations of condensed tannins can lower feeding value due to reduced availability of nutrients, especially protein, and lower cell wall digestion (Barry and Blaney 1987). The use of supplements of Na, S, Ca and N (urea) improved wool growth and liveweight gains of sheep fed mulga (*Acacia aneura*) (Gartner and Niven

1978, Elliott and McMeniman 1987) even though proximate analysis of leaf showed that these nutrients should have been adequate for growth. Interference in their availability, due to the presence of oxalates (as calcium oxalate) and tannins (which bind proteins and necessitates the excretion of sulphur as sulphate), has been proposed to explain the responses obtained with mineral supplementation (Gartner and Hurwood 1976).

Reduction in the level of tannins may be achieved in some herbaceous legumes by improving soil nutrient status - particularly that of P and S. Thus the condensed tannins of *Lotus* spp., sainfoin (*Onobrychis sativa*) and *Desmodium ovalifolium* were reduced by fertilisation (Barry and Blaney 1987, Lascano and Salinas 1982). For the tropical tree legumes, there has been little work done on either supplementation or fertilisation as strategies to alleviate any perceived problems from condensed tannins. However, for *Calliandra calothyrsus,* increasing levels of fertiliser input did not reduce tannin levels in the leaves (B. Palmer and J.B. Lowry, personal communication).

An effective, though as yet uneconomic, way of reducing the adverse effects of condensed tannins is to feed polyethylene glycol (PEG) with molecular weight of 3,350 or above (see Section 4.6).

Reduce access to the problem feed

By reducing the proportion of the problem legume in the diet, adverse effects can be reduced. This may be readily achieved under a cut-and-carry system but may not be so easy under grazing. The use of small fenced legume paddocks adjacent to the main pasture areas is one way of rationing the feed; another is to plant the legume in widely spaced rows or to grow most of the feed above grazing height as for tree leucaena (Wildin 1985).

Irrespective of the feed, it is always wise to introduce animals to it gradually. This will enable animals to 'adapt' to the new feed. Such adaptation may well involve an increase in the rumen of microorganisms capable of detoxification, or partial detoxification, of the anti-nutritive compounds.

In some cases it may be possible to avoid feeding the plant when levels of the anti-nutritive compounds are high. Another strategy would be to use the forage for fattening of animals prior to slaughter and not to use the forage for long-term feeding of growing animals. It would be important, however, to ensure that such cumulative toxins do not accumulate in the meat and so cause problems when the meat is eaten.

With plant oestrogens, limiting access to non-breeding animals will reduce the adverse effects on reproductive performance (e.g. with subterranean clover). However, no comparable problems have been recorded for tree legumes.

Use cultivars low in anti-nutritive compounds

A breeding programme conducted by the CSIRO Division of Tropical Crops and Pastures successfully produced low mimosine lines of leucaena by crossing *L. pulverulenta* and *L. leucocephala.* However, it was not possible to combine vigour with low mimosine concentration (Jones and Bray 1983).

For plant breeding strategies to be effective, a clear identification of the anti-nutritive compounds is needed. These should be readily determined by simple tests, should show a range of variation in the genetic material available, and the character should be highly heritable. Care should be taken to assess levels of other anti-nutritive compounds which may vary together with or inversely with the 'target' compound. Thus low mimosine levels could be associated with high tannin levels and low palatability.

Use rumen microbes to detoxify the compounds

Rumen micro-organisms may metabolise toxins in several ways:

- They may convert the toxin to non-toxic metabolites. Thus, under normal circumstances soluble oxalate in grasses is no cause for concern in ruminants, though if cattle on dry feed are suddenly introduced to lush pasture high in oxalates they can die from accumulation of calcium oxalate in the kidneys (Jones *et al.* 1970). Unique anaerobic bacteria (*Oxalobacter formigenes*) have been isolated which convert oxalate to CO_2 and formate. They depend on oxalate as their sole energy source (Allison 1985).

- They may convert the toxin to compounds with enhanced activity in the animal, a classic example being the conversion of the isoflavones formononetin and daidzein, present in oestrogenic clover, to equol and *O*-methylequol by dimethylation and reduction (Cox 1985). These are compounds which are more active in reducing fertility in female sheep.

- They may convert the toxin to substances with a completely different toxic property. For example, the mimosine in *L. leucocephala* has strong anti-mitotic and depilatory properties but is not goitrogenic, whereas its ruminal metabolite 3,4 DHP is a potent goitrogen (Hegarty *et al.* 1979). This will be considered in more detail later.

- They may not metabolise the toxin at all, although subsequently some change may occur in the body tissues. For example, fluoroacetic acid, present in some *Acacia* species and *Gastrolobium* species, is not metabolised by rumen microorganisms, but is converted to fluorocitrate in the body tissues. This then blocks the carboxylic acid cycle causing citrate accumulation and subsequent toxicity and death (Everist 1974).

In the future, with an increasing understanding of the structure of anti-nutritive compounds and their likely degradation pathways, it may be possible to modify bacteria genetically to contain specific enzymes that detoxify problem compounds. The approach certainly holds promise. However, much basic work will be required to achieve this objective, but the successful use of naturally occurring DHP degrading bacteria to solve the leucaena toxicity problem in Australia (see later) offers hope and encouragement for this area of work.

Thus far, the management of anti-nutritive compounds has been treated in a general fashion. For the remainder of this section discussion will focus on the use of leucaena in northern Australia and summarise progress towards successful management of the toxic amino acid mimosine.

The Leucaena Story

When research started on leucaena in the 1960s, two problems seemed worthy of special effort - slow establishment and the toxicity of leucaena to ruminants. The special advantages of leucaena over other legumes being evaluated at the time gave priority to research on these problems. Advantages were very high animal production potential and persistence in grazed pastures. At Samford, southeast Queensland, a leucaena pasture established in 1959 has produced liveweight gains per hectare double that of Siratro (*Macroptilium atropurpureum*) based pastures on similar soils (Jones and Jones 1982).

The toxicity

The toxic constituent in leucaena is a non-protein amino acid, mimosine

(-[*N*-(3-hydroxy-4oxopyridyl)](-α -aminopropionic acid) which is an antimitotic and depilatory agent as well as possessing other unusual pharmacological properties (Hegarty *et al.* 1964). Mimosine occurs in all parts of the leucaena plant, but in particularly high concentrations in the tips of actively growing shoots (8-12%), young leaves (4-6%) and young pods and seeds (4-5%). Although mimosine is the toxic agent in the plant, it is not usually the toxic agent which causes problems in the ruminant. This is because when leucaena leaves are chewed by cattle, part of the mimosine is converted to 3-hydroxy-4(1H)-pyridone (DHP) by enzymes which occur in the plant material. The bolus material reaching the rumen may then have approximately 30% of the mimosine converted to DHP (Lowry *et al.* 1983). Further conversion occurs in the rumen by bacteria so that, within a short time of entering the rumen, most of the mimosine is converted to 3,4 DHP. When animals are fed dried leucaena material, the enzymatic conversion of mimosine to DHP does not occur when the plant material is chewed since the enzyme in the plant is rendered inactive by the heat treatment. Under these conditions, animals fed leucaena for the first time may initially excrete only mimosine in the urine. However, once the animals have adapted to eating fresh or dried leucaena, they excrete DHP. When first introduced to leucaena pastures, animals can lose hair from the switch of the tail, an effect which is caused by mimosine. However, the toxicity arising from DHP develops more slowly under field conditions and is rarely acute.

The adverse effects of a high leucaena diet include excessive salivation, goitre, depressed serum thyroxine levels (T4 and T3), depressed appetite, poor liveweight gains, ulceration of the oesophagus and rumen, hair loss, lesions on the body, poor breeding performance, the production of weak, goitrous, lightweight calves, and even death. The development of goitre in ruminants in Australia invariably follows sustained leucaena feeding. In cattle, the normal thyroid weight is about 20 g. Following leucaena feeding, thyroid enlargement is often proportional to the time the animals spend on leucaena. In the Ord Irrigation area of northwest Western Australia, thyroids may attain weights of up to 500 g over a 12 month period. Serum thyroxine levels (T4) also decline with prolonged and high leucaena intakes. The decline in serum thyroxine can be rapid if leucaena is the sole diet with levels falling from a normal value of 80 nM to about 5-10 nM in 5-6 weeks (Jones *et al.* 1978). Jones and Winter (1982) found that liveweight gain of steers over a 300 day period was linearly related to serum thyroxine levels. However, only a few of the animals showed unmistakable signs of leucaena toxicity and these animals had serum thyroxine levels less than 30 nM. Other animals with depressed thyroxine levels showed no outward signs of toxicity and yet their liveweight gain was depressed compared with animals with normal serum thyroxine levels.

Hegarty *et al.* (1979) showed that DHP is a potent goitrogen although mimosine is non-goitrogenic. It was important to know whether the depressed thyroxine *per se* was the reason for the poor performance of cattle grazing leucaena. Experiments in which goats were fed leucaena diets supplemented with thyroxine to maintain normal levels, showed that supplemented goats ate their feed more rapidly and were much more alert than unsupplemented goats.

However, they had similar voluntary feed intake and liveweight change except at extremely low serum thyroxine levels. This suggested that the circulating DHP had the major effect on feed intake, and that low serum thyroxine was associated with high levels of circulating DHP. A depression in feed intake was measured when sheep were fed lucerne chaff and infused with DHP into the rumen. In this study, feed intake declined from about 1 kg per day of lucerne chaff to 0.2 kg per day over a 6 day period. Over this period, the thyroxine levels of the animals were not depressed (Bamualim 1984).

Similar clinical signs to those reported in Australia were reported in Papua New Guinea (Holmes *et al.* 1981). These authors found that some cattle also suffered cataracts, and that heifers had extremely poor breeding performance.

Supplementation with zinc sulphate prevented the development of lesions on the bodies of the animals and improved liveweight gain but had no effect on serum thyroxine levels. Possible chelation of zinc and other metals by mimosine and DHP, where concentrations of these elements are marginal in the herbage, could explain some of the variable effects reported in different leucaena feeding experiments.

It seemed clear that in order to alleviate toxicity the amount of leucaena eaten would need to be restricted. In practice, few serious problems were encountered in the subtropics where growth of leucaena was rapid for only about 5-6 months of the year, or where access to leucaena was limited to the autumn/winter period. From pen feeding trials, it was concluded that steers receiving 30% or less leucaena in their diet encountered few clinical problems due to toxicity. Control of grazing to achieve this objective was not difficult in the subtropics. However, in the Ord River Irrigation area, even the use of rotations involving pangola grass-only pastures was not a solution to the problem (Blunt and Jones 1977).

The other approach was to limit mimosine intake by breeding low mimosine varieties of leucaena. This programme, initiated by Dr E.M. Hutton, used crosses of *L. leucocephala* with *L. pulverulenta* as the basis of a new cultivar. Unfortunately, the material bred for low mimosine was less productive than the *L. leucocephala* parent and was not suitable for release as a new cultivar (Bray *et al.* 1984). It appeared that vigour was inversely proportional to mimosine concentration in the leaves and, under the heavy grazing imposed on the irrigated pastures, the low-mimosine line declined in vigour and many plants died. Survivors had higher mimosine concentrations than the mean value for the original population, and approached the value for cultivar Cunningham.

Towards a solution

By 1979, it was apparent from reports from Hawaii and the Bahamas, and from observations in Timor with tethered cattle, that ruminants were being fed substantial amounts of leucaena without any apparent ill effect. Why was it that animals in some countries appeared to suffer no effect whereas in others severe toxicity occurred? Unfortunately, the evidence from some overseas countries was not well documented although there seemed to be no doubt about the reality of the observations. In 1979, in Hawaii, the performance of goats fed lucerne, leucaena or diets containing 50% leucaena and 50% lucerne were compared. Daily intakes of the leucaena-fed animals varied from 16 to 21 g per day of mimosine and there were no ill effects on the animals. In this experiment, appetite was maintained, serum thyroxine remained normal and thyroids did not enlarge. No lesions developed in the oesophagus and surprisingly, virtually no DHP was excreted in the urine. Some animals excreted a compound which gave a blue (rather than the expected purple) colour in reaction with ferric chloride (Jones and Megarrity 1983). These results contrasted dramatically with those from similar experiments in Australia. What was the explanation? My theory was that the animals in Hawaii possessed rumen microbes which were not present in Australia and which were capable of detoxifying the mimosine and DHP consumed by the animals (Jones 1981). The evidence from *in vitro* digestion studies indicating that rumen fluid from Australian animals did not degrade DHP whereas the rumen fluid from Hawaiian goats did, supported the theory. However, it was several years before this theory was accepted and practical results achieved.

Proving the theory

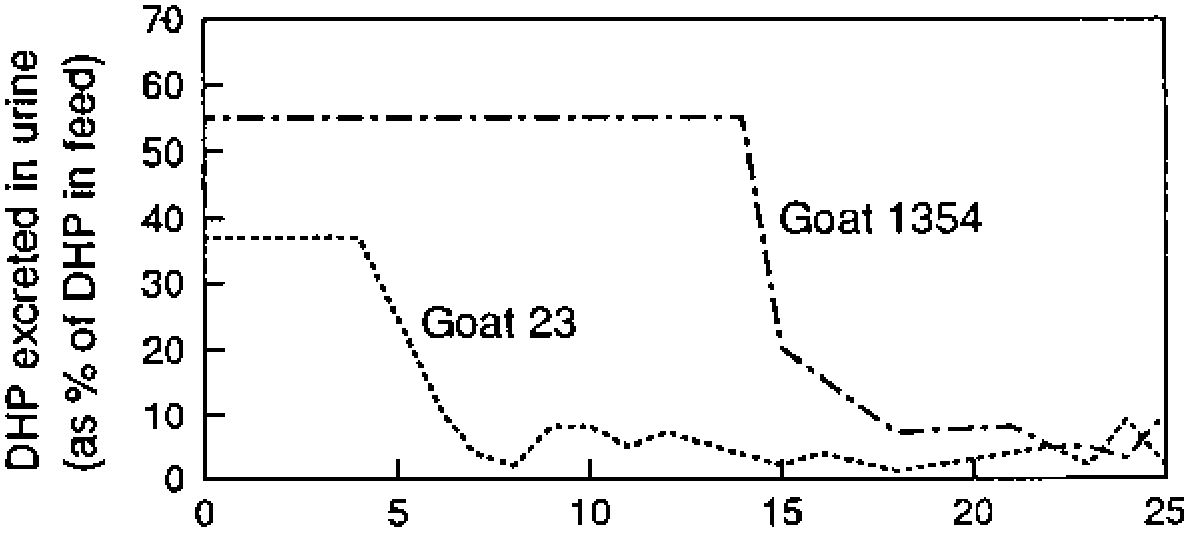
It was difficult to convince colleagues and other scientists that the reason for the difference between animals eating leucaena in Australia and Hawaii could be attributed to a rumen microorganism. Further proof was required.

Fortunately, Dr Brian Lowry and his co-workers in West Java, following the work I had done in Hawaii, also found goats capable of degrading DHP in a village in Java.

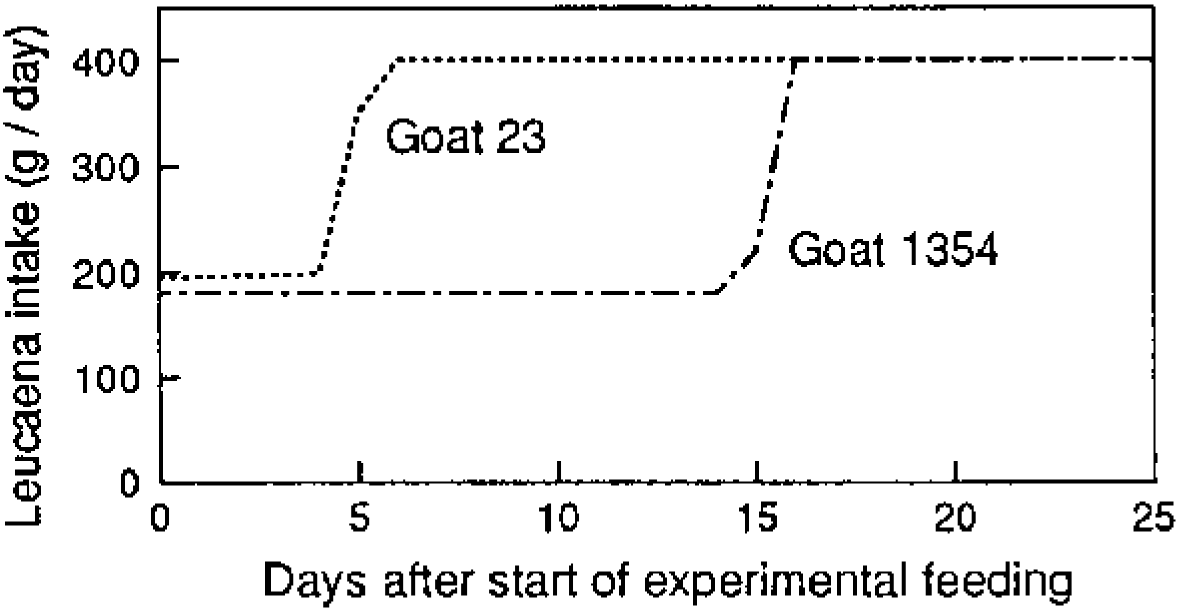
In 1981, the critical experiment was performed at Ciawi in West Java. For the experiment, four Australian goats were flown to Indonesia. They had been fed leucaena for 5 weeks before shipment and, on arrival, were fed dried Australian grown leucaena brought to Indonesia for the purpose. All four goats were fed a salt lick and separated into two pairs which were housed in separate buildings. One pair received an infusion of rumen fluid from an Indonesian goat known not to be excreting DHP when fed on a leucaena diet. The other pair were treated as controls. The results of infusion were rapid and dramatic, with DHP levels in the urine declining to virtually zero after 5 days. There was also a doubling of feed intake and, hence, of the intake of the toxic mimosine. Ten days after infusion, rumen fluid was taken from one of these goats and infused into one of the control goats. The results of this infusion were almost identical to those from the first infused goats (Figure 4.4.1).

Fig. 4.4.1. Effect of infusing Australian goats with rumen fluid from goats adapted to degrade DHP. a) Urinary DHP excretion as a percentage of the DHP equivalent of mimosine ingested. b) Leucaena intake (g dry leaf per day). Maximum offered daily was 400 g. Values prior to infusion are the mean daily output of DHP and the mean daily feed intakes respectively. Arrows indicate date of infusion from a goat able to degrade DHP.

(***a***) ***DHP excretion***



(***b***) ***Feed intake***



In vitro degradation of DHP did not occur with rumen fluid from the Australian goats prior to infusion whereas rumen fluid taken from the same animals 10 days after infusion showed rapid and complete degradation of the DHP *in vitro* within 24 h.

Getting the 'bugs' to Australia

The joint work in Indonesia (Jones and Lowry 1984) clearly showed that it was possible to introduce DHP degrading microorganisms into Australian goats but goats or rumen fluid could not be introduced into Australia for quarantine reasons. However, Hawaii did not have many of the diseases present in Indonesia. Furthermore, a culture of the microorganisms in artificial media would be easier to introduce into Australia This work was done jointly with Mr R. Megarrity.

On the island of Maui, rumen fluid from a donor goat that had been fed almost exclusively on leucaena was used to inoculate culture tubes containing growth medium and the toxins DHP or mimosine. Growth of the microorganisms in the medium occurred and the toxins were degraded. We soon discovered a population of bacteria which was essentially Gram negative rods that were responsible for the degradation. These were shown to be extremely sensitive to oxygen and so strict anaerobic conditions were essential for any work with these bacteria. On the 1st November, 1981, ten tubes each containing 9 ml of culture were introduced to the QDPI Veterinary Laboratory in Townsville, at Oonoonba where they were shown to be effective under strict quarantine conditions. Subsequently, a steer at the CSIRO field station at Lansdown near Townsville was infused with the bacteria. The animal was fed on leucaena before infusion and showed the classic signs of leucaena toxicity. Following infusion, the animal ceased excreting mimosine and DHP and its feed intake increased. For the first time, we were able to record liveweight gain of an animal eating solely leucaena over a period of several months. In a leucaena pasture, he continued to grow and achieved the remarkable liveweight gain of 275 kg in 12 months (Jones and Megarrity 1983).

Transmission of the bacteria naturally from this one animal to four other animals introduced into the same paddock occurred within a 5 week period. Activity of the bacteria was monitored by taking rumen samples and incubating these *in vitro* with a medium containing DHP or mimosine. This monitoring showed that the animals retained the ability to degrade DHP and mimosine while grazing leucaena pastures though their ability to do this was reduced when the animals were removed from leucaena. Nevertheless, after 9 months off leucaena, rumen fluid from these cattle still retained the ability to degrade mimosine and DHP *in vitro.*

Subsequent experiments at the Kimberley Research Station (KRS), in the Ord Irrigation area have shown that the bacteria can be transferred to other animals. At KRS, heifers infused with the bacteria did not exhibit the toxicity whereas control animals showed marked clinical signs of leucaena toxicity (Pratchett *et al.* 1991). At the QDPI Brian Pastures Research Station at Gayndah, steers grazing leucaena grass pastures gained 39% more weight over the 4 month period following infusion compared with controls which were not infused (Quirk *et al.* 1988). Again the infused animals ceased excreting DHP in their urine and retained normal serum thyroxine levels. In both field experiments, however, animals in the control treatments also ceased excreting DHP in their urine after about 4 months and their serum thyroxine levels began to improve. It was clear that some cross-contamination had occurred although the method was not apparent since the animals were grazed in separate paddocks and were weighed on consecutive days with a period of 4-6 weeks elapsing between the passage of the control animals through the yards.

Subsequent work (R.J. Jones, unpublished data) has shown that it is possible to obtain in *vitro* degradation of DHP and mimosine by using water extracts from dried dung samples collected in the paddocks grazed by infused cattle. It seems likely, therefore, that the bacteria were picked up from the yards which had been contaminated by dung from the treated animals. This cross-contamination effectively terminated the experimental comparison but at least it showed that the spread of the bacteria under field conditions could be rapid and so only a small proportion of the herd need be infused with the DHP degrading bacteria.

Several attempts to isolate the bacteria from water in drinking troughs situated in leucaena paddocks grazed by cattle have been unsuccessful (R.J. Jones, unpublished data). Presumably the oxygen in the water rapidly kills the bacteria in food particles which may enter the water when cattle drink.

It was a surprise to measure such a large improvement in performance at Brian Pastures since at this station there has been very little evidence of overt leucaena toxicity compared with the situation at the Ord. As noted above, however, the presence of circulating DHP can have quite a substantial negative effect on feed intake. Removal of this circulating DHP following infusion has undoubtedly led to an increased intake and corresponding improved liveweight gain.

The greatest expression of leucaena toxicity had always been observed at Kununurra in the Ord Valley of Western Australia where, under irrigation, leucaena grows rapidly and has a high mimosine concentration in its shoots and young leaves. In an experiment on well established flood irrigated leucaena in rows 4 m apart with pangola grass, six weaner steers per hectare were fattened in a 12 month period with no supplement of any kind. The results of this experiment are given in Table 4.4.1.

Practical use of the bacteria

In our experiments, cattle were infused with bacterial cultures grown in the laboratory or with rumen fluid taken from fistulated animals. In the initial experiments, we dosed cattle with approximately 300 ml of culture or rumen fluid diluted with buffer medium. Subsequently we have used a rumen injector gun to place 10 ml of culture or rumen fluid directly into the rumen from the left side of the animal. The gun is attached to a tank containing the medium or strained rumen fluid under anaerobic conditions. Valves on the tank allow us to pressurise the tank with CO_2, and to connect the gun to the tank by butyl rubber tubing. The tank containing 2 litres can then be used to infuse 200 head of cattle. Many herds in Queensland and northwest Australia have now been infused by CSIRO or the QDPI. In every case, the infusions have been successful. Furthermore, I have taken cultures of the bacteria to Ethiopia, where, at ILCA in Addis Ababa, goats and sheep were successfully infused. Similar success was achieved in China with cattle. The infused cattle ate more feed and gained 45% more weight than controls over a 38 day period (Wang *et al.* 1987).

Table 4.4.1. Summary of a grazing experiment undertaken at Kununurra Research Station using *L. leucocephala* cv. Cunningham undersown with pangola grass.

Parameter	Value
Stocking rate	6 weaner steers/ha
Gain (head/year)	237 kg (162 to 399)
Gain (ha/year)	1,442 kg
Killing out percent	54%
Carcass weight	215 kg
Age	20 months

It should be noted that prior to the use of the bacteria, steer gains were only 135 kg/steer/year at 6.2 steers/ha or 830 kg/ha/year (Blunt 1976).

Natural Distribution of the DHP Degrading Bacteria

Over the last decade we received, at the Davies Laboratory, samples of urine (1:1 vol/vol urine:conc. HCl) from ruminants fed on leucaena diets in various tropical countries. These were analysed for mimosine and its degradation products 2,3 and 3,4 DHP to assess the presence or absence of DHP degrading bacteria in the countries of origin. In addition, urine tests were made in new countries and reported to us. This enabled us to map the distribution of the DHP degrading bacteria. Distribution proved to be somewhat discontinuous as shown in Table 4.4.2.

An unusual result was obtained from Brazil where approximately 50% of samples analysed on two occasions revealed no degradation of DHP whereas the other 50% were free of DHP. Further work in Brazil showed that DHP degrading bacteria were present (Paul Rayman, personal communication).

Table 4.4.2. Distribution of DHP degrading bacteria.

Countries without the DHP degrading bacteria	Countries with the DHP degrading bacteria
Australia	Indonesia
Papua New Guinea*	Vanuatu
Fiji	Thailand
Japan	Malaysia
China	India
USA**	Seychelles
Africa:	
Ethiopia	Mexico
Nigeria	
Zaire	
Kenya	
Zimbabwe	
Tanzania	
S. Africa	

* Later samples, from the site at Lae, showed that DHP degrading bacteria were present. They were probably introduced via Javanese Zebu cattle from Indonesia (Raurela and Jones 1985).

** Dr Milton Allison (personal communication)

However, the situation in other South American countries needs to be clarified. Cattle in Paraguay appear not to have DHP degrading bacteria (Dr A. Glatzle, personal communication) whereas in Venezuela they do (Dominguez-Bello and Stewart 1990).

Isolation of the bacteria

The initial population of bacteria introduced into Australia was mixed. From this mixed culture we have now isolated pure colonies of bacteria with the ability to degrade the two isomers of DHP - 3,4 and 2,3 DHP. The bacteria are small Gram negative rods measuring approximately 1 pm x 0.5 pm. They are extremely anaerobic when actively growing, can be stored at 20℃ and will tolerate temperatures up to 50℃. Between 50° and 55℃, the bacteria are killed. Detailed work in the USA on the substrates they ferment, on their cell wall composition and rRNA sequences have clearly shown that the bacteria are not closely related to any other rumen bacterium. As a result this unique bacterium has been assigned to a new genus and species - *Synergistes jonesii* (Allison *et al.* 1992). In the laboratory they can be maintained in culture for prolonged periods (one year) without any addition of nutrients and once sub-cultured into new medium they grow and actively degrade the toxins. There is some specialisation within the bacteria in that some are capable of degrading mimosine whereas others may only degrade 3,4 DHP or 2,3 DHP. For practical purposes, I have combined two of the isolates in my cultures in order to degrade mimosine to as yet unidentified end products.

It is now known that in the degradation, mimosine is converted to 3,4 DHP then to 2,3 DHP and finally the pyridine ring is broken (Jones 1985 and unpublished data). Ring cleavage appears to be possible only at the 2,3 DHP stage.

Implications of the Leucaena Work

This work has shown firstly that secondary plant compounds such as mimosine and its degradation products can reduce the voluntary feed intake of ruminants. It would be interesting to know how widespread is the phenomenon and whether its effects can be overcome. Secondly, we have shown that rumen bacteria are not ubiquitous. We may well ask are there other rumen bacteria available overseas which would benefit the animal industries of Australia? In particular, there may be other plant toxins, such as indospicine in *Indigofera* and oestrogenic compounds found in clovers, which may be overcome by the use of suitable introduced rumen bacteria. It may also be possible to improve the utilisation of low quality forages by using better adapted rumen microbes or rumen microbes that may have been manipulated in some way to improve their ability to degrade plant fibre.

Other work, based at the University of New England at Armidale, seeks to develop bacteria to detoxify fluoroacetate. This toxin is responsible for stock poisonings following ingestion of the native leguminous trees *Acacia georginae, Gastrolobium* spp. and *Oxylobium* spp.

It has also been shown that goats grazing *Acacia* shrublands have populations of bacteria which can metabolise tannic acid. Transfer of rumen fluid from these goats to sheep fed *Acacia aneura* resulted in an increase in the digestibility of the protein (Matthew *et al.* 1991) (see Section 4.6).

Improved dry matter digestibility of the tannin-containing tropical shrub legume *Calliandra calothyrsus* in Dacron bags in the rumen of sheep also occurred when rumen fluid from goats grazing shrubs was infused into their rumens (Palmer and Minson 1993).

These examples clearly indicate a potential to reduce the effects of anti-nutritive factors in forage plants and so improve feeding value to ruminants by the use of introduced rumen microorganisms. The successes thus far have followed the use of naturally occurring organisms. In the future, the scope for improvement may well be extended by the use of genetically modified microorganisms.

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4.5 The Role of Leucaena in Improving the Productivity of Grazing Cattle

R.M. Jones

Introduction

Agronomists and farmers have recognised for decades that leucaena (*Leucaena leucocephala*) offers considerable potential for improving the productivity of cattle. Trials carried out by the University of Hawaii in the 1930s showed the value of feeding leucaena to both beef and dairy cattle (Henke 1933, Henke *et al.* 1940).

There are a number of reasons why leucaena has obvious potential for use in improving the productivity of grazing cattle:

- It is a very persistent legume under cutting or grazing. Planted on appropriate sites and given reasonable management, plants can survive for decades (Jones and Harrison 1980).

- Its productivity is frequently higher than that of alternative legumes. For example, in southeast Queensland Hutton and Bonner (1960) measured 11,000 kg/ha of edible dry matter over a 9 month (spring to early winter) period. This yield cannot be approached by other legumes in this region.

- Leucaena recovers rapidly from defoliation.

- Leucaena has high quality forage (Section 4.1), with the exception of the problems associated with mimosine (Section 4.4), and is readily eaten.

- Leucaena growth can be managed to accumulate high quality feed to meet the varying feed needs of different farm enterprises. For example, Isarasenee *et al.* (1984) and Addison *et al.* (1984) measured 4 and 5 t/ha of edible material of cv. Peru in southeast Queensland after 3 and 6 month growing periods respectively.

- Leucaena is grazed with minimal losses due to trampling or fouling and plants are not unduly damaged by grazing animals.

- Until the advent of the psyllid (Section 6.1), leucaena was relatively free of pests or diseases.

- Leucaena grown in rows combines well with companion grasses grown in the inter-row.

With these advantages, it is not surprising that many studies have been carried out on the effect of feeding leucaena, in pens or in situ, on a wide range of animals including cattle, sheep, goats, buffalo, pigs, deer, rabbits and poultry. Although this discussion is restricted to grazing cattle, much of the information will apply to 'cut-and-carry' feeding systems. Three areas of cattle production will be considered: liveweight gain, milk production and reproduction. Within each of these areas, there are occasional difficulties in interpreting studies where no information was provided regarding health problems associated with mimosine or, more importantly, DHP (see Section 4.4). As these problems can now be avoided, the benefits of leucaena may have been underestimated. In some cases, the carrying capacity of leucaena may have been over-estimated as the intake of individual animals normally increases following inoculation with DHP degrading bacteria.

The disadvantages of leucaena, including slow establishment, intolerance of waterlogging and acid soils, presence of mimosine and susceptibility to psyllids are discussed in Chapter 3, Section 6.1 and by Anon. (1989).

The Effect of Leucaena on Liveweight Gain

Studies of liveweight gain from leucaena or leucaena/grass pastures fall into two groups. The first group comprises studies where leucaena pastures have been used as a supplement to grass-only pastures. The second group of trials comprises studies where cattle grazed mixed leucaena/grass pastures throughout the year. These two groups will be considered separately.

Leucaena pastures as a supplement

The results from 13 experiments of this type, primarily from Latin America and Australia, have been summarised in Table 4.5.1. In most cases the objective was to improve liveweight gain during the 'dry' or 'cool' season by using leucaena pastures as a supplement. This was achieved by having a proportion of the total land area established to leucaena or by controlling the number of hours per day that cattle grazed a small area of leucaena. In some cases it was not stated if the leucaena was an additional land area to the grass pasture; if this was the case, cattle grazing the leucaena plus grass treatment would have been on a slightly larger area than when grazing the grass only treatment.

The increases in liveweight gain of animals given access to leucaena varied widely. This was expected in view of the differences in the quantity and quality of the base grass pasture and the amount of leucaena on offer. Other limiting factors in the experiments could be plant related (e.g. low sodium concentrations) or animal related (e.g. worm infestation restricting liveweight gain). Overall, there was a 70% or higher increase in liveweight gain in eight out of the 15 comparisons listed in Table 4.5.1. There was only one experimentwhere there was no advantage from the leucaena supplement (Carvalho Filho *et al.* 1984) and this was attributed to the high protein content of the base pasture and the low availability of leucaena at the end of the trial. In contrast, replacing 20% of *Dicanthium caricosum* pasture by leucaena in Fiji more than doubled liveweight gain (Partridge and Ranacou 1974). Falvey (1976a) reported an advantage from grazing of leucaena as a supplement but this comparison is not listed in Table 4.5.1 as the base pasture included a vigorous legume, Townsville stylo (*Stylosanthes humilis*).

Table 4.5.1. Liveweight gains (LWG) of cattle grazing either grass pastures with or without access to leucaena.

Grass species	LWG (kg/head/day)		Access to leucaena	Period of year (days)	Reference*
	-leuc	+leuc			

Native pasture	0.59	0.70	25% leuc. on area basis	sp,su (130)	1
Native pasture	0.22	0.39	4 hours/day	win (100)	2
Native pasture	0.18	0.33	25% leuc. on area basis	win,sp (160)	3
Native pasture	-0.15	0.16	25% leuc. on area basis	aut,win (180)	4
Native pasture	0.23	0.51	6% leuc. on area basis	sp,sum,aut (224)	5
Native pasture	0.25	0.35	25% leuc. on area basis	year (365)	6
Native pasture	0.25	0.56	100% leuc. on area	year basis (365)	6
Cenchrus ciliaris	0.6	0.6	10 or 20 hours/week	cool season (200)	7
Brachiaria decumbens	0.49	0.64	4 hours/day	dry season (120)	8
Hyparrhenia rufa	0.27	0.35	10% leuc. on area basis	dry season (155)	9
Cynodon plectostachyus	0.29	0.41	4 hours/day	dry season (252)	10
Dicanthium caricosum	0.21	0.50	20% leuc. on area basis	year (365)	11
Pennisetum clandestinum	0.07	0.34	3 hours/day	aut,win (90)	12
Panicum maximum	0.52	0.67	30% leuc. on area basis	rainy season	13
Panicum maximum	0.18	0.37	30% leuc. on area basis	dry season	13

* References: 1. Quirk *et al.* (1988); 2. Gandara *et al.* (1986); 3. Foster and Blight (1983); 4. Addison *et al.* (1984); 5. Zoby *et al.* (1989); 6. Quirk *et al.* (1990); 7. Carvalho Filho *et al.* (1984); 8. Paterson *et al.* (1982); 9. Paterson *et al.* (1983); 10. Palomo *et al.* (1980); 11. Partridge and Ranacou (1974); 12. Zacharias *et al.* (1991); 13. Castillo *et al.* (1989)

The general conclusion from these studies is that supplementary grazing of leucaena can substantially improve liveweight gain over that from pure grass pastures. The increase will be greatest when the base grass pasture is low in quality and when the intake of leucaena is high (assuming that DHP degrading bacteria are present). A doubling of liveweight gain is a reasonable target.

Liveweight gain from leucaena based pastures

Several experiments were carried out in northwest Australia and Papua New Guinea during the 1970s when there were obvious harmful effects of DHP on animal health associated with grazing leucaena with corresponding low liveweight gains (e.g. 0.29 kg/head/day reported by Blunt and Jones (1977)). In Papua New Guinea, even though animals were showing obvious toxicity symptoms, they still gained at 0.38 kg/head/day, only slightly lower than on buffer grass (0.44 kg/head/day) (Holmes 1979).

In situations where there have been no clinical signs of DHP toxicity, animal production from leucaena/grass pastures was appreciably higher than that from pastures of the same grass species (Table 4.5.2). Even higher liveweight gains have been reported for shorter periods, e.g. 0.8 kg/head/day over 115 days (Cardoso 1986), 0.9 over 200 days (Jones 1979), 0.9 over 168 days (Clem *et al.* 1993), 0.7-1.3 over 57-146 days (Rakuita *et al.* 1992) and 1.1 over 90 days (Wildin 1986). These gains are higher than those listed in Table 4.5.1, none of which was above 0.7 kg/head/day. They generally reflect use of leucaena during the growing season, with high levels of leucaena on offer, as compared with the restricted access to leucaena, usually during the dry season, in the experiments listed in Table 4.5.1.

In one study, year-long grazing of leucaena/grass pasture on 100% of the area was compared with both grass-only pasture and with year-long grazing on 25% leucaena/75% grass pasture (Quirk *et al.* 1990). Results showed that although 25% of leucaena on an area basis improved liveweight gain, 100% of leucaena/grass pasture gave even better gains.

Several authors have noted that gains from leucaena pastures compare favourably with those from other grass/legume or even nitrogen fertilised pastures. Wong and Devendra (1983) reported gains from leucaena/Guinea grass (*Panicum maximum*) pastures in Malaysia equal to or greater than those from nitrogen fertilised pastures or from a Guinea grass/herbaceous legume mixture. Jones and Jones (1982, 1984) found that in subtropical southeast Queensland, leucaena/grass pastures produced from 310 to 430 kg liveweight gain/ha. These gains were approximately double those from Siratro (*Macroptilium atropurpureum*) based pastures on the same soil type, Siratro being the best alternative commercially available tropical legume, and equal to those from nitrogen fertilised pastures on the same soil type (Jones and Jones 1980). Following inoculation of cattle with DHP degrading bacteria, irrigated leucaena/pangola grass pastures in northwest Western Australia have produced 1,420 kg of liveweight gain/ha/year compared with 1,330 kg from irrigated pangola grass fertilised with 330-600 kg/ha/year of nitrogen (Jones and Megarrity 1985). As shown in Tables 4.5.1 and 4.5.2, the consistent increases in liveweight gain achieved by including leucaena in grass pastures have been obtained from a wide range of grass species.

Table 4.5.2. Liveweight gains (LWG) from cattle grazing grass only and leucaena/grass pastures (stocking rate as head/ha in brackets).

Grass species	**LWG (kg/head/day)**		**Duration of experiment**	**Reference***
	- leuc.	**+ leuc.**	**(days)**	
Native pasture	0.25 (0.7)	0.56 (0.7)	365	1
Imperata cylindrica	0.22 (0.75)	0.36 (1.5)	315	2
Digitaria decumbens	0.39 (3.3)	0.49 (3.3)	364	3

* References: 1. Quirk *et al.* (1990); 2. Moog (1983); 3. Garza *et al.* (1978)

There have been differing reports about yellow pigmentation in fat of cattle that had grazed leucaena prior to slaughter. Markedly yellow fat was observed in carcasses of Hereford cattle that had grazed leucaena/grass pastures at Samford, southeast Queensland (RJ. Jones, personal communication). In contrast, carcasses of crossbred cattle that had grazed irrigated leucaena/grass pastures for 11 months prior to slaughter in the north of Western Australia had a fat colour score of only 2.6 on a scale of 1 (white) to 6 (dark yellow) (Pratchett *et al.* 1992). In a similar study from this environment, only 4% of carcasses were rejected because of yellow fat (Ryan *et al.* 1992). The meat from carcasses in both these studies was rated by both quality measurements and consumer testing to be suitable for the Western Australian table market.

The Role of Leucaena in Improving Milk Production

Leucaena has considerable potential for incorporation into feeding systems for dairy cows in the tropics and subtropics. Leucaena is suited to cut-and-carry operations or, given adequate labour or mechanical equipment, can be harvested and fed in pens. Alternatively, small areas of leucaena can be grazed as convenient, e.g. for a specified time after morning milking. Grazing can be controlled by electric or temporary fencing, by herding or by careful tethering. One limitation of feeding leucaena to dairy cows is that it has been reported to produce a taint in milk (Henke 1958) which is not removed by pasteurisation (Stobbs and Fraser 1971). However, Hamilton *et al.* (1969) found that the taint could be removed by pasteurisation.

The results of experiments, primarily from Latin America, where leucaena has been fed to dairy cows are summarised in Table 4.5.3. In each case, the base grass pasture was fertilised with nitrogen. In some experiments, the leucaena was grown in an additional area to that of the main grass pasture, whereas in others (e.g. Milera and Santana 1989) the areas of the grass and grass + leucaena treatments were equal. Base concentrates were fed in some experiments, but not in others.

The average increase in milk production obtained from feeding leucaena was 14% (range of 2-33%). Where recorded, there was usually an increase in fat and protein % as well. In Malaysia, Hassan *et al.* (1989) measured a higher milk production/from grazed *Brachiaria decumbens/leucaena* pastures (6.1 kg of milk per day) than from cows on 'cut-and-carry' feeding of the same pasture mixture (4.8 kg/day). Milk production from the grazed Brachiaria/leucaena pastures was also higher than from grazed *Setaria sphacelata* fertilised with 300 kg/ha of N (4.9 kg/day).

Milera and Santana (1989) mentioned other advantages of leucaena viz. cows fed leucaena ate less concentrate and nitrogen fertiliser requirements were reduced. Saucedo *et al.* (1980) also recorded higher liveweight gains from cows and calves grazing the grass pasture supplemented with leucaena

Table 4.5.3. Increases in milk production achieved in experiments where leucaena was fed as a supplement to pure grass pastures.

Grass species	**N rate (kg/ha/year)**	**Increase in milk prod'n from leucaena (%)**	**Experimental details**	**Reference***
Cynodon plectostachyus	200	2	3-4 h leucaena grazing	1
Chloris gayana	115	7	fresh leucaena fed in pens (2-4 kg/day)	2
Panicum maximum	150	12	morning grazing of leucaena	3
Cynodon dactylon	?	16	6 h leucaena grazing	4
Digitaria decumbens	239	33	2 h leucaena grazing	5

* References: 1. Ruan and Pino (1981); 2. Flores *et al.* (1979); 3. Milera and Santana (1989); 4. Saucedo *et al.* (1980); 5. Suarez *et al.* (1987)

However, even with the provision of leucaena, milk production is likely to be limited by feed quality. For example, Suarez *et al.* (1987) recorded a 33% increase in milk production from supplementary grazing of leucaena, and a 57% increase from supplementary feeding of 6 kg of concentrate per cow per day.

There are few reports where milk production was measured from cows whose main feed supply was leucaena/grass pastures or leucaena alone. Stobbs (1972) measured 6,290 kg of milk and 272 kg fat per hectare from Jersey cows grazing a leucaena/green panic (*Panicum maximum* var. *trichoglume*) pasture. In Hawaii, Plucknett (1970) reported that Friesian cows grazing leucaena/Guinea grass pastures, with some supplement, produced 9,780 kg milk/ha. Also in Hawaii, Henke and Morita (1954) produced 5,130 kg of milk per cow over a 305 day lactation from cows fed an average of 28.5 kg of fresh leucaena a day with an additional low protein supplement. Henke (1958) compared the financial returns from milk production of cows fed cut leucaena or nitrogen fertilised Napier grass (*Pennisetum purpureum*). Both systems were profitable, but their relative superiority depended on factors such as the costs of nitrogen fertiliser, protein concentrate and land.

As for liveweight gain, the additional benefits from feeding leucaena will obviously vary with the nutritional status of the base pasture and the amount of leucaena fed. For example, the response to leucaena obtained by Milera and Santana (1989) could be anticipated as their associated grass had only 13% crude protein in the leaves and 8.5% in the stems compared with 24.5% in the leucaena; c. 13% crude protein is marginal for dairy production. However, Flores *et al.* (1979) recorded benefits from feeding leucaena where the grass contained 18% crude protein and the intake of leucaena was only 0.82 kg DM/cow/day.

Flores *et al.* (1979) concluded that leucaena provided some protection of protein against degradation in the rumen. Hence the benefits of feeding leucaena are, in part, similar to those achieved from feeding protected protein such as formaldehyde treated casein. However, the possibility of leucaena providing a higher intake of digestible energy should not be overlooked.

The Effect of Leucaena on Reproduction in Cattle

Grazing studies on the effect of leucaena on reproduction of cattle in Australia and Papua New Guinea, carried out in the absence of DHP degrading bacteria, contrast markedly. Holmes *et al.* (1981) recorded a very detrimental effect in Papua New Guinea where only one out of ten heifers grazing leucaena became pregnant over a 7 month mating period. In northwest Australia, where DHP toxicity was severe, most cows which grazed leucaena during the wet season had stillborn calves (Jones *et al.* 1976). Jones *et al.* (1989) in southeast Queensland recorded a much less severe depression, with a calving percentage of 66% for cows grazing leucaena/grass pastures year-long compared with 88% in an equivalent herd grazing grass-only pastures. Falvey (1976b) recorded a slight reduction in calving percentage from 75% (six out of eight heifers) to 63% (ten out of 16) in animals that had access to leucaena, while Cooksley *et al.* (1981) recorded a calving percentage of 71% from cows grazing native pasture supplemented with urea/molasses and 76% from cows grazing native pasture with some leucaena. There have been reports of calves from cows fed on leucaena having a lower birth weight (e.g. Hamilton *et al.* 1971).

These differences are best ascribed to the proportion of leucaena in the diet, particularly during early pregnancy (Holmes *et al.* 1981). The studies of Holmes *et al.* were carried out on almost pure leucaena stands. In the trial of Jones *et al.* (1989) leucaena comprised c. 40% of the diet during the summer months, the main period of leucaena growth, and cows grazed leucaena/grass pastures year-long and were mated in late spring. In the study of Cooksley *et al.* (1981), leucaena was grazed only from June to November (winter and spring), when mimosine levels were low and cows were not mated till December when they were not grazing the leucaena pastures.

Preliminary evidence from northwest Australia suggests that inoculation with DHP degrading bacteria prevented abortion which otherwise occurred in heifers grazing a diet high in leucaena (Pratchett *et al.* 1991). Moreover, in the early Hawaiian studies there was no adverse effect on reproduction (Henke 1958, Henke and Morita 1954, Plucknett 1970). Presumably DHP degrading bacteria, later isolated from Hawaiian goats (Section 4.4), were present. This also suggests that the adverse effect of leucaena on reproduction reported by Holmes *et al.* (1981) could be attributed to DHP.

Grazing Management of Leucaena

Conceptually there are two ways to graze leucaena. Trees can be allowed to grow above the grazing height of cattle. The lower parts of leucaena trees can then be grazed continually and cattle can also graze seedlings which develop from seed set above grazing height (Wildin 1986). The forage above grazing height can be kept as a drought reserve. However, this forage may lose quality through senescence and from infestation by mould. In some situations, tree leucaena has weed potential due to the high amounts of seed set.

Alternatively, plants can be grazed as hedgerows to keep the whole canopy within grazing height (Figure 4.5.1). The inedible framework of woody stem is kept to approximately 1.0-1.5 m in height and cattle graze the edible material developing from this. Hedgerow leucaena is a more efficient way of utilising leaf than tree leucaena. Where there is full utilisation of leucaena from high stocking rates, some form of rotational grazing with rest periods of 4-12 weeks may be necessary for part of the growing season.

Fig. 4.5.1. Leucaena grazed as a hedgerow is kept within grazing height.

In practice, most commercial stands of leucaena in Queensland are now kept within grazing height. Some are rotationally grazed (Clem *et al.* 1993) while others are continuously grazed for extended periods of time. This may follow a period of spelling which enables the yield of leucaena to accumulate. Provided that thick stems, greater than c. 2 cm, are not allowed to develop, cattle seeking out edible material at the top of the canopy can break stems and keep the leucaena at grazing height. Bulls are particularly effective at breaking down thick stems. If there are too many thick stems bearing edible material above grazing height, these stems can be cut back mechanically or by hand.

In frosted areas, leaf and sometimes above-ground stem may be killed in some or all years. This will influence when the stand should be grazed; edible material should preferably be grazed in autumn before the onset of frosts. Stands should then be leniently managed in spring and early summer to allow the inedible framework to form again.

In subtropical Queensland, leucaena is frequently used to fatten animals from the middle to the end of the growing season. Later grazing using weaners or breeders over winter is a common practice (Wildin 1986). The area of leucaena required to make an impact on farm production will depend on factors such as the number of animals to be fed, length of grazing period, productivity of leucaena and the target growth rates of animals.

In the dairy industry in subtropical Australia, the potential role of leucaena is probably to provide high protein feed in autumn, before irrigated ryegrass is available and when the quality of tropical grasses is low. It is possible to estimate the area of leucaena that may be required to make a useful impact. Assume, for example, that there are 100 dairy cows which are strip grazed and consume approximately 8 kg of fresh material (c. 1.6 kg of dry matter) per day over a 2 month period. This requires 1.6 x 100 x 60 or 9,600 kg of leucaena. Given that leucaena can accumulate to give 3,500 kg of edible dry matter per hectare, which is harvested with 80% efficiency, this requirement could be met by 3.4 ha of leucaena. The same form of calculations can be used to estimate areas for a beef cattle property, but in that situation there is much less scope for controlling the daily intake of leucaena.

Conclusions

All the evidence presented demonstrates the high potential of leucaena to improve meat and milk production from grazing cattle. There is no need for further formal research work to document this general finding about the role of leucaena in animal production. However, further 'developmental' or on-farm research, experience or demonstration will often be required to develop ways to utilise leucaena most efficiently in commercial practice and to encourage farmers and graziers to use it (e.g. Clem *et al.* 1993). The optimum procedures will vary with many factors from farm to farm, region to region and country to country (see Chapter 7).

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4.6 The Role of Acacia aneura in Animal Production

S.M. Miller

Introduction

Approximately 13 million sheep are grazed in Queensland. Of these, six million are in the southwest region of the state, producing 42% of the state's wool clip. These figures indicate the important contribution of this area to the Queensland wool industry. The major limitation to stable wool production is frequent droughts which characterise the region (Pritchard and Mills 1986). During extended dry periods, the dominant native grasses are unable to fully support animal production. Drought management consequently focuses on progressive destocking, supplementary feeding of retained animals and, in some circumstances, not joining ewes during the drought period.

The major drought forage available in southwest Queensland is the leaf of the mulga tree (*Acacia aneura*). Mulga was first reported to have been successfully used to maintain a flock of 60,000 sheep through a drought of two and a half years in 1886 (Everist 1949). It has both tree- and shrub-like habits and can provide a maintenance diet for sheep and cattle.

The mulga lands occupy approximately 150 million hectares across Australia and represent a large reserve of usable supplementary feed (McMeniman and Little 1974). Confined to areas of rainfall between 200 and 500 mm (Gartner and Anson 1966), mulga grows predominantly in brown and red/brown fine sands and sandy loams (Everist 1949). These soils become hard and dusty when dry and are characterised by a hardpan 30-120 cm below the surface. This feature facilitates water retention in the subsoil for long periods, a major reason for the successful adaptation and colonisation by mulga of these dry areas. The additional feature of highly sclerophilised leaves aids in water retention. Many other plant species grow in association with mulga stands including other native trees, shrubs and grasses (Everist 1949).

Four types of mulga are present in this region. Umbrella shaped mulga is most commonly used for drought feeding. Its high leaf yield and low tree density make it suitable for continuous lopping without destruction of the tree. Whipstick mulga is the name given to dense stands of immature thin trees. Utilisation is best achieved by pulling the stand with chains between tractors. Tall mulga cannot be lopped due to its tall bare trunk. Consequently, felling is the only practical means of utilisation (Goodchild and McMeniman 1986, (Figure 4.6.1). Low shrubby mulga provides useful fodder despite its relatively low leaf yield. In dense stands, lopping of low mulga is uneconomical. Consumption of fallen leaves and pods is mainly restricted to good stands of tall mulga.

Value of Mulga

Phosphorus and energy

Although a successful drought forage, a number of problems have been highlighted during sustained feeding of mulga. Based on chemical composition determinations, Harvey (1952) and Everist *et al.* (1958) established mulga as a maintenance feed only, despite its apparent high crude protein content (10-14%). Rohan-Jones *et al.* (1972) concluded from digestible energy, CO_2 entry rate and rumen fluid volatile fatty acid determinations, that mulga-fed animals were in a negative energy balance.

For these reasons much of the early work concentrated on energy and mineral supplementation to lift the value of mulga above that of a maintenance diet. Everist *et al.* (1958) and Gartner and Anson (1966) established that phosphorus supplementation was essential to maintain a positive phosphorus balance in grazing animals since low levels resulted in mobilisation of skeletal phosphorus reserves. Little and McMeniman (1973) subsequently used the measure of bone phosphorus deposition in the ribs of sheep as an indicator of nutrient status and made recommendations regarding the need for additional mineral supplementation. McMeniman and Little (1974) showed that phosphorus supplementation of sheep increased dry matter intake (DMI), wool growth and liveweight Supplementation with molasses overcame the energy deficiencies of mulga and an additive effect was observed when phosphorus and molasses were fed together (McMeniman 1976).

Subsequently, Entwistle and Baird (1976) demonstrated that it was primarily the mineral component of molasses that resulted in increased production. They found that 66% of the response obtained when feeding 200 g/day molasses was achieved with the first 50 g/day. This appeared to eliminate energy as the major contributing factor although there were still significant differences between liveweight gains on 200 g/day and on 50 g/day of molasses.

Sulphur and other minerals

Hoey *et al.* (1976) established that sulphur in molasses was responsible for approximately 50% of the response gained from the first 50 g/day. This conclusion was supported by Gartner and Niven (1978), who found that sulphur supplementation increased DMI (38%) and wool growth (45%). Sulphur in the form of $CaSO_4$ produced the most significant (Hoey *et al.* 1976) and calcium was shown not to be involved (Gartner and Niven 1978). The other minerals present in molasses (calcium, copper, zinc, manganese, sodium, iron, magnesium and potassium) had no significant effect on production (Hoey *et al.* 1976). The primary mode of action of the supplements in increasing production was through increased DMI and not increased digestibility (Harvey 1952, Niven 1983).

Fig. 4.6.1. Sheep grazing felled mulga in the Charleville region.

Nitrogen

McMeniman *et al.* (1981) measured rumen ammonia levels of 3.94.7 mg/100 ml in sheep on high mulga intakes, levels below the 5 mg/100 ml necessary for efficient rumen function (Satter and Slyter 1974), suggesting that the supply of intestinally available protein was inadequate. Nitrogen, made available as cotton seed meal, increased DMI and dry matter digestibility of mulga with subsequent increases in liveweight and wool growth. However, a urea supplement produced no response in mature sheep (Entwistle and Baird 1976) and a limited response in young sheep (McMeniman *et al.* 1981), thus suggesting that a true protein source is necessary to maintain the condition of animals on a mulga diet (Niven and McMeniman 1983). Protein supplementation has the additional benefits of increasing reproductivity and lamb survival.

Tannins

Chemical analyses of mulga showed that nitrogen and sulphur were present at adequate levels. Gartner and Hurwood (1976) subsequently reported that the presence of tannin (7-10%) was reducing mineral availability by complexing with leaf protein following maceration of the leaf tissue. Tannins are secondary metabolites with a high capacity to form complexes with proteins. These complexes are stable at rumen pH and remain undegraded in the rumen, resulting in reduced protein availability, thus limiting animal production.

There are two types of soluble tannins present in a large number of plant species. These are the hydrolysable tannins (HTs) and the non-hydrolysable or condensed tannins (CTs). HTs are characterised by a central carbohydrate core with a number of phenolic carboxylic acids bound by ester linkages. As a direct consequence of their polyester structure, the molecules can be hydrolysed into simpler fragments (McLeod 1974). HTs are present in many plants and have been shown to be responsible for growth inhibition of agriculturally important animal species. Unlike HTs, CTs have no carbohydrate core, but rather they are derived from the condensation of flavonoid precursors without participation of enzymes. CTs are more widely distributed in higher plant species than the hydrolysable variety and are thought to be more active in precipitating proteins. Since mulga contains mainly CTs, the remainder of this review will refer to this class of tannins.

Reversible associations are formed between CTs and many other substances (for example, alkaloids and proteins), with an affinity determined by both molecular mass and molecular configuration (McManus *et al.* 1981, 1985). The affinity for substances increases with increasing molecular weight. Such bonding is dynamic with individual linkages being broken and reformed randomly and continuously (Barry and Manley 1986, McLeod 1974). Griffiths (1982) demonstrated that interactions are pH dependent with complexes becoming unstable at both high and low pH.

Maceration of plant material results in the formation of tannin:protein complexes and the creation of a dynamic pool of free CTs. Tannins in this pool are responsible for the inhibition of enzymes, microbes and proteins in the digestive tract. Barry and Forss (1983) define the pool of free CTs as that which has exceeded the binding capacity of plant proteins. This pool is interchangeable with the tannin:protein complexes. These tannins influence plant matter digestibility, acting in a number of ways to achieve this (McLeod 1974, Schaffert *et al.* 1974, Barry 1989, Horigome *et al.* 1988):

- by interfering with digestive through the formation of tannin:enzyme complexes (Feeney 1969),
- by interfering with digestive enzymes through the formation of substrate protein:tannin complexes (Makkar *et al.* 1988),
- by combining with proteins in the gut wall and preventing nutrient uptake (McLeod 1974), and
- by inhibiting the growth and enzyme activity of rumen fungi, protozoa and bacteria (Akin 1982, Akin and Rigsby 1985, Makkar *et al.* 1988).

Each of these mechanisms contributes to reduced animal production.

Supplements for mulga

Energy and minerals

Dry mixes are a cheap and easy way to provide supplements of nitrogen, phosphorus and sulphur. One to two grams of each mineral is required per sheep daily. Dicalcium phosphate, sulphate of ammonia and double superphosphate are used as the sources of minerals in a dry mix. Salt should be fed for the first 10 days as a safety precaution. If the animals have a salt craving, premature introduction to the dry mix may result in accidental death due to over-consumption of the lick with resultant nitrogen toxicity. The dry mix is fed in open ended troughs and made available to the animals at all times.

Intake of the mineral mix will vary among individual animals, paddocks and class of sheep. If intake is not optimal, consumption can be increased by the addition of molasses or water, or reducing the amount of phosphorus supplement. Reducing the salt content will reduce intake. The dry mix and associated feeding techniques are also suitable for cattle. Pregnant and lactating ewes, and sheep in poor condition may require additional energy and protein supplements. Molasses and a suitable protein meal are commonly used for this purpose.

The main effect of these dry mix supplements is to increase intake of mulga thus increasing the supply of nutrients to the sheep. Death rates are considerably reduced in supplemented compared with non-supplemented animals.

Polyethylene glycol

While feeding polyethylene glycol (PEG) as a marker substance in tannin feeding studies, Jones and Mangan (1977) observed that DMI and nitrogen digestibility were significantly increased in both sheep and cattle. Rowan and Lawrence (1986) also measured increases in the growth rate of pigs when fed soybean meal supplemented with PEG. PEG was found to bind tannins and preferentially displace protein from existing tannin:protein complexes. The net effect was an increase in the available digestible protein, resulting in an increase in nitrogen digestibility. The PEG:tannin complex is very stable and is unlikely to be broken down during passage through the digestive tract.

The dramatic increase in intake observed during supplementation with PEG is likely to be due to two factors. The immediacy of the increase may be an effect of PEG on the taste sense of the animal. PEG may, upon entering the mouth as a consequence of rumination, bind the tannins, breaking the tannin:receptor bond similarly to tannin:protein complex displacements. This would reduce the astringent nature of the fodder thus encouraging a rapid increase in intake. The second, longer term factor is the increase in microbial activity produced as a result of the increased levels of available protein in the rumen. This would lead to increased rumen digesta flow and hence intake. Despite the increases in intake, nitrogen digestibility and wool growth attributable to PEG, increases in liveweight have not been as great as those achieved with molasses supplementation (Entwistle and Baird 1976). Supplementation with both PEG and molasses maximises all of these factors (Pritchard *et al.* 1988, Eady *et al.* 1989).

Due to the cost of PEG it has not been used as a commercial supplement for sheep consuming mulga. Consequently, there is a need for cheaper alternative chemicals that will mimic all or some of the actions of PEG. Studies conducted at Charleville during 1990 were unable to identify an alternative compound. These studies are continuing as more chemicals become available.

New Directions

Microbial alternatives

The diverse and dynamic population of microorganisms in the rumen presents an alternative, long-term solution to the problems associated with tannins. The detoxifying capabilities of rumen bacteria have long been exploited by animals to allow grazing on otherwise unproductive pastures. The ability of goats to survive on a mimosine-rich diet in Hawaii, one considered toxic in Australia, was recognised and has led to the isolation of DHP degrading bacteria. Inoculation of cattle with these organisms has enabled the utilisation of mimosine-rich leucaena pastures in northern Queensland (Jones and Megarrity 1986) (Section 4.4). The possibility therefore exists for suitable tannin degrading microorganisms to be isolated from adapted animals and transferred to the rumen of sheep and cattle. Bacteria capable of breaking down tannin:protein complexes have only recently been reported (Osawa 1990). Current studies at the Charleville Pastoral Laboratory have identified tannin degrading bacteria in the rumen of feral goats (Matthew *et al.* 1991). Further investigations are under way to assess production effects attributable to these bacteria when introduced into the rumen of sheep.

A second, longer term alternative is genetic engineering of rumen bacteria to degrade tannins. This may be achieved through the modification of pre-existing anaerobic degradative pathways or introduction of genes from anaerobic microorganisms incapable of effectively the rumen. Alternatively, genes for tannin degradation may be found in aerobic microorganisms such as soil-borne organisms inhabiting mulga leaf fall areas.

Summary and Conclusions

Mulga represents a significant reserve of forage for sheep and cattle, particularly during droughts. Mulga is deficient in nitrogen, phosphorus, sulphur and energy, and supplementation is necessary to maintain animal condition during prolonged feeding. The presence of tannin in the mulga leaf exacerbates the mineral deficiencies.

The tannin binding properties of PEG offer an opportunity to obtain large increases in animal production with minimal supplementation. However, cost is a limiting factor, as PEG is too expensive to be used at the levels necessary to obtain significant production increases. Therefore, economic alternatives must be found.

Long-term approaches include the isolation of suitable tannin degrading microorganisms from successfully adapted native and feral animal species and colonisation of these microorganisms in the rumen of sheep and cattle. Alternatively, genes c engineering of existing rumen bacteria to degrade tannins may be achieved by modifying existing degradative pathways or through identification and transfer of suitable genes enabling tannin degradation. These approaches will minimise the need to supplement animals on mulga diets while maximising survival and wool production.

Further research into the area of tannin:protein interactions in animals fed mulga may therefore lead to increases in feeding efficiency at minimal cost to the grazier.

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5.1 The Use of Tree Legumes for Fuelwood Production

P.A. Ryan

Introduction

Fuelwood is the cheapest fuel available per unit of heat in most developing countries. The annual use of fuelwood has been estimated at 1,200 million cubic metres worldwide (Arnold and Jongma 1978). Fuelwood can be harvested on demand and is easily stored and dried. It can be produced from most tree species and from a wide range of silvicultural systems. However, if fuelwood production is a primary management aim of tree planting, a variety of factors needs to be considered to optimise both the quantity and value of fuelwood produced. For example, a species with high volume production is of little fuelwood value if the wood is very light or if the burning wood produces toxic smoke.

In this section, some of the factors that determine the suitability of tree legumes for fuelwood will be discussed and some of the principles of plantation management and how these apply to fuelwood production will be considered.

Fuelwood Properties

Most wood burns relatively easily, though the wood of some species (e.g. species of *Syncarpia*) is fire retardant and will not burn except in hot fires in mixture with more flammable woods. Other woods, while they may burn readily, may not be suitable because of excessive spark production or odorous, toxic or irritating smoke. The wood of *Sesbania grandiflora* for example is not highly regarded as fuel because of the excessive smoke it produces when burning (Hegde 1990). The importance of these factors for domestic fuelwood use depends on the type of stove used, cooking methods and the adequacy of ventilation. Local preferences may also be important depending on the effects of the fuelwood on the flavour of the cooked food.

Other fuelwood properties include calorific value, wood density and wood moisture content. Gross calorific value is the total energy content per unit weight of wood determined from bomb calorimetry tests in the laboratory. Wood density and specific gravity are expressions of how much wood substance is present in a given volume of wood, i.e. how 'heavy' or 'light' a wood is. Although this is a simple relationship, it is complicated by the number of ways it can be derived. Three common expressions are basic density (the mass of oven dry wood per unit of green volume) air-dry density (the mass of air dry wood per unit of air dry volume) and specific gravity (the dry weight of a given volume of wood divided by the weight of an equal volume of water). Specific gravity of wood ranges from about 0.1 to 1.4 (Zobel and van Buijtenen 1989) (Table 5.1.1).

The significance of these factors in determining the utility of particular species for firewood is frequently misunderstood. Gross calorific value is not an important property since there is little variation among species (mean ± SD = 19.73 ± 0.98 MJ/kg for hardwood species) (Harker *et al.* 1982). However, the total energy contained in wood is not converted completely to available heating energy since this includes heat generated by the combustion of hydrogen (about 6% of wood mass). In practice, fires are open to the atmosphere and the heat generated by the combustion of hydrogen is lost as latent heat of vaporisation of the water. This loss is equivalent to about 1.4 MJ/kg (Harker *et al.* 1982). Heat is also lost in vaporising moisture contained in the wood. Thus the moisture content of fuelwood is the most significant factor affecting the production of usable heat when wood is burnt (Table 5.1.2). The initial moisture content of a tree when cut (i.e. when the wood is green) and the rate at which wood dries are important factors to be considered in assessing the potential utility of a species for fuelwood. Some of the characteristics of fuelwood of a range of tree legumes are presented in Table 5.1.1.

While there is little variation among species in total energy content per unit weight of wood, differences in wood density result in substantial differences in energy content per unit volume of wood. Consequently, wood density of a species may be an important consideration where the bulk of a load rather than its weight limits the amount that can be transported. The rate of heat production during burning is dependent on the piece size of the fuelwood but is also influenced by wood density. Where cooking requires slow steady concentrated heat production, fuelwood needs to be relatively dense and piece size needs to be relatively large. Small pieces of light wood burn too quickly to be suitable for this type of cooking. However, low density woods can be used for quick hot fires while high density woods are suitable if cut into small pieces.

Table 5.1.1. Fuelwood characteristics for a range of tree legumes.

Table 5.1.2. Effect of moisture content on the heating value of fuelwood.

Moisture (%)[1]	0	10	25	50	75	100	150	250	400
Heating value (%)[2]	100	90	78	63	52	44	33	20	10

[1] Moisture content is the weight of moisture as a percentage of wood oven dry weight for a fixed weight of green fuelwood

[2] Heating value is the amount of usable heat produced by wood at a given moisture content compared with that produced by oven dry wood

Drying Fuelwood

Wood begins to dry out as soon as it is cut and progresses through several stages. In the first stage of drying, free water is lost until fibre saturation point (about 24% moisture content) is reached. Drying beyond this point to equilibrium moisture content (about 15%) takes progressively longer since it involves the removal of bound water. The moisture content at these levels and the rate of drying vary depending on humidity and temperature.

In practice, drying to about 24% moisture (which provides 80% of the energy yield of totally dry wood) is adequate. Cutting the wood into small lengths and splitting while wood is green will increase the rate of drying. This is especially important for those species which are slow to dry.

Managing Trees for Fuelwood Production

The way in which trees are managed for fuelwood production will depend on the aims and priorities of the particular land management system in use. For example, in mixed tree/pasture systems, the management of trees where wood production is the primary aim and pasture secondary will be different from that where pasture is of major importance and wood is a by-product. While the basic silvicultural principles are the same, their application varies and providing the principles are understood, management systems appropriate to any system can be devised.

Spacing and thinning

The general sigmoidal pattern of growth relative to age applies both to individual trees and to populations of trees grown together in stands. Growth may be measured in a variety of ways: stem diameter (usually measured at 1.3 m), tree height, stand basal area (sum of the cross-sectional area of all the stems in the stand), tree or stand wood volume, and tree or stand biomass. The harvesting age at which long-term yields are maximised (the silvicultural rotation) is the age at which the current annual increment (e.g. of volume) equals the mean annual increment. At this stage, cutting and replanting the stand will provide a greater yield in the long term than allowing the stand to continue to grow even though tree size will continue to increase. This principle also applies to maximising total volume, merchantable volume or biomass production, or the profitability of a commercial plantation.

'There are remarkably few data on fuelwood yields from dense plantations of trees of any kind and even fewer for leguminous trees. Forest mensuration data commonly focus on timber volumes of widely spaced trees not on total biomass of dense plantations.' The values for leucaena in Table 5.1.3 indicate that dense spacing is a necessary criterion for maximal early mean annual increments (Brewbaker *et al.* 1984). Data from other trials (Brewbaker *et al.* 1982) confirm these observations and suggest that a 4-6 year harvest of trees at 1 x 1 m or 1 x 2 m spacings may provide maximum yields when moisture is not limiting.

In the Philippines, *Gliricidia sepium* is grown in woodlots to produce fuelwood for curing tobacco. Trees are spaced at 1.5 x 2.0 m or 2.0 x 2.0 m and fuelwood size is ideal for the kilns. Annual yields of up to 20 m^3/ha have been recorded from these lots. Living fences with spacings as low as 50 cm produce much smaller sized wood (Glover 1989).

An additional factor to be considered in the management of fuelwood plantations is the relationship between age, stand density and wood density. As a general rule for mature trees, wood density increases from the pith to mature heartwood and then declines from heartwood to sapwood. These properties tend to be related to age and to position within the tree. Young trees or trees harvested from dense plantings will tend to have a lower specific gravity than those that are older or that have grown more quickly at lower stand densities. Consequently, young trees may provide suitable firewood for quick hot fires but the firewood will not be satisfactory for slow, sustained heat production.

Wood density is especially important where wood is grown for charcoal production. While low density woods can be used to produce charcoal, it tends to be of poor quality and crumbles easily. The best charcoal is derived from high density woods. Most tree legume species produce good charcoal and some, including species of *Acacia, Leucaena* and *Prosopis,* are widely renowned (Brewbaker *et al.* 1984) (Table 5.1.1).

Table 5.1.3. Effect of plant density on wood yields of *Leucaena leucocephala* (after Brewbaker *et al.* 1984).

Location	**Age (years)**	**Density (plants/ha)**	**Annual increment (m^3/ha/year)**

Waimanalo Hawaii	1	40,000	87
	4	20,000	70
Kauai Hawaii	1	40,000	71
	4	20,000	93
Molokai Hawaii	1	40,000	97
	3	20,000	72
Taiwan	1	40,000	20
	4	5,000	41

Pruning, lopping, pollarding and coppicing

Trees can be managed by applying various cutting treatments to provide a sustained source of firewood while allowing the tree to continue to grow. Some of these treatments are particularly suitable for systems where the trees fulfil multipurpose roles.

Pruning to remove the lower branches flush with the stem (to c. 5 m above ground level) may provide useful though relatively small amounts of firewood and will not affect the growth of the tree unduly providing about 67% of the green crown is retained. Pruning, particularly of trees which carry a low, dense crown, could be carried out in agroforestry systems to increase the amount of light reaching the pasture underneath or to increase the amount of clear, knot-free wood and thus improve the value of the tree for sawn timber or veneer.

Lopping (cutting off branches but leaving stubs of 30-100 cm, frequently as high as can be reached by climbing) and pollarding (cutting out the top of the tree) are common management practices in agroforestry. Frequently both lopping, leaving branch stubs to climb on, and pollarding are carried out at the same time, the branches and upper stem being used for firewood.

Coppicing is the most extreme of these treatments and, in forestry terms, generally involves cutting the tree at about 10 cm above ground level. In many cases, continual harvesting is possible over a number of rotations without the need to replant before yields begin to decline. Gliricidia has been cut at 20-30 cm above ground on a 2-4 year cycle for over ten cycles in Timor, Indonesia (A.P.Y. Djogo, unpublished data). However, tree species vary in their capacity to produce coppice shoots when cut; some (like leucaena and gliricidia) reshoot readily while others (e.g. *Sesbania grandiflora*) will die. Individual species may vary also in their response to cutting depending on their age and size. Species that do not sprout readily from stumps may do so when cut at a greater height above the ground (say at 100 cm) with the retention of a live branch. Coppice regrowth, even from those trees that sprout readily, may be more vigorous when a live branch is retained. Cutting should be carried out when trees are not under stress (e.g. from drought or waterlogging) to maximise the survival of stumps and the vigour of coppice.

Nutritional Considerations

Regular harvesting of tree legumes for fuelwood may result in a substantial removal of nutrients depending on management. The amount of nutrients immobilised in the biomass of a tree may vary among species and sites and also with age and stocking density (Table 5.1.4). Nutrients are distributed unevenly throughout a tree, the concentration generally being highest in the foliage component and decreasing in the order: foliage >> stem bark > branches > stemwood. The amount of nutrient removed at harvest depends on the biomass and the nutrient concentration of each component removed. Significant nutrient removals can result from harvesting branches for firewood because of the higher nutrient content in branch wood and bark. However, this depends on both the age of the trees and the branch and stem diameter. As stem diameter increases, the proportion of bark in the biomass declines and consequently, the relative loss of nutrient due to bark removal declines. Nutrient concentration in wood also declines with increasing stem diameter due to withdrawal and translocation of nutrients from older wood. These factors need to be taken into consideration in determining the spacing at which trees are planted (since diameter tends to increase as spacing increases) and also the age at which trees are harvested. Leaves (either live or as ground litter) should never be harvested for burning as this leads to substantial depletion of nutrients from the site.

Control of Wildfires

Brewbaker *et al.* (1984) reviewed wildfires and found that 'fire is probably the major cause of loss of forests planted for fuelwood in the tropics'. Fuelwood lots established without adequate control of perennial grasses are especially prone to fire damage. These authors state that 'most newly planted forests are adjacent to agricultural land and fire is the principal weapon of subsistence farmers against insidious grasses and other weeds. It is also their major tool in revitalising rangelands and preparing farmlands for planting.'

Table 5.1.4. Biomass and nutrient content of a number of tree legume species at different locations and of different ages.

Species	Country	Age	Total above ground biomass	Total nutrient content (kg/ha)			Source
		(years)	(t/ha)	N	P	K	
Acacia dealbata	New Zealand	8.0	182	1006	43	638	1
Albizia lebbeck	Puerto Rico	3.0	29	534	33	149	2, 4
Albizia procera	Puerto Rico	5.5	124	540	102	370	2, 4
Leucaena leucocephala (K-8)	Puerto Rico	5.5	47	370	39	220	3, 4
Leucaena leucocephala	Puerto Rico	5.5	33	210	23	127	2, 4
Prosopis juliflora	Kenya	8.0	216	1674	116	1219	3

References: 1. Frederick *et al.* (1985); 2. Lugo *et al.* (1990); 3. Maghembe *et al.* (1983); 4. Wang *et al.* (1991)

'Escaped fires may account for as much as half the loss of newly planted forests in the tropics' (Brewbaker *et al.* 1984). These authors documented fireburns in planted pine and eucalypt forests in Western Samoa of 5,000 ha, in the Philippines of 3,000 ha, in Sri Lanka of 2,000 ha, in Nepal of 1,000 ha and in Thailand of 500 ha. None of these forests was planted with firebreaks and Brewbaker *et al.* (1984) suggested that future reforested areas must either be planted with fire tolerant species, or be provided with firebreaks or buffer zones of multipurpose species for community use.

Among leguminous trees, 'many *Acacia* and *Prosopis* species have fire retardant foliage but are often planted in grasslands that are prone to fire. Firebreaks of leucaena and gliricidia have proved highly effective in the Philippines provided the break is densely planted (1x2 m) and adequate in width (10-20 m)' (Brewbaker *et al.* 1984). Both species grow back from the root crown after fire unless burned thoroughly to the earth line. Similarly, some *Casuarina* and *Acacia* species could be used as firebreaks and will regenerate from the crown after fire.

Conclusions

Most tree legume species are potentially suitable for fuelwood production providing that the wood is not fire retardant and that levels of sparks, smoke, odours and tastes are acceptable. The rate of combustion depends on wood density (specific gravity) and firewood piece size. There is little variation among species in the gross calorific value of wood and this is not an important property. Effective heating value, however, depends on the moisture content of the wood when burnt. The rate at which wood dries is therefore a very important property. Tree legumes which have been identified as outstanding fuelwood species include *Acacia auriculiformis* and *A. mangium* for acid soils, *A. mearnsii* and *Leucaena diversifolia* for highland sites, and *L. leucocephala* and *Gliricidia sepium* for lowland tropical sites (NAS 1980, 1983b, Brewbaker *et al.* 1984).

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5.2 Forage Tree Legumes in Alley Cropping Systems

B.T. Kang and R.C. Gutteridge

Introduction

One of the greatest challenges facing agriculture in the tropics is the need to develop viable farming systems for the rainfed uplands that are capable of ensuring increased and sustained crop production with minimum degradation of the non-renewable soil resource base.

Much of the agricultural land in the humid tropics is currently Used for traditional farming based on the bush fallow. This is a low productivity but biologically stable system with long fallow periods that can sustain agricultural production for many generations (Kang and Wilson 1987). However, in many regions, shortening or abolition of the fallow period has resulted in increased land degradation, invasion by weeds and substantial crop yield decline. The use of fertiliser inputs alone has largely been ineffective in overcoming these problems (Lal and Greenland 1986), and there is a need to develop an integrated soil fertility management approach to address these issues.

The incorporation of woody species into crop production systems is one option that has received significant attention in recent years (Kang *et al.* 1990).

Alley Cropping

Alley cropping or hedgerow intercropping is an agroforestry practice in which perennial, preferably leguminous trees or shrubs are grown simultaneously with an arable crop. The trees, managed as hedgerows, are grown in wide rows and the crop is planted in the interspace or 'alley' between the tree rows (Figure 5.2.1). During the cropping phase the trees are pruned and the prunings used as green manure or mulch on the crop to improve the organic matter status of the soil and to provide nutrients, particularly nitrogen, to the crop. The hedgerows are allowed to grow freely to shade the inter-rows when there are no crops. Alley cropping retains the basic restorative attributes of the bush fallow through nutrient recycling, fertility regeneration and weed suppression and combines these with arable cropping so that all processes occur concurrently on the same land, allowing the farmer to crop the land for an extended period.

Fig. 5.2.1. Alley cropping of maize and *Leucaena leucocephala* in experimental plots.

Benefits of Alley Cropping

Some of the beneficial effects that have been claimed for alley cropping include:

- improved crop performance due to the addition of nutrients and organic matter to the soil/plant system,

- a reduction of the use of chemical fertilisers,

- an improvement in the physical nature of the soil environment. The addition of mulch can lower soil temperatures, reduce evaporation, and improve soil fauna activity and soil structure resulting in better infiltration, reduced runoff and improved water use efficiency,

- on sloping land, the tree rows act as a physical barrier to soil and water movement, resulting in significant reductions in erosion losses (Paningbatan *et al.* 1989),

- the provision of additional products such as forage, firewood or stakes when a multipurpose tree legume is used as the hedgerow, and

- an improvement in weed control. During the fallow period shading of the interspaces may reduce weed growth, while in the cropping phase, the mulch may inhibit germination and establishment of weeds (Ssekabembe 1985).

Crop Performance

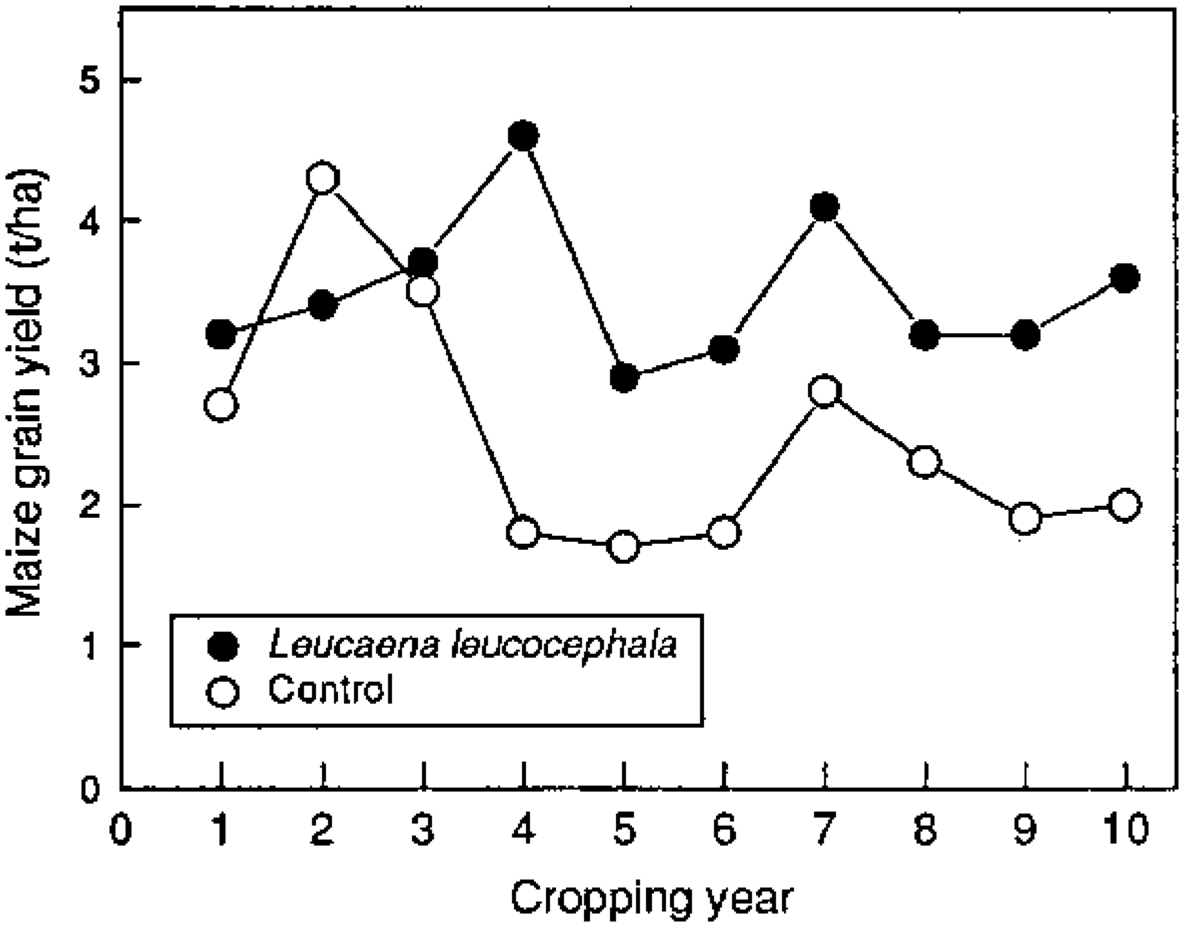
Experimental evidence supporting claims of beneficial effects of alley cropping is provided by a number of studies conducted largely in humid or subhumid regions on high base status soils. Kang *et al.* (1981) increased maize grain yields from 1.9 t/ha in unfertilised control plots to 3.5 t/ha in plots mulched with *Leucaena leucocephala* (leucaena) from 4 m wide rows. A similar magnitude of response was obtained by Dofeliz and Nesbitt (1984) in the Philippines again with leucaena at 4 m row spacings.

In the third year of cropping, a *Gliricidia sepium* (gliricidia) alley system on a degraded alfisol soil in Nigeria gave 2.42 t/ha of maize while control plots yielded 1.74 t/ha (Atta-Krah and Sumberg 1988).

B.T. Kang (unpublished data) has demonstrated the long-term yield sustainability of alley cropping in trials conducted over 10 years in southern Nigeria (Figure 5.2.2). With additional inputs of N. P. K fertiliser, maize yields in the leucaena alley cropping plots were maintained at an average of 3.5 t/ha while in fertilised control plots yields fell to 2 t/ha.

Although the results from alley cropping in humid regions on high base status soils have been quite positive, the performance of the system in other agroecological zones has been less encouraging. In the semiarid lowland tropics, Singh *et al.* (1989) reported that the yields of castor, cowpea and sorghum alley cropped with leucaena hedgerows spaced at 10 m for a period of 4 years were lower than in the control treatment. Yield declined from 30 to 150% of the sole crop yield as the distance from the hedgerows declined from 5 m to 0.3 m. These authors attributed much of the yield decline to severe moisture competition. In Peru, Szott (1987) conducted alley cropping trials using *Inga edulis* and *Cajanus cajan* on a Typic paleudult. Yields of alley cropped cowpea, maize and rice were extremely low and were equal to or less than that of the control treatment. Evensen and Yost (1990) initially reported positive results from the alley cropping of upland rice and cowpea with rows of *Paraserianthes falcataria* on a Tropeptic haplorthox in west Sumatra, Indonesia, particularly with addition of a low rate of lime. However, yields declined after 4 years and were restored only after fertiliser input was increased.

Fig. 5.2.2. Effect of alley cropping with *L. leucocephala* on grain yield of maize grown on degraded Oxic paleustalf compared with control (no tree) treatment in Nigeria (fertiliser rate, years 1-3, 90N, 40P, 40K; years 4-10, 45N, 12P, 25K kg/ha) (B.T. Kang, unpublished).



Effect of Alley Cropping on Soil Properties

An important benefit of alley cropping is the addition of large amounts of organic materials from the prunings as mulch or green manure (Table 5.2.1) which can have favourable effects on soil physical and chemical properties, on microbiological activity and hence on soil productivity. Several studies (Kang *et al.* 1985, Lal 1989b, Kang and Ghuman 1991) have demonstrated significant positive effects of alley cropping on soil fertility parameters such as organic C levels, total N and extractable P levels over a range of climatic and soil conditions. The magnitude of these effects, however, varied with hedgerow species and management as this influenced the quantity and quality of prunings. Factors such as C:N ratio, lignin and polyphenol contents influence the decomposition rate of the mulch, the subsequent release of nutrients and their uptake by the crop. Gutteridge (1990) showed that mulches from *Sesbania sesban,* gliricidia and leucaena were effective sources of N for maize growth while those from *Calliandra calothyrsus, Acacia cunninghamii* and *A. fimbriata* were ineffective in the short term. This may have been due to the high polyphenol and/or lignin content of the latter species.

Table 5.2.1. Biomass nutrient content of leaves and twigs of two tree legumes grown on an Alfisol at Ibadan, Nigeria (duo and Kang 1989).

Species		Biomass of leaves &	Nutrient content of leaves a

	twigs	**twigs (kg/ha/year)**				
	(t/ha/year)	**N**	**P**	**K**	**Ca**	**Mg**
Leucaena leucocephala	7.4	247	19	185	98	16
Gliricidia sepium	5.5	169	11	149	66	17

Guevara (1976) found that only about 38% of N in leucaena prunings was recovered by a maize intercrop while Evensen (1984) noted, that compared with urea, mulching with leucaena leaf was only 41% as efficient in supplying N to maize.

The efficiency of utilisation of N from the prunings can often be improved by incorporation. Read (1982) found that incorporation of leucaena leaf produced a higher N uptake than when applied as a surface mulch. Evensen (1984) increased the efficiency of mulched leucaena leaf to 63% that of urea by incorporation. Kang *et al.* (1981) also found that incorporation improved maize yields both in the presence and without additional nitrogen fertiliser (Table 5.2.2). Use of fresh rather than dry prunings also improved the rate of N release and uptake by maize (Read 1982).

Hedgerows have the ability to recycle nutrients and although this aspect has not been widely studied, Hauser (1990) demonstrated this phenomenon in an alley cropping system with leucaena. He found higher concentrations of N. K, Ca and Mg in the surface soil than in the subsoil under the hedgerows. This was attributed to leaf litter fall and nutrient uptake by the trees from the subsoil. In the centre of the alley plots, the reverse situation occurred with lower nutrient levels in the surface soil due to crop uptake and higher levels in the subsoil due to leaching. This result shows that alley cropping can reduce the downward displacement of nutrients.

Effect of Alley Cropping on Soil Erosion

A large number of experimental results have confirmed the significant role of alley cropping in reducing runoff and soil erosion (Young 1989, Hawkins *et al.* 1990, Kang and Ghuman 1991). Lal (1989a) showed that erosion in plots tilled and alley cropped with gliricidia and leucaena was reduced by 73 and *83%* respectively compared with a tilled control treatment. R.C. Gutteridge (unpublished data) found that rows of leucaena planted at 5 or 10 m intervals across the slope were as effective as conventional contour banks in reducing erosion on a 10% slope in southeast Queensland. In a trial lasting 3 months on a Typic tropudalf, erosion was greatly reduced by the presence of *Desmanthus virgatus* hedgerows spaced at 6 m intervals (Paningbatan 1990). A total of 1,424 mm of rain fell during the experimental period. Total soil loss was 127 t/ha in the control treatment, 41 t/ha with *Desmanthus* hedgerows and contour cultivation, and 0.2 t/ha with hedgerows, application of prunings as a mulch and zero tillage. Young (1989) attributed the beneficial effects of alley cropping in controlling soil erosion partially to the barrier effect of the hedgerows, but mainly to the presence of prunings applied as mulch.

Table 5.2.2. Grain yield of maize fertilised with nitrogen and/or leucaena prunings. Prunings were incorporated or applied as a surface mulch (after Kang *et al.* 1981).

Leucaena prunings (t/ha)	**N rate (kg N/ha)**	**Leucaena prunings**	
		Incorporated	**Surface mulch**
		Grain yield (kg/ha)	
5	0	2,313	2,013
	50	3,035	2,300

	100	3,435	3,020
10	0	3,213	1,855
	50	2,578	2,338
	100	3,068	3,023

LSD = 688 ($P < 0.05$)

Effect of Alley Cropping on Weed Suppression

The germination and growth of most weed species are usually stimulated by exposure to light. Thus some control of weeds may be effected if a closed canopy can be maintained during the fallow period in an alley cropping system. Anoka *et al.* (1991) found that the shoot biomass of *Imperata cylindrica* decreased by about 80% under uncut hedgerows of gliricidia and leucaena in Nigeria. Yamoah *et al.* (1986) also reported lower weed yields under hedgerows of *Flemingia macrophylla,* gliricidia and *Cassia siamea* when they remained uncut for 2 years.

There also appears to be a shift in weed composition following alley cropping. Siaw *et al.* (1991) showed a significant change towards more broadleaf weeds after alley cropping with leucaena and *Dactyladenia barter*) compared with the control treatment.

In most alley cropping systems, the weed suppression effect of the hedgerows is not fully exploited and further studies of the effect of different hedgerow species, fallowing and manipulation of cutting regimes may improve the effectiveness of the system in reducing weed infestation.

Management of Alley Cropping Systems

Biologically, the effectiveness of alley cropping systems depends to some extent on the soil type and agroecological zone in which the system is used but it is also very dependent on management strategies adopted. Factors such as choice of tree species, orientation, layout and manipulation of the hedgerows and crop husbandry practices are all important in determining the outcome of the alley cropping system.

Choice of tree species

The choice of tree species for alley cropping is extremely important and to a large extent determines the success or failure of the system. Rachie (1983) detailed a number of attributes which should be considered when selecting a tree species for alley cropping. These include:

- a rapid growth rate,
- ability to withstand frequent cutting,
- good coppicing ability (regrowth after cutting),
- ease of establishment from seeds or cuttings,
- nitrogen fixing capacity,
- deep-rooted with a different root distribution to the crop,
- multiple uses such as forage and firewood,
- ability to withstand environmental stresses such as drought, waterlogging, and extremes of pH,
- high leaf to stem ratio,
- small leaves or leaflets,
- dry season leaf retention and
- freedom from pests and diseases.

The first three of these attributes also mean that the tree will be competitive with the associated crop.

A wide range of tree species has been used in alley cropping experiments or demonstrations (Table 5.2.3) but leucaena has been by far the most favoured species (Kang *et al.* 1990). A number of comparative trials in humid/subhumid zones on high base status soils have shown leucaena to be superior to other species and this may partly explain its widespread use (Kang and Reynolds 1986). However, on acidic low base status, soils leucaena has not been as successful as species such as *Flemingia macrophylla* (Kang *et al.* 1991) and *Erythrina peoppigiana* (Kass *et al.* 1992). There is a need for a wider range of tree species suited to low activity, acid, infertile soils. Ethnobotanical surveys in regions dominated by these soils may help identify appropriate species.

Table 5.2.3. Tree species used in alley cropping.

Species	Countries
Legumes	
Cajanus cajan	Nigeria
Calliandra calothyrsus	Indonesia, Western Samoa
Cassia siamea	Kenya, Nigeria
Erythrina peoppigiana	Costa Rica
Flemingia macrophylla	Nigeria, Rwanda
Gliricidia sepium	Nigeria, Costa Rica, Sri Lanka, Philippines
Inga edulis	Costa Rica
Leucaena leucocephala	Nigeria, Kenya, Philippines, Sri Lanka, Indonesia, India, Thailand, Australia
Paraserianthes falcataria	Indonesia
Sesbania sesban	Rwanda, Kenya, Australia, Ethiopia
Sesbania grandiflora	Nigeria, Western Samoa
Non-legumes	
Alchornea cordifolia	Nigeria
Dactyladenia barteri	Nigeria
Gmelina arborea	Nigeria
Grevilea robusta	Kenya

Hedgerow manipulation

One of the major benefits of alley cropping is the mulch provided by the hedgerow species, in the form of prunings, to the associated crop. Factors such as cutting height and frequency, hedgerow spacing and intra-row density will all influence the quantity of prunings produced.

In humid and subhumid areas, tree row spacings range from 2 to 7 m with 4-6 m most commonly used (Lawson and Kang 1990). Tree spacings within the rows should be as close as possible and experience with species such as leucaena, gliricidia and *Sesbania sesban* indicates that trees should be spaced at 10-15 cm or as near as possible to a solid hedge along the row. This helps to favour leaf production over stem, provides a more effective barrier to soil movement on sloping lands and creates a better microenvironment for crop growth. Closer spacing both within the row and between the rows also allows for improved distribution of nutrients to a greater proportion of the intercrop. On the other hand, close spacing between the hedgerows reduces the amount of land available for the crop and can result in increased competition for the growth factors of light, moisture and nutrients between hedgerow and crop.

Competition for light

In Nigeria, Kang *et al.* (1985) demonstrated competition for light in a maize/leucaena alley cropping study. The maize rows adjacent to leucaena received 51-69% of the available light compared with 75-81% received by mid-alley rows. In a subsequent crop, leucaena was pruned to 75 cm during crop growth and no significant yield reductions were observed. In southeast Queensland, Australia, Mekonnen (1992) found that maize grain yields in rows adjacent to leniently cut hedgerows of *L. diversifolia* were reduced by 88% largely due to competition for light.

Further work in Nigeria found that decreasing alley width from 4 to 2 m reduced both maize and cowpea yield associated with higher partial shading at the narrow spacing. Four tree species were tested in this study and their ability to depress yields of maize was in the order *Leucaena* > *Gliricidia* > *Alchornea* > *Dactyladenia* (Figure 5.2.3) and was well correlated with the size and leafiness of the tree (Lawson and Kang 1990). Other studies on this aspect have indicated considerable variation in light transmission among species. The more erect branching habits of gliricidia and *Flemingia macrophylla* cast less shade than the spreading lateral branches of *Cassia siamea* which shaded the centre of a 4 m wide alley (Anon. 1983). In another study, Getahun (1980) showed that *Sesbania grandiflora* transmitted more light than leucaena which was in turn better than *Alchornea cordifolia.* The fast growing pulpwood species *Paraserianthes falcataria* and *Gmelina arborea* showed considerably greater capacity for shading making them unsuitable for alley cropping unless cut back very frequently.

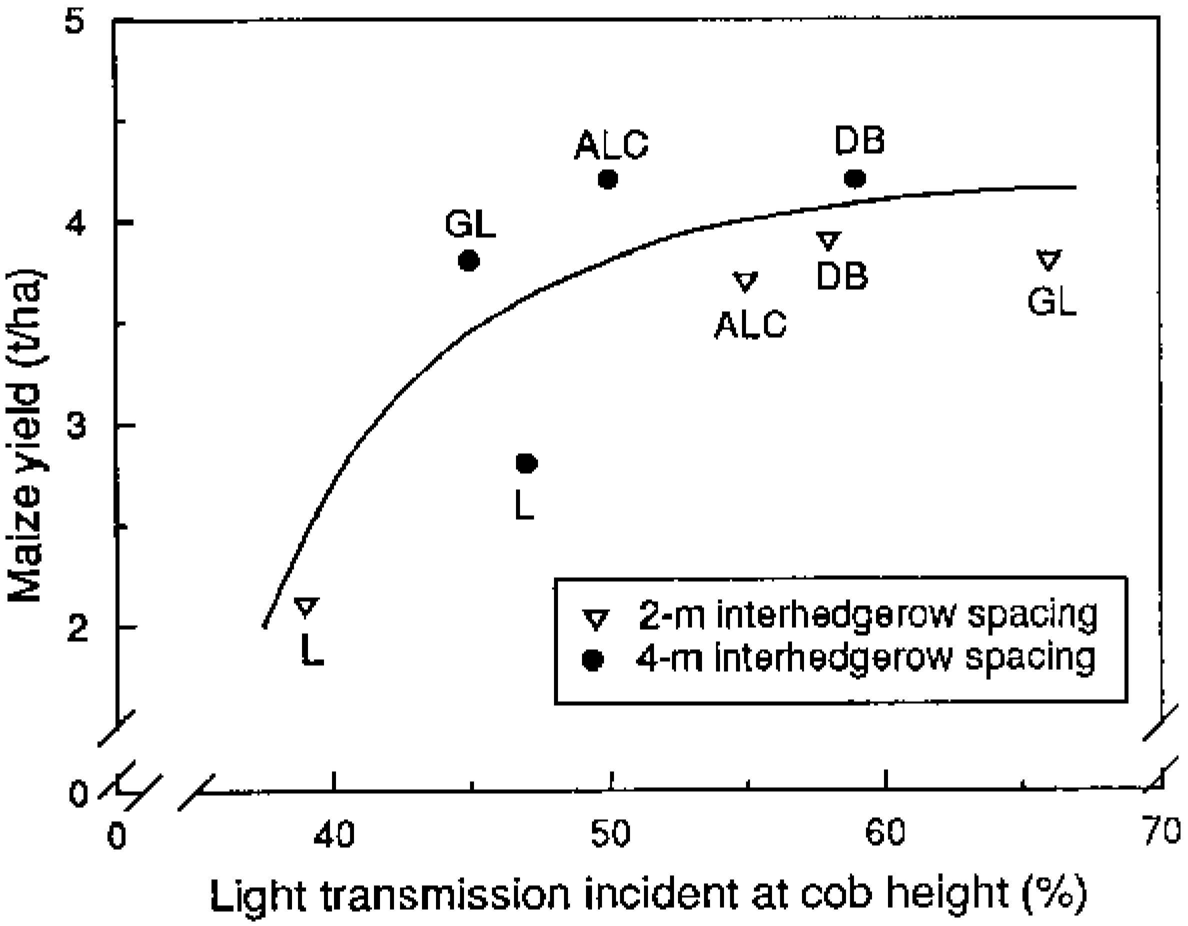
Although more frequent pruning at a lower pruning height can minimise the shading effect of the hedgerow, the effectiveness of the hedgerows for biomass production and nutrient recycling is also reduced (Duguma *et al.* 1988).

These studies have demonstrated that hedgerow species have the ability to shade adjacent crops in alley cropping systems. Thus timely pruning must be incorporated into the management calendar particularly to assist shorter statured crops such as cowpea which endure greater levels of shading and consequent greater yield reduction than taller statured crops.

Competition for moisture and nutrients

Recent reviews of alley cropping research (Ssekabembe 1985, Kang *et al.* 1990) have indicated few detailed studies of the effects of competition for moisture and nutrients. This may be partly explained by the reduced importance of moisture stress in lowland humid sites where most work has been conducted. On the other hand, it may be due to the assumption that trees place their roots deeper in the soil profile than most crops and that competition is therefore avoided (Berendse 1979). A study by Kang *et al.* (1985) on a degraded Entisol supported this latter assumption. They found that maize grown in association with leucaena drew moisture mainly from 0 to 30 cm soil depth while leucaena tapped the 60-90 cm zone. Verinumbe and Okali (1985) grew maize between coppiced teak trees (*Tectona grandis*) and separated the effects of shading and root competition by the use of barriers and judicious pruning. They found that shading alone depressed maize yield by 40%, root competition alone had no effect but shading and root competition combined depressed yield by more than 60%. Other studies by Ewel *et al.* (1982) with larger fruit and timber trees indicated that competition between tree and crop for moisture does occur and that it increases with the vigour of the above-ground biomass production.

Fig. 5.2.3. Effect of partial shading of hedgerow species on grain yield of associated maize crop (DB = *Dactyladenia barter*), ALC = *Alchornea cordifolia,* GL = *Gliricidia sepium,* L = *Leucaena leucocephala*) (Lawson and Kang 1990).



In drier areas, and even in humid zones on acid soils, competition between the hedgerow and the crop for nutrients and moisture can be very severe as the woody species and the crop have a tendency to concentrate their roots in the surface soil because of subsoil acidity. Studies by Fernandes *et al.* (1990), Basri *et al.* (1990) and Evensen and Yost (1990) showed significant reductions in the performance and yield of crops particularly when grown in the first few rows adjacent to the hedgerows. Root pruning of hedgerows can partially reduce competition but it is not always effective in the long term. The question of competition for moisture and nutrients requires further research. There is limited evidence from subhumid areas where interactions between competition, conservation and enhancement effects of trees, make interpretation of results more complex (Nair 1987).

Conclusions

The biological merits of alley cropping make it an important conservation farming practice for smallholders and resource-poor farmers. However, with minor modifications, it could also be adapted to the broadacre farming systems of the world.

The system exploits moisture and nutrients deep in the soil profile. It permits nutrient recycling, improves soil structure, provides good soil erosion control and reduces the need for chemical fertilisers.

Following a decade of intensive research on alley cropping in various parts of the tropics, a better understanding has now emerged of the potential and limitations of the system and the areas requiring further research.

Competition for light can largely be eliminated by judicious pruning of the tree species during the cropping phase. Below-ground competition for moisture has not been well defined and further research is required especially in subhumid regions. Identification of additional tree species suited to low base status, acid soils is also an important research goal as well as defining better management practices to enhance the beneficial effects of the system.

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6.1 The Leucaena Psyllid

R.A. Bray

Introduction

In the past, *Leucaena leucocephala* (leucaena) has been notable for the general absence of problems due to major diseases or insect pests. The successful spread of the common leucaena to much of the tropical world may have been partly due to leaving its main diseases and pests behind. However, in recent years, the leucaena psyllid has proved to be a significant factor in the continued use and expansion of this valuable multipurpose plant.

The leucaena psyllid (*Heteropsylla cubana,* sometimes called 'jumping plant lice') is a small yellow-green insect about 1-2 mm long (Figure 6.1.1). It is native to Central America and the Caribbean, where it has presumably co-existed with leucaena for thousands of years. Although it has been reported to occur on a few other leguminous shrubs and trees, these are not damaged to any great extent, and it is probable that the psyllid can only complete its life cycle on plants in the genus *Leucaena.*

The psyllid first became a problem on experimental plantings in Florida (USA) in 1983. From there it spread rapidly: April 1984, Hawaii; February 1985, Western Samoa and Fiji; October 1985, Philippines; March 1986, Papua New Guinea and Indonesia; April 1986, Australia; November 1986, Thailand; 1988, India and Sri Lanka; 1991, Mauritius; 1992, Reunion and coastal East Africa. It is reasonable to assume that, sooner or later, all areas where leucaena is grown will be affected. In Australia, following the first recording at Bowen in north Queensland in April 1986, the insects had within 3 months spread 800 km to Gympie, and by mid-October had reached Brisbane.

The extremely rapid rate of spread suggests that air currents (including high-level winds and cyclone/typhoon activity) are largely responsible for its dispersal, together with movement by aircraft and other man-made transportation. However, it is not uncommon to find psyllids on very isolated stands of leucaena, suggesting that the influence of man is not of great importance.

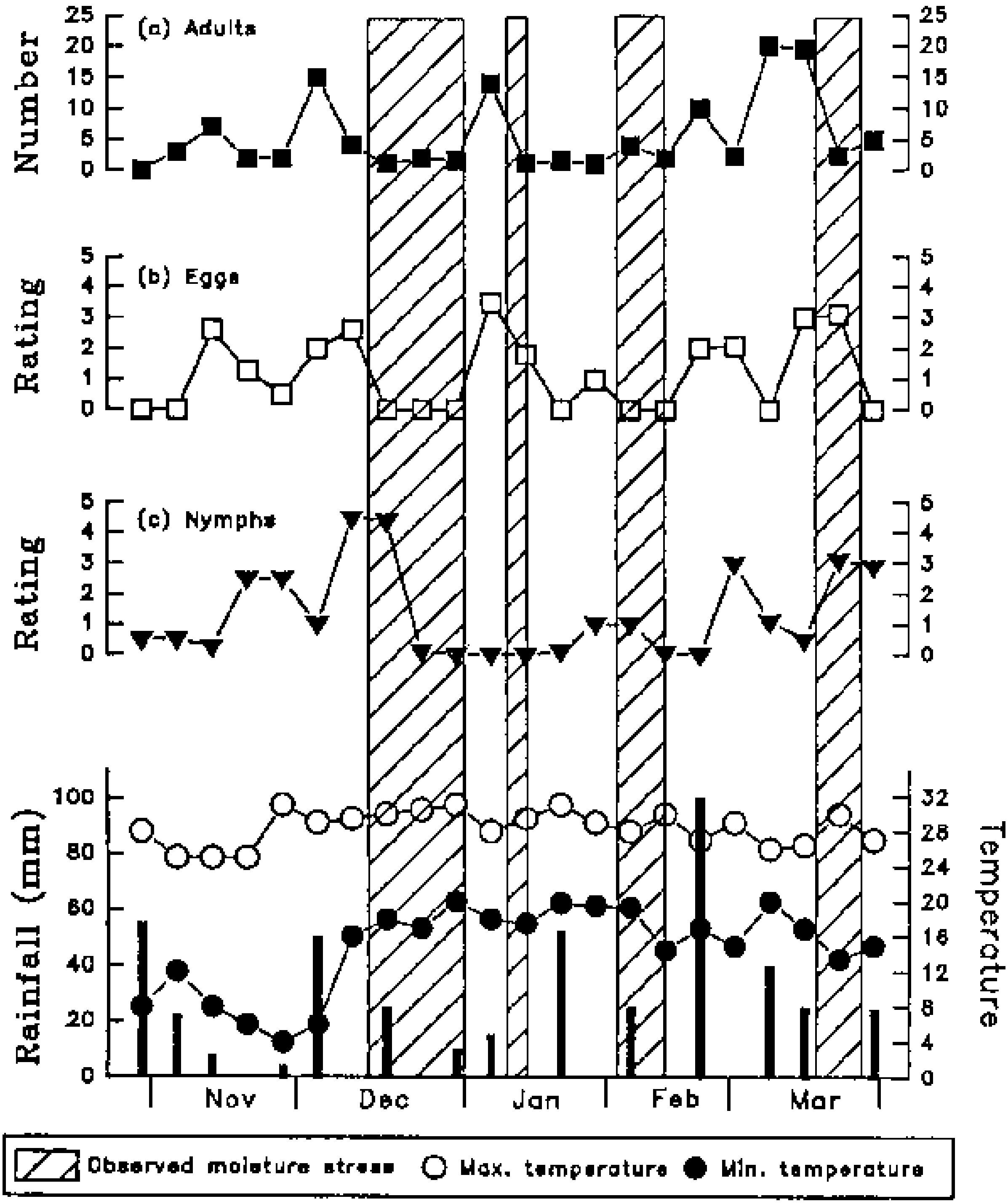
Fig. 6.1.1. Adult leucaena psyllid (*Heteropsylla cubana*) (x40).

Life Cycle

The female psyllid lays its eggs on very young shoots where they are lodged between the folds of the developing leaflets. The eggs are oval, 0.3 mm long and 0.1 mm wide. Newly laid eggs are white, but turn orange or reddish brown after a day or two. Individual females can lay up to 400 eggs. Eggs hatch in 2-4 days, and there are five nymphal stages. The nymphs rapidly become quite mobile, and can congregate in large numbers on the growing points of young shoots. The total time from egg to adult may vary somewhat with the environment, but is generally between 10 and 16 days. Thus there is the potential for extremely rapid population build-up, and many generations per year.

In the field, psyllid populations normally fluctuate quite widely over time. There have been a number of attempts to assess the effect of environmental factors on psyllid development (see, for example several papers in Napompeth and MacDicken 1989). These usually involve trying to relate environmental factors such as rainfall and temperature to various estimates of psyllid abundance. We have carried out such studies at Samford, southeast Queensland, and Figure 6.1.2 illustrates the type of data obtained. In our work, we monitored numbers of adult psyllids, egg numbers and nymph numbers. Egg-laying (which requires young developing leaves) was rather cyclic, but large numbers of eggs did not always result in large numbers of adults. The peak numbers of nymphs tended to occur soon after rain. A feature of the psyllid seems to be the variability that often exists between adjacent sites. Moisture and nutrient status also influence these variations, and stand density, humidity and exposure to wind could also be important. Management for forage greatly increases psyllid numbers.

Fig. 6.1.2. Numbers of adults and estimated changes in abundance of eggs and nymphs of the leucaena psyllid at Samford during 1987/88. Temperatures shown are mean maximum and minimum for the week preceding the observation and rainfall is the total for that week.



There is no consensus concerning the effect of rainfall and temperature, as in some cases psyllid numbers are reported to be at a maximum during the wet season, and in others, during the dry season. However, it is fairly certain that neither hot dry conditions nor sustained periods of intense rain are favourable for the build-up of psyllid populations. It is clear that when conditions are good for the growth of leucaena, they are usually also good for the multiplication of the psyllid. Large populations of the psyllid cannot develop when the leucaena itself is suffering from moisture stress, or has its growth limited by cool temperatures. Frost will effectively kill psyllids.

One of the difficulties involved in this type of work is that because of the short time involved in the various stages of psyllid development, environmental variables must be measured frequently, ideally on a daily basis. For example, in the Samford work, we frequently found that adult psyllids would appear within a day or two of rain, although they were not previously apparent. Also, one or two days of dry, 35℃ temperatures has been sufficient to reduce markedly existing populations. A more detailed discussion of psyllid biology may be found in Waterhouse and Norris (1987).

Damage

The leucaena psyllid damages the plant by its sucking action, although it is possible that there is also some phytotoxic principle involved, as occurs with some other psyllids. Both the nymphs and adults feed by sucking from the phloem of the developing shoots and young foliage. The insects exude drops of sticky fluid on the leaves causing the leaflets to stick together. The overall effect is to prevent the growth of new leaves. Since older leaves are not damaged to any great extent, casual observation may suggest that a particular leucaena stand has little or no damage. It is essential to examine the growing points and young foliage for the presence of psyllids, and subsequent leaf loss, to assess adequately the extent of any damage. Frequently, where psyllids have been active, there will be no new leaves for a distance of up to 30 cm from the 'growing point', representing a loss of up to 10-12 leaves, or several months' growth. This can be readily seen from a distance.

Quantification of the damage caused by the psyllid is difficult. Within the first 2 years of invasion by psyllids in the Philippines and Indonesia, defoliation was sufficiently severe to reduce cattle weight gains and stocking rates dramatically. Recent reports would suggest that psyllid damage is sometimes reduced and stocking rates have in places returned to normal. In experiments in north Queensland and Indonesia the effect of psyllids on dry matter yield was examined by comparing the yield from plots sprayed with insecticide and unsprayed plots over a period of 1 year (Palmer *et al.* 1989). In north Queensland total production when psyllids were not controlled was reduced to about 45% of that in the sprayed treatment. At one site in Indonesia, total yield was reduced by about one-third, while at the other there was no effect of psyllids on yield. In southern Queensland, annual losses of leaf production of over 50% have been recorded (Bray and Woodroffe 1991). Stem (wood) yield was even more severely affected. However, it is likely that losses in the drier areas of central Queensland are less, probably of the order of 20%.

Techniques for Assessing Psyllid Numbers and Damage

There have been several attempts at assessing the numbers of psyllids present in their different life cycle stages (see papers in NFTA (1987) and Napompeth and MacDicken (1989)). Rating systems have been developed (e.g. Bray and Woodroffe 1988a, Wheeler 1988) based on the numbers of adults and nymphs observed. However, careful counting (Elder and Mayer 1990) suggests that these methods give gross underestimates of the numbers of eggs present, and are unable to distinguish between different levels of nymph infestation. Accurate estimation of egg and nymph numbers must apparently involve time-consuming laboratory counts. For most non-entomological purposes, it is probably sufficient to assess psyllid presence on the basis of 'none, few or many', rating a large number of plants in any one field.

Damage ratings have also been made with arbitrary rating schemes, commonly using a scale ranging from 1 (slight puckering of leaflets) to 6 or 7 (total defoliation of the shoot) or in some cases to 9. These have been quite effective but give no indication of the real loss due to psyllid infestation. The ultimate test of resistance is, of course, to establish the reduction in yield of a particular genotype due to the presence of the psyllid. This is very difficult and time consuming.

The ideal method of assessing resistance must account for a number of factors, including variation in plant phenology (e.g. height, branching, foliage density, shading, plant age), and availability of water and nutrients, which may confound any observed 'resistance'. Accurate experiments to assess resistance must be designed to provide sufficient replication of each entry, susceptible controls and a 'saturated' psyllid environment, such as the high populations generated by stands of susceptible varieties. The plants being compared should be similar in age and phenology and be exposed to the same environmental conditions. Only when these conditions are fulfilled can there be confidence in the assessment. We have characterised the resistance of a number of species using potted seedlings exposed to psyllids in the field (Bray and Woodroffe 1988a).

What Options are there for Combatting the Psyllid?

Do nothing

In any situation, there is a balance between a whole range of biological and abiotic entities. The arrival of the leucaena psyllid where it has not occurred before represents a significant disturbance of the existing ecosystem. Given time, a balance has been reached in most areas invaded by psyllids. This *laissez faire* strategy assumes that the effects of predators, parasites and diseases already present, together with climatic influences, will serve to keep the psyllid to acceptably low levels. Obviously, the psyllid has been controlled very effectively in its native habitat in this manner.

Use of insecticide

An initial reaction to the psyllid infestation in Indonesia was to spray with insecticides. Although the psyllid is readily killed by low doses of several insecticides, including dimethoate (0.03%), this treatment is generally ineffective. Not only is it difficult to be sure that all trees (including those not in gardens or pastures) are sprayed, but it is hard to ensure complete coverage of large plants. In addition, the extreme mobility of the psyllid means that new recruits may arrive on the wind soon after spraying. At Samford, we have found that it is impossible to keep small plots free of psyllids even by spraying every 2 weeks, when significant areas of unsprayed plants exist in the vicinity. Spraying could perhaps be worthwhile to try and save seedling plants, or to protect valuable plants in nursery situations, such as for seed production. Other important considerations with the use of insecticide are that beneficial native insects will also be killed, and that pesticide residues may be present in the leucaena when fed to animals.

Management options

There are varying reports of the extent of psyllid damage in leucaena grown under various management systems. In central Queensland, it is reported that leucaena grown as large trees seemed to suffer more damage than when grown as hedgerows. However, in other situations, trees that are grown for wood and not harvested for foliage show minimal damage after psyllid populations stabilise. Where moisture stress does not occur and forage harvest or grazing is continuous, psyllid populations are likely to remain high with significant levels of damage. Drought leads to leaf drop and great reduction in psyllid populations.

Biological control

In any environment there will exist some insects that feed on one or more stages of the life cycle of the psyllid. The larvae of the common ladybird beetles are particularly good in this respect, but do not seem to be able to keep the populations under control. However, it may be worth observing existing predator populations. Work in Hawaii has identified two useful predators, *Curinus coeruleus* and *Psyllaephagus yaseeni. Curinus,* a beetle that attacks psyllid larvae, is a general predator and has been widely distributed to several countries in southeast Asia It has yet to be established how effectively it is contributing to reduction in psyllid populations in the field. *Psyllaephagus* (a wasp that attacks the eggs of the psyllid) is a more specific parasite restricted to the genus *Heteropsylla,* but has not been widely released. The use of entomogenous fungi, now being studied in Taiwan, the Philippines and Papua New Guinea (Hollingsworth *et al.* 1991) may offer possibilities for psyllid control.

The introduction of biological control agents to a country or region is not a decision that can be taken lightly, or independently from neighbouring countries, due to the complexity of the interactions in any biological system. As an example, one Australian programme is seeking to control the tropical weed *Mimosa* through the introduction of a psyllid of the genus *Heteropsylla.* Any attempt to control the leucaena psyllid by the introduction of *Psyllaephagus* could negate this programme. There is also concern in India that the introduction of a general predator such as *Curinus* could have a bad effect on populations of the lac insect.

The exploration of the psyllid's native area for further predators and parasites should continue. It is not an easy task, and any new organism will need to be carefully tested before release.

Selection and breeding

There are three possible approaches:

- Uses of psyllid-tolerant genotypes of *L. leucocephala.* Variation in tolerance of psyllids exists in this species, with arboreal cultivars like K584 and K636 (University of Hawaii) showing major increases in yield under psyllid pressure in several countries. These cultivars appear to have long-lived leaves and the capacity to produce many new axial branches when growing tips are damaged.

- Use of other species of *Leucaena.* Of the available species, *L. diversifolia* and *L. pallida* are the most promising, having performed well in the NFTA trials. However, there is considerable variation within these species, and all collections do not have the same degree of resistance. Both Hawaiian (K376, K784) and Australian (CPI46568) lines show promise. However, although these species may be valuable for wood production or soil conservation purposes, they have not yet been adequately assessed for animal feed. Preliminary experiments indicate that, although not as digestible as *L. leucocephala,* they can still provide a useful source of supplementary feed (B. Palmer, personal communication). More information is needed on their establishment requirements, yield, coppicing ability (regrowth), palatability and feeding value.

  Some form of breeding programme using interspecific hybridisation. Most species of the genus *Leucaena* are resistant to psyllids, and many can be hybridised with *L. leucocephala* (Brewbaker and Sorensson 1990). After four cycles of selection, hybrids of *L. leucocephala* and *L. pallida* are being tendered for release to forage growers in Hawaii by the University of Hawaii. Selection has led rapidly to high levels of psyllid resistance, maintaining productivity and with some erosion of nutritive quality. The species *L. leucocephala* is recognised for its superiority in fodder quality (intake, digestibility), and long-term breeding of forage varieties will probably profit by back-crossing generations. In any event more information is needed concerning the nature and stability of resistance, and about possible variation among psyllid populations.

Use of other genera

There are a number of other species of tree and shrub legumes which can be used as alternatives to leucaena, although none can match all its virtues at this time. *Gliricidia, Sesbania, Calliandra* and *Codariocalyx* all offer good prospects. However, there remain many unanswered questions with these genera in regard to their perenniality, palatability and nutritional quality. What is clear is that when any species is grown on a large scale, it becomes a potential target for damaging pests and diseases. Thus it is unwise to rely too much on any one species, and future plantings of tree legumes should ensure that a range of species is used.

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6.2 Diseases of Tree Legumes

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Introduction

Tree legumes include an extensive range of multipurpose, widely adapted species (Nair *et al.* 1985) which are useful components of agricultural and silvicultural systems (NFT 1989). They are important throughout the tropics as sources of forage, firewood, charcoal, green manure and timber (NFT 1989, Hughes and Styles 1989). Over the last 15 years there has been a rapid explosion of reports of diseases affecting tree legumes. Over 80% of references cited in this section date from 1979 or later. However, we know very little about many important aspects of these diseases including control strategies.

This section consolidates information on diseases of the most important tree legumes used for forage. Emphasis is given to foliage diseases which may directly reduce forage production and quality. We report some of the preliminary findings from recent surveys of diseases of *Calliandra, Gliricidia* and *Leucaena* in Central America. Potential control strategies of common diseases and future research needs specifically for forage trees in animal production systems are briefly discussed. A recent review (Lenné 1992) of diseases of multi-purpose woody legumes in the tropics complements this section.

Acacia

Seed and seedling diseases

Seedling blight, defoliation and dieback due to *Glomerella cingulata* (anamorph *Colletotrichum gloeosporioides*) caused serious losses to *A. mangium* in nurseries in Papua New Guinea (FAO 1981) and Indonesia (Lee and Goh 1989) and to *Acacia* spp. in India (Mohanan and Sharma 1988, Sharma and Bhardwaj 1988) especially under humid conditions (Mohanan and Sharma 1988). Leaf spot caused by *Cylindrocladium quinqueseptatum,* a common foliar pathogen of trees, caused defoliation of seedlings and young trees of *A. auriculiformis* and *A. mangium* in India (Mohanan and Sharma 1988). The rust *Uromyces digitatus* reduced growth of *A. auriculiformis* in nurseries and young plantations in Indonesia (Turnbull 1986). Powdery mildew, *Oidium* sp., severely affected *A. mangium* in Hawaii (NAS 1983a) and caused up to 75% mortality of *A. mangium* seedlings in nurseries in Thailand (Chalermpongse 1990).

Fusarium solani, Phytophthora spp., *Pythium* spp. and *Rhizoctonia solani* may cause serious damping-off of tree legume seedlings (Lee 1985, Sharma and Bhardwaj 1988, Zakaria 1990). In Malaysia, damping-off damages *A. mangium* where seedlings are crowded or soils too damp (Lee 1985) with losses as high as 30% (Liang 1987, Zakaria 1990). In Malaysia, seedlings of *A. mangium* are also affected by brown root disease (*Phellinus noxius*) and charcoal rot (*Macrophomina* sp.) resulting in stunting, chlorosis and death (Lee 1985). Root-knot nematodes, *Meloidogyne* spp., caused high mortality of seedlings of *A. mangium* in Sarawak, Malaysia (Chin 1986).

Foliage diseases

Limited information is available on the importance of the many foliage (leaf twig and branch) diseases caused by at least 10 fungal genera which have been widely recorded on *Acacia* spp. (Browne 1968, Gibson 1975, Mohanan and Sharma 1988, Lenné 1992).

Cercosporella theae caused dark sunken lesions on leaves and twigs and may cause defoliation of *A. mangium* in Malaysia (Browne 1968, Gibson 1975, FAO 1981). *Exserohilum rostratum* caused dark irregular lesions with pale centres on foliage of young *A. auriculiformis* in India (Mohanan and Sharma 1988). Powdery mildew, including *Oidium* sp., was moderately severe on *A. auriculiformis* and *A. mangium* in Australia (Ryan and Bell 1989).

Many rusts occur on leaves, twigs and pods of *Acacia* spp. Information on host range, symptoms, distribution, biology and ecology has been reported (Bakshi and Singh 1967, Browne 1968, Gibson 1975, Dick 1985, Morris 1987). Many have restricted host ranges (Gibson 1975). An exception is *Uromycladium tepperianum* which is hosted by 118 *Acacia* and *Albizia* spp. (Browne 1968). More than 60 species of rusts are confined to *Acacia* spp. In Australia, New Zealand and southeast Asia, most rusts belong to the genus *Uromycladium* while in tropical America, India, Myanmar and Africa, *Ravenelia* is most common. *Uromyces* sp. is widespread on *A. auriculiformis* in Indonesia (Santosa *et al.* 1984). Although rusts have been described as an 'indeterminate threat' to *Acacia* spp. (FAO 1981), few rusts are presently considered important.

In Malaysia, the importance of pink disease, caused by *Phanerochaeta salmonicolor,* varies among sites on *A. mangium.* In peninsular Malaysia, occasional crown and tree death has been observed (NAS 1983a, Lee 1985) but in Sarawak and Sabah, severe pink disease has been reported (Chin 1982, Khamis 1982) where the fungus attacks the bark, girdling branches and causing dieback (Zakaria 1990). *Rhizoctonia solani* causes web blight of *A. auriculiformis* and *A. nilotica* in India (Mehrotra 1990) resulting in premature defoliation as severe as 30-70%. Three biotypes of the fungus have been identified (Mehrotra 1990).

Sandal spike, caused by a mycoplasma-like organism, affects *Acacia* spp. in India only (Browne 1968, Ghosh 1981, Sen Sarma 1984, Nayar 1988). Symptoms include foliage dwarfing, shortened internodes, excessive branching, pale green or reddish leaves standing out stiffly from twigs, suppressed flowering and small fruit. Spiked trees usually die within 3-5 years of attack (Browne 1968, Nayar 1988). An extensive review of the disease is provided by Nayar (1988). Virus-like disorders have been observed on *Acacia* spp. (Seliskar 1964); however, none have been well characterised.

Root diseases

Root diseases caused by *Macrophomina phaseolina, Armillaria mellea* and

Ganoderma spp. may seriously affect *Acacia* spp. (FAO 1981). These pathogens have been recorded on *A. auriculiformis* and *A. nilotica* in India and Pakistan (Bagchee 1945). Red rot disease, caused by *Ganoderma* sp., affects *A. mangium* in Malaysia (Lee 1985). In Papua New Guinea, *A. auriculiformis* is affected by root rot caused by *Ganoderma* and *Phellinus* spp.; in one study area, approximately 10% annual mortality has been recorded (Skelton and Howcroft 1987).

Brown root disease caused by *Phellinus noxius* affects *A. mangium* in Malaysia (Khamis 1982) and the Solomon Islands (Ivory 1990). The fungus rapidly extends along the roots to the collar then upwards to the stem base. Trees yellow, wilt and die. In older trees, often only part of the crown is affected. Wilt and root rot due to *Fusarium solani* has been reported on *A. nilotica* and *A. auriculiformis* in India (Bagchee 1945, 1958) while *Botryodiplodia theobromae* is associated with root disease of *A. auriculiformis* in India, *A. mangium* in Malaysia and *A. nilotica* in India and Kenya (Gibson 1975). Six *Acacia* spp. including *A. tortilis* and *A. nilotica* were susceptible to *Meloidogyne javanica* and *M. incognita* in Senegal (Pros 1986). *Acacia auriculiformis* is attacked by nematodes in Zanzibar (NAS 1979).

Albizia

Seed and seedling diseases

Rhizoctonia solani caused destructive damping-off of seedlings in nurseries of *A. lebbeck* in India (Mehrotra 1989) and Sri Lanka (Bandara 1990). Leaf rusts caused by *Ravenelia* spp. are important seedling diseases of *Albizia* spp. in India (Sharma and Bhardwaj 1988).

Foliage diseases

Endothella albiziae caused defoliation of *Albizia* spp. including *A. lebbeck* in Africa, the Philippines and Pakistan (Gibson 1975). *Camptomeris albiziae* caused leaf blotch and foliar necrosis of *A. lebbeck* in tropical Africa, India, Sri Lanka, Pakistan, the Dominican Republic (Browne 1968, Gibson 1975) and Bangladesh. A similar leaf blotch, *Camptomeris albiziicola,* has been recorded on *A. lebbeck* in India (International Mycological Institute, unpublished data).

Cercospora glauca and *C. albiziae* caused leaf spots of *A. lebbeck* in USA, China and Nepal and in India, Sudan and Tanzania (Gibson 1975, Bakshi 1976), respectively. *Colletotrichum lebbeck* has been widely recorded on pods and leaves of *A. lebbeck* in Pakistan, the Philippines and Jamaica (Gibson 1975) causing grey, circular shot-hole lesions. *Phyllosticta albizinae* may seriously defoliate young plantations of *A. lebbeck* in India (Bakshi 1976). *Rhizoctonia solani* causes leaf web blight of *A. lebbeck* in India (Mehrotra 1990).

Many rusts belonging to the genera *Ravenelia* and *Uredo* are recorded only on *Albizia* spp. (Gibson 1975). *Uromycladium tepperianum* and *Sphaerophragmium acaciae,* have wider host ranges including *Acacia* spp. (Gibson 1975). Information about these rusts is well documented (Browne 1968, Gibson 1975, Bakshi 1976); however, in most cases, their importance has not been determined.

Dieback and canker of *Albizia* spp. are caused by *Nectria ditissima* on *A. lebbeck* in Madagascar (Gibson 1975). In Mauritius, leaf mosaic of *A. lebbeck* is believed to be caused by a virus (Seliskar 1964, Gibson 1975).

Stem diseases

Fusarium solani caused grayish-black cankers on 15-20 year old trees of *A. lebbeck* in India (Bakshi 1976). The pathogen invades through wounds and later develops a stratified canker through repeated killing of the cambium (Bakshi 1976). In severe infections, the canker may extend 2-4 m almost girdling the stem and causing drying of the crown. Trees may snap at the region of the canker.

Root diseases

The most important disease *of A. lebbeck* is vascular wilt caused by *Fusarium oxysporum* f sp. *perniciosum* which is widespread in the USA and has also been reported from Argentina and Puerto Rico (Gibson 1975). The fungus invades fine roots causing gummosis of the vessels. Two races of the pathogen exist (Gibson 1975).

Calliandra

Of 26 disease records on at least nine *Calliandra* spp., 18 were rusts, mostly *Ravenelia* spp. from Mexico, Central America, the Caribbean and Brazil (Lenné 1990). Dieback caused by *Nectria, Thyronectria* and *Phomopsis* spp. was common in the Caribbean and West Africa; leaf blotch caused by *Camptomeris calliandrae* occurred in Costa Rica; and pink disease (*Phanerochaete salmonicolor*) has been noted in Papua New Guinea (Lenné 1990). Rough coppicing may facilitate infection by fungi such as *Xylaria* spp. and pink disease which may infect and kill weakened stumps (NAS 1983b). In recent surveys, blossom blight (unknown cause) and associated reduced pod formation was observed in Honduras and Guatemala (E.R. Boa and J.M. Lenné, unpublished data). Yet, in both its native range and Indonesia, *C. calothyrsus* has not suffered any serious diseases to date.

Erythrina

Fungal diseases have been recorded on at least 15 *Erythrina* spp. throughout the tropics including leaf spots, mildews, moulds, scorches and blights (Lenné 1990), yet no information is available on their importance and no serious diseases have been documented on *E. indica* or *E. poeppigiana.* Scab caused by *Elsinoe erythrinae* causes defoliation in Brazil and rusts caused by *Dicheirinia binata, Phakopsora pachyrhizi* (soybean rust) and *Uredo erythrinae* are widely reported on *Erythrina* spp. in Mexico, Central and South America, and the Caribbean (Lenné 1990, Figueiredo *et al.* 1983).

Erythrina witches' broom is widespread on *E. micropteryx* and *E. corallodendron* in Venezuela (Seliskar 1964) and may affect other species. Virus-like symptoms have been recorded on *E. senegalensis* in Sierra Leone and referred to as *Erythrina* mosaic (Seliskar 1964). Vein clearing and banding/bulging between the veins has been observed on *E. lithosperma* in Sri Lanka associated with cocoa trees affected by cocoa vein banding virus (Seliskar 1964).

Root rot pathogens including *Armillaria mellea* on *E. crista-galli* in the USA and *E. subumbrans* in Tanzania, *A. tabescens* on *Erythrina* sp. in the USA, *Botryodiplodia theobromae* on *E. orientalis* in India, *Fusarium* spp. on *E. indica* in India and *E. subumbrans* in Malaysia, and *Rhizoctonia ramicola* on *Erythrina* sp. in the USA have been noted yet no information exists on their importance (Lenné 1992). Wilt caused by *Fusarium solani* has been recorded on *E. stricta* in India and *E. subumbrans* in Malaysia (Lenné 1992).

Faidherbia albida

Rhizoctonia solani causes leaf web blight of *F. albida* in India (Mehrotra 1990). *Faidherbia albida* is a good host of root-knot nematodes, *Meloidogyne javanica* and *M. incognita* (Pros 1986).

Gliricidia sepium

Cercosporidium gliricidiasis, chocolate or brown leaf spot, is widely recorded on *G. sepium* throughout Central and South America, the Caribbean (Lenné 1990), Africa (Lenné and Sumberg 1986), southeast Asia and the Pacific. Recent surveys confirmed its common occurrence in Honduras and Guatemala (E.R. Boa and J.M. Lenné, unpublished data). Under humid conditions, it causes defoliation. *Colletotrichum gloeosporioides,* expressed as small, dark, rounded leaf spots, is more common than *C. gliricidiasis* in Nigeria (Lenné and Sumberg 1986). *Gliricidia sepium* was defoliated by *Cladosporium* sp. in Costa Rica (Glover and Heuveldop 1985) and the pathogen has also been recorded in Jamaica and Venezuela (Lenné 1990). Scab (*Sphaceloma* sp.), manifested as brown scab-like lesions on petioles and stems, was found for the first time on *G. sepium* in Honduras during recent surveys. Its relation to other legume scabs is being determined. Leaf spots caused by other fungi are listed in (Lenné (1990). Surveys have also found leaf scorch/scauld and powdery black leaf spot at several sites. Investigations are in progress to determine the causal agents.

Although widely grown throughout the tropics, *G. sepium* has apparently remained free of serious diseases. Recent surveys in Central America, however, noted the common occurrence of serious 'little leaf disease' (thought to be caused by a mycoplasma-like organism) in fenceline and natural populations of *G. sepium* (E.R. Boa and J.M. (Lenné unpublished data). This was associated with extensive dieback and tree death, especially in Honduras. Investigations are in progress to verify the causal agent(s). Twig, stem and branch dieback of *G. sepium* in Central America, Asia and Africa have been associated with various fungi in the past (Lenné 1990). The same fungi may also be involved in Honduras and Guatemala. Recent surveys showed that pink disease occurs in Papua New Guinea (Lenné 1990).

Virus-like symptoms, including leaf curl, shoe-string leaves, foliar distortion, mosaic and mottle have recently been noted in many natural stands of *G. sepium* in Central America. Further investigation of these populations is planned. Viruses are potentially very serious to future development of *G. sepium* especially if they are seed-borne.

Leucaena

Leucaena leucocephala is the most intensively researched, widely used and best known forage tree. Many diseases caused by fungi, bacteria, a possible virus and nematodes have been recorded on *Leucaena* species throughout the tropics and detailed information is available in a recent review (Lenné 1991). The most important diseases of *Leucaena* spp. and new information from recent surveys in Central America are summarised in this section.

Foliage diseases

Camptomeris leaf spot (CLS), caused by *Camptomeris leucaenae,* reduces forage production and quality of *L. leucocephala* throughout Central and South America, the Caribbean, India, Taiwan and Philippines (Lenné 1991). The pathogen is specific to *Leucaena* and has been recorded on seven species. CLS is characterised by chlorotic patches on upper surfaces of leaflets and blotches of profuse sporulation in crowded black pustules on lower surfaces. Coalescence of lesions results in chlorosis and defoliation (Lenné 1980a). The most susceptible species are *L. leucocephala* and *L. collinsii* (Moreno *et al.* 1987). The protein content of severely affected leaves was reduced by 18%. Resistance has been identified in accessions of *L. lanceolata, L. trichodes, L. diversifolia, L. macrophylla, L. pulverulenta* and *L. shannoni* and may be widely available in these and other species (Lenné 1991).

Blight canker, caused by the fungal complex *Calonectria rigidiuscula* (anamorph *Fusarium decemcellulare*) and *F. roseum,* has been recorded in Taiwan (Chang and Chen 1984, Chang and Tao 1984). Symptoms include wilt, blight, branch death, canker and tree decline. It is sporadically distributed in Taiwan with higher incidence in plantations on sandy soils (Chang and Chen 1984).

Stem diseases

Gummosis, the exudation of gum from the main trunk, stems and branches of *Leucaena* spp., with associated leaf senescence, dieback and stunted growth, is described as the most serious disease of *L. leucocephala* in India and Sri Lanka (NAS 1984). Yet, little is known of its pathology and economic importance (Lenné 1991). Putative causal organisms vary among countries and regions within countries and include *Phytophthora drechsleri* (Van Den Beldt and Hodges 1980) and at least four species of *Fusarium* (Lenné 1991). Some researchers consider gummosis to be a physiological phenomenon (Anderson 1984, Hegde 1984). To date, gummosis has been recorded on *L. leucocephala* and *L. diversifolia* only with Peruvian, Hawaiian and giant types of *L. leucocephala* being seriously affected in India.

Serious stem canker caused by *Pirex subvinosus* has resulted in wilting, necrosis and death of *L. leucocephala* at Kununarra, Western Australia since 1980 (Shivas and Brown 1989). It was first reported as a pathogen of *L. leucocephala* in India (Sankaran and Sharma 1986). From 1984 onwards, up to 10% of trees have been killed by the fungus in Kununarra (Shivas and Brown 1989). The pathogen is considered a serious threat to cultivation of *L. leucocephala* in Australia.

Pod diseases

Pod diseases reduce seed production and infect seed (Lenné 1991). Pod rot caused by *Fusarium* sp. has been recorded in Colombia, Brazil and India on *L. collinsii, L. diversifolia, L. macrophylla, L. pulverulenta* and *L. shannoni* with high incidence (Lenné 1991). Pod rot, caused by *Pseudomonas fluorescens* biotype II, has been recorded on *L. leucocephala* in Belize, Brazil, Colombia, Mexico and Panama (Lenné 1980b, (Lenné *et al.* 1981) and recently in Guatemala. Under humid conditions, pods and seed rot rapidly reduce seed production (Lenné 1980b, (Lenné *et al.* 1981). *Leucaena esculenta, L. leucocephala* and *L. pulverulenta* were more susceptible than *L. diversifolia* and *L. shannoni* in inoculation studies (Lenné *et al.* 1981). Seed infection with *P. fluorescens* can be as high as 95% (Moreno *et al.* 1987).

A probable *Ravenelia* sp. rust occurs on pods of *L. salvadorensis* in Honduras causing blister-like pustules filled with brown spore masses. It has not, however, been observed on other *Leucaena* species growing at the same site. The rust has also been found associated with overgrowth of a *Fusarium* sp. which could be involved in a pod rotting complex (C.E. Hughes, personal communication). Although the rust does not appear to affect growth or forage production, it may affect seed production of *L. salvadorensis.*

Root rots

Root rots caused by *Ganoderma* and *Fusarium* spp., *Pseudolagarobasidium leguminicola* and *Pirex subvinosus* kill *L. leucocephala* throughout Asia and Australia (Lenné 1991). Root rot, caused by *Ganoderma lucidum,* has been reported on *L. leucocephala* in India (Raina 1980, 1983, Pathak 1986) while *G. applanatum* and *G. tornatum* affect *L. leucocephala* in Papua New Guinea (Straw 1984). *Ganoderma lucidum* causes wilting, drying of apical meristems, stem blackening, defoliation, root rot and tree death. Seven year-old trees had 10-15% mortality at moist sites (Pathak 1986). In Taiwan, a root and stem rot caused by *Pseudolagarobasidium leguminicola* has been recorded sporadically in *L. leucocephala* plantations especially on clay loam soils in the mountains (Chang and Chen 1984, 1985). Symptoms include decreased crown growth, root rot, dieback, girdling of the lower stem and death. Root rot caused by *Fusarium oxysporum* and *F. moniliforme* var. *subglutinans* is an increasing problem in forage and shade plantings in Sri Lanka (Bandara 1987). Root and collar rot, caused by *F. solani,* has been recorded in India and Mauritius (IMI, unpublished data). In the southwest Pacific, *L. leucocephala* was severely affected by brown root rot caused by *Phellinus noxius* (Ivory 1990).

Prosopis

A large number of fungi have been recorded on *P. juliflora* but no information is available on their importance. These include leaf spots caused by *Pleospora scirrhioides* widely reported from India, *Pleospora* sp. from Pakistan and *Septoria prosopodis* from India, rusts caused by *Ravenelia* spp. from Mexico and USA, and dieback caused by *Diplodia dalbergiae, D. prosopidina, Nectria flavistroma* and *N. purtonii* from Pakistan and India (Browne 1968, IMI, unpublished data).

Pod spot and seed blight of *P. juliflora* caused by *Macrophomina phaseolina* is described as a new disease of mesquite from northeast Brazil (Muchovej *et al.* 1989). Affected pods showed brown discoloration while infected seeds did not germinate. *Prosopis juliflora* is an excellent host of root-knot nematodes *Meloidogyne javanica* and *M. incognita* in inoculation studies (Pros 1986). Weak reproduction of *Scutellonema cavenessi* also occurred on *P. juliflora* (Pros 1986).

Sesbania

Pathogens affecting common *Sesbania* spp. worldwide have been reviewed (Evans and Rotar 1987, Murphy 1990). Severe disease problems have been reported occasionally (Evans 1986).

Seedling and foliage diseases

Colletotrichum capsici collar and seedling blight has been recorded on *S. grandiflora* in India (Srinivasan 1952). Severe leaf spot and defoliation caused by *Pseudocercospora sesbaniae* occurs widely on *S. grandiflora* in India (Kumar and Joshi 1983), Myanmar and the Philippines (IMI, unpublished data) and on *S. sesban* in India (Josh) and Kumar 1986). Disease incidence was 47.2% on one cultivar. The rusts *Uromyces poonensis* on *S. grandiflora* in India (Josh) and Kumar 1986) and *Uredo sesbaniae* on *S. sesban* in India have been reported (Evans and Rotar 1987). *Protomycopsis thirumalacharii* causes angular black leaf spot of *S. grandiflora* in India (Pavgi 1965, Haware and Pavgi 1976) while *Erysiphe polygon*) (powdery mildew) has been recorded on *S. sesban* in India (Evans and Rotar 1987).

Xanthomonas campestris pv. *sesbaniae* causes leaf and stem spots and defoliation of *S. sesban* in India (Bradbury 1986). Sesbania mosaic virus caused decreased nitrate reductase activity (Srivastava 1986) and interfered with nodulation (Rao and Shukla 1988) of *Sesbania* spp. in India (Sreenivasulu and Nayudu 1982). An unnamed, sap-transmitted virus caused mild mosaic and mottling on leaves and defoliation of *Sesbania* spp. (Singh and Srivastava 1985).

Root diseases

Sclerotium rolfsii caused wilt of *S. sesban* in a forage experiment under dry conditions in Hawaii (Evans 1986, Evans and Rotar 1987). Wilt occurred after cutting with cumulative incidence up to 50%. It has also been recorded on *S. sesban* in Malaysia (Turner 1971). *Fusarium oxysporum* f. sp. *sesbaniae* causes root rot and wilt of *S. sesban* in India (IMI, unpublished data).

Sesbania grandiflora is very susceptible to nematodes (NAS 1980). Root-knot nematode *Meloidogyne incognita* is potentially destructive to *Sesbania* spp. in India (Trivedi *et al.* 1986) and *M. javanica* has also been recorded on *Sesbania* spp. in Pakistan (Munir *et al.* 1986). The cyst nematode *Heterodera trifolii* occurs on *S. grandiflora* in Hawaii (Holtzmann and Aragaki 1963).

Potential Control Strategies

Because almost no information exists on actual losses caused by diseases of forage tree legumes, the economic importance of most diseases is unknown and potential control strategies only can be discussed.

Seed and seedling diseases affect many tree legumes and have been well documented for *Acacia.* Pathogens are capable of destroying seedlings before and after emergence (Gibson 1975). Damping-off is the most important seedling disease. It is caused by a wide range of fungi and can rapidly cause appreciable losses (Gibson 1975). Chemicals are commonly, successfully and economically used to control seed and seedling diseases of tree legumes in nurseries (Ibnu and Supriana 1987, Mohanan and Sharma 1988, Chalermpongse 1990, Pongpanich 1990, Zakaria 1990, Lenné 1991). If the pathogen is seed-borne, control by seed dressing can be effective. Chemical treatment reduced fungal and bacterial infection of seed from infected pods of *Leucaena* (tonne 1991). Removal of seed debris (Yuan *et al.* 1990), soil drenches and heat or steam sterilisation of the seed bed prior to sowing are also useful measures (Gibson 1975). Cultural control by reducing the density of seedlings, restricting watering and modifying the seedling environment so that it is less suitable for disease development are valuable control practices (Gibson 1975, Sharma and Sankaran 1987). Yet, diseases of seedlings and young trees sown in extensive plantings for forage production will be difficult and costly to control by normal nursery practices. Seed treatments, especially with systemic fungicides which may be incorporated in pellets with rhizobium, may be the major viable option in the field.

Tree pathologists have generally minimised the importance of foliar diseases because they rarely affect timber production, usually the most valuable forest product. However, if the tree legume is grown as a source of forage, effects of foliage diseases on forage production and quality become more significant. Limited work has been done on control of foliage diseases of tree legumes. Potential control strategies include cultural control through cutting and grazing, selection of resistant germplasm and manipulation of natural biological controls. Camptomeris leaf spot of *Leucaena* was reduced by periodic 8-weekly cutting of forage in Colombia (Moreno *et al.* 1987). Management of the regrowth of tree legumes primarily used for forage is a widely applicable disease control measure. Natural biocontrol fungi have been recorded on leaf blotches (Lenné 1991) and rusts (Khan *et al.* 1989) and could be manipulated for disease management. Resistance is considered the best long-term strategy for control of foliage diseases of tree legumes and has been achieved for some diseases (Gibson 1975, Lenné 1991).

Avoidance and eradication have been used for common stem and root diseases. Application of fungicides directly to cankers successfully reduced gummosis of leucaena; however, the economics of this practice must be compared with the value of wood and forage. When branches are cut for forage, care should be taken to avoid injuries, which are potential sites for fungal invasion (Sharma and Sankaran 1987, Lee *et al.* 1989). Clear site selection is recommended to avoid soil-borne root rots (Gibson 1975, Bakshi 1976). Other measures including trenching to isolate infection centres and treatment of roots with fungicides (Bakshi 1976) are expensive, time consuming and often ineffective (Gibson 1975, Ivory, 1990). Soil solarisation was as effective as fungicides in controlling *Fusarium* root rot of *Leucaena* in Sri Lanka (Bandara 1987) and may have wider application.

Except for seedling diseases, the state of knowledge of strategies for controlling diseases of tree legumes is inadequate. Yet, a greater range of control strategies is potentially available for tree legumes in many systems. Mixtures of trees and crops in agroforestry systems may promote reduction in diseases by physical barrier effects and genetic diversity for resistance (Beets 1984). Control strategies should always be related to the systems in which the trees are grown and the purpose for which they are to be used. Labour intensive strategies may be feasible at the village level.

Future Research Needs

The extent of knowledge of diseases of tree legumes in the tropics is generally poor. Knowledge of diseases is mainly restricted to records in host lists with limited information on importance and pathogenic variability, and even doubts regarding the true status of the 'pathogen'. Standard texts including Browne (1968) and Gibson (1975) are urgently in need of revision. Conflicting reports of the importance of diseases have been made from the same country. There are many important forage species for which little or no pathological information is presently available. Limited work has been done to assess losses caused by known diseases and the economics of control.

The narrow global genetic base of many tree legumes such as *L. leucocephala* presents few problems to any rapidly disseminated disease. Widespread damage to *L. leucocephala* caused by the leucaena psyllid emphasises the importance of diversifying the narrow genetic bases of tree legumes and the need for greater awareness and knowledge of their pests and diseases. In recent years, significant variation has been collected in *Acacia, Calliandra, Leucaena* and *Gliricidia* by CSIRO, on, CGIAR centres and the University of Hawaii. This variability is now being evaluated in trial networks. These networks represent an invaluable opportunity to widely survey diseases and pests of tree legumes. Present and future efforts to increase the diversity utilised in key genera should facilitate selection for resistance among superior provenances. Close international and institutional collaboration is needed.

Damaging and potentially damaging diseases have been identified on some important tree legumes. As the use of tree legumes for forage continues to expand in the tropics, disease problems will continue to increase both in occurrence and severity. Attempts should be made now to develop country and region specific information bases through coordinated surveys, efficiently using the existing trial networks, and to develop strategies to control diseases quickly.

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6.3 Insect Pests of Forage Tree Legumes: Biology and Non-chemical Control

G.H. Walter and W.H. Parry

Introduction

Native and exotic tree legume species are grown as multipurpose trees in agroforestry systems throughout the tropics. Species in both categories harbour insects that defoliate, produce galls or leaf mines, eat seeds, suck sap or bore in stems, roots or branches. Some insects, mainly sap suckers, also transmit pathogens. The debilitating impact of insects on forage quality and quantity or on seed production may be so great that remedial activity is desirable (Sen-Sarma 1987).

Introduced plants usually 'accumulate' a range of associated herbivorous insect species. Some invade from elsewhere, whereas other insects may have been pre-adapted to the introduced plants, perhaps through their adaptation to a close relative. Other insects may simply be present in low numbers and use the trees as alternative hosts at times when their usual host is unsuitable or unavailable. The list of insects that attack an introduced plant species in most cases increases rapidly at first and then gradually with time (Strong *et al.* 1984), presumably as the distribution of the plant increases and as the rate of encounter of insect species pre-adapted to the host are slows down.

Usually it is insects that have been accidentally introduced or that have invaded on their own (e.g. entry of the leucaena psyllid into Australia (Bray and Sands 1987)) that are the major pests. Since their natural enemies (predators and parasitoids) usually do not accompany them when they are introduced, the high densities achieved are seen to be a consequence of their 'escape' from natural enemies. There are, however, other variables to consider; the introduced plants may be present at much higher densities than in their native habitat, and selected cultivars that are planted may be more susceptible to insect attack.

Most of the serious damage to trees is caused when the insects reach high densities, although some species cause considerable damage even when relatively few are present. Few stem borers, and sometimes just one, may be sufficient to kill a tree (Conway 1978). Such aspects of an insect's life history may determine appropriate methods of control. Species that cause serious damage only at high densities may be reduced to acceptably low levels by biological control or the breeding of resistant cultivars, whereas others may need to be dealt with in other ways (Conway 1978).

In the following section we summarise the information available on insect pests relevant to several important tropical forage tree legumes, and make the few generalisations that are possible. Finally, we deal with practical control tactics (besides insecticidal control) that may be used to prevent insect damage.

Insect Pests of Forage Tree Legumes in the Tropics

Table 6.3.1 summarises the data available on known pests of several important forage tree legumes. Several general papers contain additional information (e.g. Sen-Sarma 1987, Kumar 1990). Undoubtedly the list will grow with time. However, it is significant that none of the insects mentioned has been comprehensively studied to unravel their host plant relationships and other aspects of their ecology. For some, even their pest status is unclear. This lack of understanding impedes development of acceptable control measures. Our knowledge of the biology and ecology of the most studied pest of forage tree legumes, the leucaena psyllid (*Heteropsylla cubana*), is still insufficient to achieve acceptable control (Napompeth and MacDicken 1990).

The leucaena psyllid does, however, demonstrate the devastation that insect herbivores can inflict. Even in more natural situations than Agroforestry, insects may consume more than other, larger herbivores. For example, over 60% of total leaf material consumed by herbivores in a South African savannah was eaten by insects, mostly lepidopteran larvae (Gander 1982). Such data must be considered as being only indicative as, in nature, damage levels are likely to vary among systems and among situations. In any case, the extent to which herbivorous insects have reduced the impact of weed species is a good measure of their capabilities against plant species, legume trees included (Hoffmann 1988, Moran and Hoffmann 1989, Hoffmann *et al.* 1990, Dennill and Donnelly 1991).

In dealing with specific examples of insect pests, their adaptations and ecology must be considered. Each species presents us with its own challenge, which may vary with changing environmental conditions from area to area and from time to time (Walter 1994). For example, trees may vary in their physiological status and this may in turn influence insect behaviour and abundance. Some herbivorous insects 'perform' better on stressed trees and the environmental cause of the stress thus induces herbivore outbreaks (White 1969, 1970a,b). Other insects (e.g. *Acizzia russellae* on *Acacia karroo*) may be primarily adapted to flushing growth, the production of which may enhance 'performance' (Webb and Moran 1978). Little is known about such influences on tropical forage tree legumes, but Singh (1986) found that the amount of damage to *Acacia nilotica, Dalbergia sissoo* and *Prosopis cineraria* varied with soil type. This presumably influenced the physiological status of the tree in relation to the pests, which were bagworms (*Cryptothelea cramerii*) and several species of chafer beetles (*Holotricha consanguinea, H. serrata, Adorata* spp. and *Anomala* spp.).

Although virtually all insect species exhibit some degree of host specificity and many are indeed species-specific in their host requirements, some herbivores can feed and reproduce on several host species, sometimes even on ones that are not closely related. Such polyphagous species present problems when populations transfer from one host species to a cultivated species. For instance, many borers have a wide host range. The teak sapling borer, *Sahyadrassus malabaricus,* feeds on many trees besides teak, including *Eucalyptus* spp. and the legumes *Paraserianthes falcataria* and *Calliandra calothyrsus.* Forage tree legumes planted in close proximity to teak plantations, for example, may be subjected to rates of colonisation by this pest that are higher than on trees further from teak plantations. Care should therefore be taken when planting tree legumes to ensure that such situations are avoided. However, in researching and interpreting the population biology of polyphagous species it is imperative to eliminate the possibility that one is combining species from different host plants, simply because they look alike. Mahon *et al.* (1982) provide an example involving such sibling species of leaf miners on jarrah (*Eucalyptus marginata*)*,* flooded gum (*E. rudis*) and prickly bark (*E. todtiana*)*.* The principles and appropriate techniques applied in the unravelling of sibling species complexes have been outlined by Paterson (1991).

Also of possible relevance to the cultivation of tree legumes is the phenomenon of 'induced resistance'. This arises when herbivory induces chemical changes in the plant, which may cause negative feedback on insects of the same species and sometimes even on other species (Haukioja 1991). The effect is so strong that it may influence population numbers of insects, even to the point of playing a role in population cycles (Haukioja 1991). The extent to which insect herbivory affects the nutritive value of tree legumes grown for forage is not known and requires evaluation (Bryant *et al.* 1991).

Non-insecticidal Techniques in Insect Control

Insecticides have been recommended for the control of a number of forage tree legume pests (Sen-Sarma 1987). For example, Monocrotophos was used to control the bark-eating caterpillar (*Indarbela quadrinotata*) on *Albizia lebbeck* in the Punjab (Sandhu *et al.* 1987). Although insecticides can be effective in increasing forage yield (e.g. Palmer *et al.* 1989) they are generally too costly for this purpose and less expensive alternatives should be sought.

Table 6.3.1. Insects that damage some important tropical forage tree legumes. The insect fauna associated with each plant in its area of origin is not included, and neither is *Heteropsylla cubana.*

Tree	Insect	Damage	Impact and comments	Place	Ref.*
Acacia nilotica	*Celosterna scabrator* (Cerambycidae)	stem and root borer	devastated trees, and taungyas had to be abandoned. May make establishment difficult.	India	1, 2, 3
	Cryptothelea cramerii (Psychidae)	leaf feeder	defoliation	India	4
	Ophiusa lanata (Noctuidae)	defoliator	under taungya situations	India	1
	Oxyrachis tarandus (Membracidae)	sap sucker	polyphagous pest	India	37
	Sphenoptera chalcichroa arenosa (Buprestidae)	bark tunnelling	dieback and gradual tree mortality	The Sudan	5
	Caryedon serratus (Bruchidae)	destruction to stored seeds	unknown	India	6
	Batocera rufomaculate (Lamiidae)	stem borer	not stated	India	37
Albizia	*Bruchidius* spp. (Bruchidae)	seed borer	unknown	India	7
	Bruchidius sparsemaculatus (Bruchidae)	seed borer	a new pest	India	8
	Ferrisia virgata (Pseudococcidae)	sap sucker	attacked in screenhouse	Nigeria	9
	Glophodes pyloalis	leaf feeder	serious defoliation	India	4
	Indarbela quadrinotata (Metarbelidae)	bark-eating caterpillar	considered a pest	India	10

lebbeck	*Oxyrachis tarandus* (Membracidae)	sap sucker	polyphagous pest	India	37
	Psylla hyalina (Psyllidae)	sap sucker	sometimes damages seedlings and saplings	India	11, 12, 13
	Spirama retorta (Noctuidae)	leaf feeder	defoliation	India	4
Calliandra calothyrsus	*Leucopholis irrorata* (Scarabaeidae)	leaf feeder	foliar damage of ornamentals	Philippines	14
	Myllocerus viridanus (Curculionidae)	polyphagous leaf feeder	considerable defoliation	India	15
	Pachnoda ephippiata (Cetoniinae)	feeds on fruits, flowers, and leaves	often total loss of seeds	Kenya	16
	Sahyadrassus malabaricus (Hepialidae)	borer	unknown	India	17
	"Similar to *Hypsipyla robusta*" (Pyralidae)	stem borer	about 40% of trees infested	Philippines	18
	Unidentified lymantriid	flower feeder	unknown	Philippines	14
Gliricidia sepium	*Azeta versicolor* (Noctuidae)	leaf feeder	defoliation; decreased yield of vanilla crop it was shading	Costa Rica	19
	Ferrisia virgata (Pseudococcidae)	sap sucker	attacked in screenhouse	Nigeria	9
	Sahyadrassus malabaricus (Hepialidae)	borer	is a pest	India	20
Leucaena collinsii	*Acanthoscelides macrophythalmus* (Bruchidae)	seed eater	unknown	Mexico	21
Leucaena diversifolia	*Acanthoscelides macrophythalmus* (Bruchidae)	seed eater	unknown	Mexico	21
	Spatularia mimosae (Tineidae)	seed feeder	high proportion of seeds damaged	Philippines	22, 23
Leucaena leucocephala	*Acanthoscelides macrophythalmus* (Bruchidae)	seed eater	unknown	Mexico	21
	Araecerus fasciculatus (Anthribidae)	seed boring beetle	major pest	Philippines	24, 25
	Asterolecanium pustulans (Asterolecaniidae)	sap sucker on branches and trunks	can kill trees	Taiwan	26
Leucaena leucocephala	*Coccus elongatus* (Coccidae)	sap sucker	occasional damage to stem, leaves and	Taiwan	

			seedlings		
	Coccus longulus (Coccidae)	sap sucker on branches and trunks	can kill trees	Taiwan	26
	Cerambycidae (undetermined sp.)	bores into stems and branches	minor pest	Philippines	25
	Cossus sp. (Cossidae)	bores into stems and branches	minor pest	Philippines	26
	Diaspididae (undetermined sp.)	sucks sap from stems and leaves	major pest, defoliate seedlings	Philippines	28
	Ferrisia virgata (Pseudococcidae)	sucks sap from stems, branches, leaves and fruits	major pest, causes wilting and defoliation	Philippines, Nigeria, India	28, 25, 9
	Gryllotalpa africana (Gryllotalpidae)	feeds on the roots	minor pest	Philippines	25
	Hemiberlesia implicate (Diaspididae)	sap sucker on branches and trunks	can kill trees	Taiwan	26
	Ithome lassula (Cosmopterigidae)	feeds on flower heads	affects commercial seed production	Australia	29
	Oncideres pustulata (Cerambycidae)	severs branches	serious pest	New World	30
	Spatularia mimosae (Tineidae)	seed feeder	major pest	Philippines, Taiwan	27, 25, 23
	Zeuzera coffeae (Cossidae)	bores into stems and branches	minor pest	Philippines	25
Leucaena pulverulenta	*Oncideres pustulata* (Cerambycidae)	severs branches	serious pest	New World	30
Leucaena sp.	*Apogonia rouca* (Scarabaeidae)	leaf-feeder	damages newly-emerged leaves and seedlings	India	31
	Oncideres sp. (Cerambycidae)	branch ring girdler	unknown	New World	30
Prosopis alba	*Oncideres pustulata* (Cerambycidae)	severs branches	serious pest	New World	30
Prosopis chilensis	*Oncideres pustulata* (Cerambycidae)	severs branches	serious pest	New World	30
Prosopis cineraria	*Celosterna scabrator* (Cerambycidae)	root and stem borer	has started attacking this host	India	37
	Oxyrachis tarandus (Membracidae)	sap sucker	polyphagous pest	India	37
Prosopis juliflora	*Oxyrachis tarandus* (Membracidae)	sap sucker	polyphagous pest	India	37
Sesbania	*Bruchophagus mellipes* (Eurytomidae)	seed feeder	requires control in stored seeds	India	34, 32

aculeata	*Dasychira mendosa* (Lymantriidae)	polyphagous leaf feeder	pest	Bangladesh	33
Sesbania esculenta	*Bruchophagus mellipes* (Eurytomidae)	seed feeder	unknown	India	34
Sesbania grandiflora	*Ceroplastodes* sp. (Coccidae)	sap sucker	rapid range extension and establishment	Andaman & Nicobar Islands	35
Sesbania rostrata	*Bruchophagus mellipes* (Eurytomidae)	seed feeder	unknown	India	34
Sesbania sesban	*Bruchophagus mellipes* (Eurytomidae)	seed feeder	unknown	India	34
	Ceroplastodes sp. (Coccidae)	sap sucker	rapid range extension and establishment	Andaman and Nicobar Islands	35
Sesbania speciosa	*Bruchophagus mellipes* (Eurytomidae)	seed feeder	unknown	India	34

* References: 1. Singh and Singh (1987); 2. Anon. (1981); 3. Ralph (1990); 4. Singh (1986); 5. El-Atta (1988); 6. Singal and Toki (1990); 7. Tewari and Arora (1984); 8. Verma *et al.* (1987); 9. Kadiata *et al.* (1992); 10. Das *et al.* (1985); 11. Hegde and Relwani (1986); 12. Singh *et al.* (1989); 13. Peter *et al.* (1990); 14. Braza (1991); 15. Ahmed (1989); 16. Kaudia (1990); 17. Nair (1982); 18. Luego (1989); 19. Young (1988); 20. Devasahayam *et al.* (1987); 21. Oakes (1981); 22. Braza (1988); 23. Braza (1989); 24. Braza (1987); 25. Braza and Salise (1988); 26. Chang *et al.* (1982); 27. Chang (1980); 28. Balakrishnan *et al.* (1991); 29. Beattie (1981); 30. Felker *et al.* (1983); 31. Pawar (1986); 32. Verma (1991); 33. Das (1990); 34. Bhalla *et al.* (1988); 35. Shah *et al.* (1989); 36. Sen-Sarma (1987)

The use of azadirachtin, an isolate of neem seed kernels, is recommended against defoliators in places where it is economical because it is said to be safe to humans (Sen-Sarma 1987).

Behavioural and genetical methods of control

Many insect species (particularly those that mate predominantly at night) communicate sexually with volatile chemicals called pheromones. For many pests, pheromones have been analysed and synthesised. As a bait in appropriately designed traps, pheromones are effective in luring conspecific insects (of the sex that responds to the pheromones), even when densities are so low that the insects are otherwise undetectable. Pheromone traps are thus useful for monitoring insect population levels so that other control measures can be instituted at the most appropriate time. Pheromones are also used in orchards to 'confuse' mating efforts and thus reduce oviposition. This latter application may be impractical for agroforestry conditions except perhaps under unforeseen circumstances that may arise in the future.

Sterile insect methods have been used successfully against insects that are pests at low density (e.g. screwworm flies in America) or pests that need to be exterminated on accidental introduction into a new area (e.g. medflies in California). These methods would generally be too costly for agroforestry.

Plant varietal resistance

Breeding programmes can produce tree varieties that are resistant to a particular pest species that causes severe damage. This has been done with leucaena and some bred cultivars are being developed which are quite effective against the leucaena psyllid. Unfortunately, resistance in this species is associated with high tannin content, which decreases the forage value of the plant. However, the resistance mechanism in leucaena is not understood, and this retards progress in selecting for resistance as breeders have no way of assaying their progress on the basis of chemical analysis rather than on observed resistance to the pest (A. Castillo and H.M. Shelton, unpublished data).

Transgenic potato and cotton plants, with the gene for producing *Bacillus thuringiensis* toxin introduced into their genome, are now being investigated for possible cultivation. This may be a possibility for defoliating pests (usually caterpillars) of tree legumes that are killed by the toxin.

Cultural methods or ecological management

Cultural control methods are diverse and rely on a good understanding of the pest species' ecology in relation to the production system. Not all would be appropriate for pest management in forage tree systems because the environment is not manipulated to the extent it is in cropping systems. However, combinations of plants in mixed systems can be selected to ensure that pest populations are not inadvertently enhanced by the provision of a good alternative host for a particular pest species. Also, stored seed may be protected by manipulating the storage environment and practising good sanitation nearby.

Biological control

Effective biological control has many advantages, especially if it is of the self-sustaining type. Unfortunately the success rate of biocontrol is, in general, quite low. A substantial effort in locating species-specific parasitoids or predators is necessary, as shown by the exploration for leucaena psyllid natural enemies (Waage 1990). Furthermore, an appropriate research base on the species status of the natural enemies and host would substantially reduce the possibility of costly mistakes, which is an ever-present possibility (Paterson 1991). It is noteworthy that the leucaena psyllid is thought to have 'host races' (Waage 1990), which is often a good hint that host-specific sibling species may be present.

Conclusions

Alternatives to chemical control are available for dealing with insect pests of tree legumes. Biological and varietal control are probably best suited to the requirements of forage production and to the means and available resources of the grower. Chemicals can be quite effective even if little is known about the pest species, and the same chemical can be used to kill insects of several species. In contrast, alternative methods of control require a substantial understanding of each insect pest species as the design of the treatment centres around the unique adaptations and ecology of each species. To date, such understanding of forage tree legume pests is lacking.

Insect biocontrol has been successful in the past with relatively little research effort and the programmes that have worked well are the most widely quoted, for example, the Australian bug (*Icerya purchasi*) in California (Doutt 1958). Most introductions in biocontrol projects have, however, not succeeded and to improve the success rate we must follow basic principles in species theory (Paterson 1991). The appropriate research on the host relationships of parasitoids in nature and the specificity of predator-prey relationships in nature must also be conducted for each species involved. Climate matching between the proposed biocontrol site and the area that is explored for natural enemies may enhance the chances of success (Kennett *et al.* 1966).

Finally, the breeding of resistant varieties may be aided considerably by an understanding of the chemical or other basis of resistance and of the way in which the target insects are affected.

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7.1 Management of Mulga (Acacia aneura) Scrublands in Southwest Queensland

I.F. Beale

Introduction

The mulga lands of southwest Queensland are dominated by the woody species *Acacia aneura,* and have been grazed by domestic animals since about the 1860s. In this time, grazing has gone from a very extensive system with animals dependent on natural waters to relatively well fenced properties that are well supplied with permanent waterpoints. Grazing is now non-migratory with stock spending their entire year within the property boundary. This section deals with some points of management that have been highlighted by experience.

Climate

The climate of southwest Queensland is semiarid to arid. Its features are:

- predominantly summer (October to March) rainfall, with an increasing winter component towards the south,
- high summer temperatures,
- increasing frost incidence towards the south,
- high rainfall variability,
- high evaporation rates, and
- frequent drought incidence.

Rainfall and evaporation

Average annual rainfall decreases from 500 mm in the east to less than 180 mm in the west. Rainfall also decreases in a southerly direction, with Blackall receiving 528 mm annually and Cunnamulla 366 mm.

Rainfall is generally, although not always, summer dominant. Evaporation is high and ranges from 2,100 to 3,000 mm annually - four to five times the annual rainfall. Average monthly evaporations vary from 280 mm in December to 75 mm in July (all from a free water surface).

Temperature

Mean temperatures increase with a southeast to northwest trend. The hottest months are January and December with mean maximum and minimum temperatures at Charleville of over 35℃ and 21℃ respectively. In the coldest month, July, the equivalent temperatures are 19℃ and 5℃ respectively.

Temperature extremes recorded in the area range from 46℃ to -6℃. The bulk of pasture growth occurs in the summer months provided moisture is available. High temperatures affect the eating, drinking and resting behaviour of stock, even when good forage is available. Animal production can therefore fall in excessively hot weather.

Extremely low temperatures limit pasture growth and can also adversely affect animal performance, for example, increased lamb mortality in open areas.

Rainfall effectiveness, plant growth and drought

Rainfall is well below evaporative demand, and moisture deficit is common. Soil moisture is generally inadequate for reliable cropping. This confines rural industry mainly to the grazing of sheep and cattle.

During rainfall, some water enters the soil and some is lost as runoff. If sufficient moisture is retained, vegetative growth results. Under the high evaporative demand the soil dries rapidly and plant growth ceases without further rain. Hence plants in the region are characterised by relatively short periods of growth separated by longer periods of inactivity. Extended periods of low soil moisture and a low pasture growth lead to feed shortages. Droughts are a regular feature of the region, not freak events.

Soil Characteristics

Soil type

The soils are characteristically infertile red earths (Gn 2. 11, Gn 2.12) sandy loams to clay loams. Major features of the soils are severe deficiency of available phosphorus and nitrogen, high levels of iron, manganese and aluminium, an acid profile and a densely packed surface layer (bulk density > 1.4). Even in good conditions, these soils have nutrient levels that are low (Table 7.1.1). Topography is gently undulating, with isolated residuals.

Soil/water considerations and soil erosion

Due to the high soil bulk density (Table 7.1.1), infiltration of water is slow in mulga areas. With rainfall already low, and growth usually limited by moisture availability, loss by runoff exacerbates unfavourable conditions for plant establishment and growth. The amount of runoff and the requirement for ground cover have been addressed by Pressland and Lehane (1980, 1982) and Miles (1990a). As an example, a site with a ground cover of about 35% lost about 80% of the water resulting from a storm. A neighbouring site with 70% cover lost about 15%. Unfortunately, the ready availability of water for stock and the use of mulga as a supplement for livestock allows animals to be maintained on mulga country even in drought, and can result in values of ground cover of much less than 35%.

Table 7.1.1. Properties of a mulga soil from the Charleville Experimental Reserve.

Depth (cm)	Bulk density (g/ml)	pH (1:5, H_2O:Soil)	Total P (ppm) (acid)	Avail. P (ppm)	Total N (%)
0-25	1.8	5.5	263	8	0.05
2.5-5.0	1.6	5.4	230	4	0.06
5.0-10	1.6	5.5	228	3	0.04

10-25	1.6	5.0	223	3	0.04
25-50	1.6	4.9	171	2	0.04
50-100	1.6	5.2	168	2	0.02

Depth (cm)	**Exchange cations**				**Org. C (%)**	**C:N**
	Ca	**Mg**	**Na**	**K**		
0-2.5	1.7	0.3	0.05	0.36	1.3	26
2.5-5.0	0.9	0.1	0.05	0.29	1.0	17
5.0-10	1.6	0.2	0.05	0.31	0.9	22
10-25	1.6	0.2	0.05	0.29	0.8	20
25-50	0.9	0.1	0.05	0.19	0.5	12
50-100	1.2	0.2	0.05	0.16	0.4	20

Nutrients in mulga soils occur in the top 10 cm of soil, with little nutrient cycling to lower soil depths. Loss of this small amount of top soil reduces plant growth potential to about half (Pressland 1985, Pressland and Cowan 1987, Miles 1990b). Loss of ground cover allows accelerated loss of this soil layer.

In contrast, there is a build-up of plant nutrients under the canopy area of some deep-rooted trees (particularly *Eucalyptus* spp.) which can aid establishment and production of herbaceous species (Ebersohn and Lucas 1965, Christie 1975c).

Vegetation

Native species

Mulga (*Acacia aneura*) occurs over a wide geographical range in Australia (Nix and Austin 1973) (Figure 7.1.1). In this range, the area around Charleville achieves some of the highest plant densities and yields of mulga. The undisturbed area at the Charleville Experimental Reserve has a density of about 7,500 stems per hectare. Mulga is a surface rooted species. It appears that fire previously kept mulga density low so that plant communities appeared as an open savannah.

There are other trees associated with mulga, for example, poplar box (*Eucalyptus populnea*) with densities of about 100 per hectare. This is a deep-rooted species. Often there is also a woody shrub population with species such as green turkeybush (*Eremophila gilesii*), grey turkeybush (*E. bowmanii*) and false sandalwood (*E. mitchellii*) common.

The herbaceous ground layer is comparatively poor and is dominated by shallow-rooted species. A range of perennial and annual species may be present depending on season, woody plant density and amount of grazing. While forte species are common after cool season rain, leguminous forte species are rare.

Some of the native grasses are very useful for grazing, for example, mulga Mitchell (*Thyridolepis mitchelliana*) and mulga oats (*Monacather paradoxa*). Others (*Aristida* spp.) provide ground cover but are undesirable from an animal production perspective. In this case, their sharp awned seed heads cause vegetable fault in wool and pelts, reduce income, and can cause problems with animal health. Some species are known to be poisonous to livestock, for example, wild parsnip (*Trachymene* spp.), *Solanum* spp. and *Euphorbia* spp. Others that occur on more fertile drainage lines include fuschias (*Eremophila* spp.) and ellangowan poison bush (*Myoporum desert*)*.*

The potential use of mulga in other regions of the world requires consideration of environmental factors influencing the growth of these species. These include an infertile acid soil, a seasonal rainfall pattern and hot summers with frosts in winter. Similar homoclimates are rare worldwide (Meigs 1955).

Introduced species

Introduced species have not been successful in the mulga region. Extensive testing of introductions at the Charleville Pastoral Laboratory (more than 500 accessions) has not produced species superior to the buffer grass (*Cenchrus ciliaris*) cultivars previously introduced. The spread of buffer grass in mulga country is limited by soil phosphorus levels (Christie 1975a,b, Christie and Moorby 1975, Silcock *et al.* 1976) and other factors including slowness to tiller and a long juvenile period before flowering (Silcock and Whalley 1974, Silcock and Williams 1976). Establishment can be enhanced by the use of phosphorus pelleting of the seed (Silcock and Smith 1982), but good management is required to maintain a viable pasture.

Fig. 7.1.1. Distribution of mulga (*Acacia aneura*) in Australia. (Nix and Austin 1973).

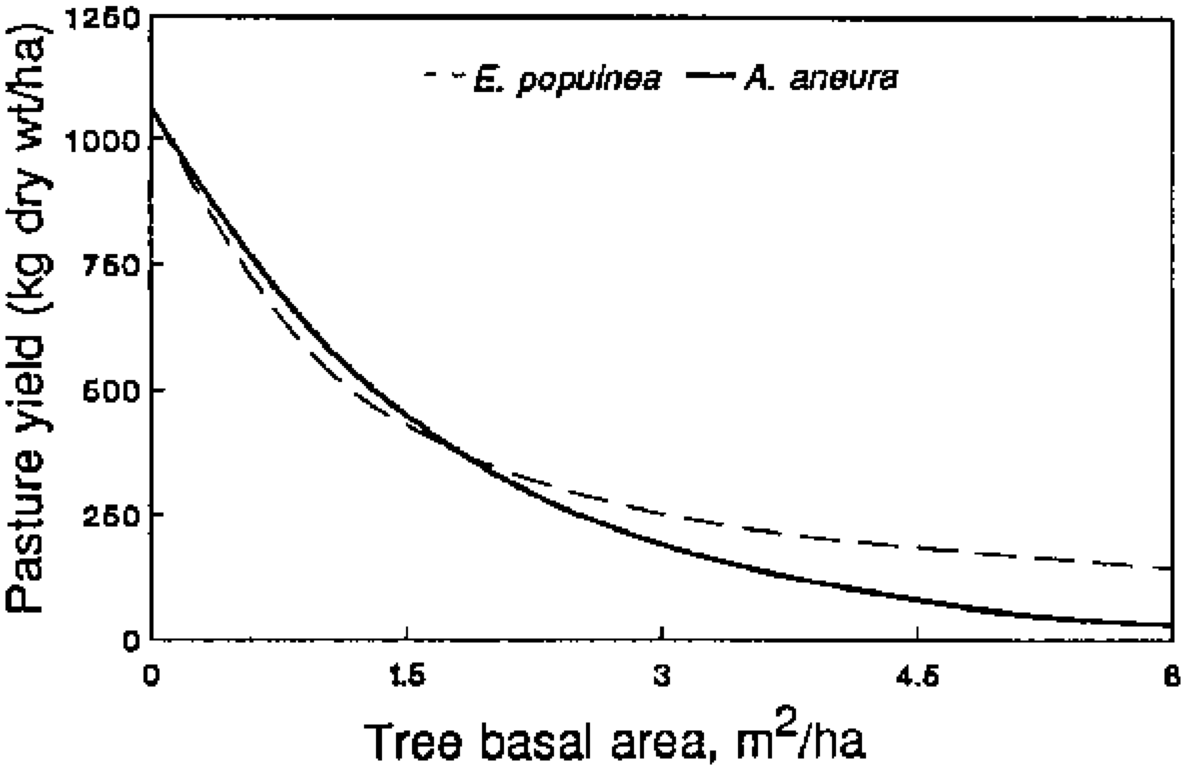
Introduced weed species (both woody and others) are also of some concern, for example, mesquite (*Prosopis* spp.) at Quilpie and McKinlay and prickly acacia (*Acacia nilotica*) in the northwestern Mitchell grass region (Section 7.2).

The poor results with introduced pasture species has led to a focus of effort on management of native pasture species. This includes research on establishing a native seed industry, commencing with mulga Mitchell (*Thyridolepis mitchelliana*) and mulga oats (*Monacather paradoxa*).

Ecology

In general as the amount of woody species increases as measured by canopy cover or basal area, the amount of pasture produced decreases (Figure 7.1.2) (Beale 1973, Walker *et al.* 1972). The same is true of woody shrubs (Carter and Johnston 1986). In this region, grass growth is favoured by summer rains whereas woody species are favoured by winter rains. Thus there is a need in the management of mulga scrubs to balance the production of ground storey pasture against the need for reserves of mulga for drought fodder.

Fig. 7.1.2. The relationship between tree density and herbage yield in mulga and poplar box wood lands.



It has been calculated that, for a mulga property of 12,000 ha, with 710 mulga trees per hectare and 5,000 sheep, that 7,000 ha of mulga could be cleared for ground storey production without depleting drought reserves (Pressland 1975).

Woody shrub species (green and grey turkeybush, hopbush, Cassia) are generally unpalatable. Their increase reduces pasture production without making a meaningful contribution to animal production. There is a need to control these species as a pattern of increase has been observed (Burrows *et al.* 1985).

Management of the region is also complicated by vegetation responses to climate and management as outlined by Burrows (1980). This is similar to the states and transitions of rangeland vegetation change proposed by Westoby *et al.* (1989). Miles (1990b) has outlined a likely grazing gradient for mulga (Figure 7.1.3). Some of the transitions are unlikely to reverse without assistance and cost.

Work is in progress to improve management on a property scale by using rainfall use efficiencies for the various land system areas to estimate potential plant growth and thus carrying capacity.

Fig. 7.1.3. Vegetational changes down the degradation gradient for a mulga community (after Miles 1990b).

Germination and Establishment

Some germination of pasture species usually occurs after effective rainfall (20 mm in summer, 10 mm in winter). Germination is more prolific in spring and autumn months with midsummer and midwinter being unfavourable. Microhabitats favour seed germination, but these areas may change or migrate with time, for example, accumulations of wind blown sand or surface washed litter.

Generally seed viability increases with seed age up to 3 years, with the effect being more pronounced in grasses. Dormancy is evident in fresh seed but largely disappears after 1 year (Silcock and Williams 1975a,b, Silcock and Smith 1990).

Range Condition

Much of the mulga lands is in a degraded state as shown by Mills *et al.* (1989). In a survey of some 70 properties (3 million hectares) they found:

- unpalatable woody shrubs on 51 properties (about 132,000 ha),
- potential woody shrub problems on another 17 properties (about 630,000 ha),
- 56 of the properties (79% of the area) had less than the recommended mulga density of 160 trees/ha,
- 54 properties had more than 60% of the soil surface exposed (64% of the area),
- erosion affected 32 properties substantially, was minor on 11 and was negligible on 32,
- perennial grass cover was comparatively low (less than 6% canopy cover) on 30 properties, and
- pasture biomass levels were less than 100 kg/ha on about 80% of the area, indicating low regional productivity.

Management

Pasture utilisation levels

Seasonal pasture production has been used as a basis for grazing management. It has been found that stocking rates set to use about 20% of the end of summer growth over the next year tended to maximise production per animal and to minimise fluctuations in animal numbers (and hence stock trading) and the effects of drought, and thus were financially preferred.

In mulga, in the short term, grazing needs to be managed to maintain ground cover to reduce rainfall runoff and soil erosion. Stock management (particularly in drought with mulga feeding) can work against this. In the longer term, effects of animal behaviour (for example, patch grazing) can change vegetation composition over time.

Control of weeds

While most of the problem species can be controlled relatively easily with chemicals, the cost of this is generally prohibitive. Thus chemical control is generally restricted to special problems and small areas. As property values in the mulga region are low, control methods must be low cost.

The control method that has the most potential is fire, but graziers are generally reluctant to use it. Species vary in their succeptibility to fire. Generally woody species are easier to control as seedlings. As woody species increase in size, there are losses in pasture production and potential fuel load. Thus chances of a control burn decrease. The effect is magnified by heavy stocking rates (Carter and Johnston 1986) (Table 7.1.2).

Table 7.1.2. Percentage of years with total standing dry matter greater than 1000 kg/ha (1889-1984) as affected by canopy cover and utilisation.

% Canopy cover	Pasture utilisation	Pasture utilisation
	20%	40%
0.0	63.8	36.2
7.5	36.2	14.9
10.0	12.8	2.1
20.0	0.0	0.0
50.0	0.0	0.0

Stocking rate

The effects of increasing stocking rate on animal production per head and per area were outlined by Jones and Sandland (1974). Production per area rises to a peak value and then falls. In practice, the best financial returns are at a stocking rate below that at which maximum production is obtained. Indications are that, in semiarid and arid conditions, conservative stocking rates minimise climatic risk and can be financially viable in the long term (Beale *et al.* 1986, Morrissey and O'Connor 1988).

Stock management in the mulga lands is traditionally by continuous grazing, with animal performance the main criterion of management. Rates have in general been derived by traditional wisdom. While these may be reasonable in concept, there are two problems:

- while the rates are initially reasonable, there may well be changes in vegetation induced by effects of grazing, and
- where the resource is in decline, these rates may not be adjusted to match the rate of decline.

It can be argued that both of these problems are evident in the mulga lands. Management to ensure that stocking rates are based on the feed available rather than on unit area, is a start to overcoming these problems.

Grazing time

While continuous grazing can be detrimental in the long term, there also appears to be little place for more formalised rotational systems (Bryant *et al.* 1989). However, strategic management such as spelling pastures to allow seed set to allow recovery from grazing particularly after drought or to allow fuel build-up for burning will be necessary in mulga country. This is an evolving area of research and management, and will be influenced by work such as that of O'Reagain and Turner (1992) who concluded that:

- stocking rate has a major impact on range condition and animal production,
- continuous and rotational grazing differ little in effect on range condition or animal production,
- sheep have a greater potential for range degradation than cattle or goats though this effect can be reduced by stocking in mixtures with cattle,
- separation of vegetation types is important, and
- regular rests for seeding, regrowth and fodder accumulation, are essential.

Effect of stock supplementation

Supplementation with mulga feeding is examined in Section 4.6. Supplementation can increase animal productivity so fewer stock need to be mainlined, but it can also cause stock to be maintained on an area for longer, and promote loss of ground cover. This can lead to increased runoff and soil erosion and long term loss of productivity.

Kangaroos, native and feral animals

Kangaroo numbers have increased with the development of permanent water points for domestic livestock. They now compete with domestic livestock, and are estimated to cost the wool industry up to $A200 million in lost production annually. The effects of the grazing kangaroos can also contribute to land degradation (Miles 1989) (Table 7.1.3).

Mixed animal grazing

Holmes (1986) found that graziers in some parts of the mulga zone run both sheep and cattle. It appears that there is a complementary grazing effect, but there has been no research on optimum ratios. All properties are grazing kangaroos as well.

Monitoring sites

With changes in grazing management systems, there is a need to monitor effects of changes in management. Thus the Mulga Assessment Program has been developed to encourage graziers to monitor botanical and ground cover changes on their own properties. Plant identification manuals have been produced to assist in the monitoring process.

Table 7.1.3. Biomass comparisons of two monitor sites in the mulga lands of southwest Queensland under various exclusion regimes.

Site	Exclosure type	Biomass (kg/ha)	
		Year	
		1987	1988
1	Kangaroos and livestock excluded	521	460
	Livestock excluded	343	278
	Open	309	269
2	Kangaroos and livestock excluded	313	302
	Livestock excluded	132	120
	Open	128	108

Management of the Whole Property as an Enterprise

In summary, grazing involves a programme of whole property or enterprise management, which takes into account:

- drought and other seasonal conditions,
- use of land system information for fencing, water point distribution and retention of wildlife habitats,
- monitoring of both range and animal condition,
- management of pasture, livestock and wildlife,
- management of finances and marketing, and
- monitoring of potential effects of supplementation on degradation.

Degradation is expensive to treat in extensive low input-low output regions. The best degradation control is not to allow movement from the first state on Figure 7.1.3.

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7.2 Acacia nilotica: a Tree Legume out of Control

J.O. Carter

Introduction

Acacia nilotica, a species of thorny acacia introduced into northwestern Queensland late last century or early this century, is spreading at an alarming rate. Large areas of formerly treeless, Mitchell grass (*Astrebla spp.*) plains are being invaded by this species creating problems with management of sheep and cattle. Although it is serious weed, the species produces reasonable quality browse, high in tannins.

Taxonomy

Acacia nilotica (L.) Del. is a thorny wattle native to India, Pakistan and much of Africa. Nine subspecies are currently recognised (Brenan 1983); only one subspecies, *Acacia nilotica* subsp. *indica* (Berth.) Brenan, is found in Australia. Until 1940, the Australian species was regarded as *Acacia arabica*; however, Hill (1940) cleared the confusion with nomenclature and declared the name given by Linnaeus in 1753 as the correct one.

Distribution and Habitat

This acacia is widely distributed in tropical and subtropical Africa from Egypt and Mauritania to South Africa. Some subspecies are widespread in Asia as far east as Burma. *Acacia nilotica* subsp. *indica* grows in Ethiopia, Somalia, Yemen, Oman, Pakistan, India and Burma. It has been cultivated in Iran, Vietnam (Ho Chi Min City), Australia (Sydney and Queensland) (Brenan 1983) and the Carribbean. This subspecies is commonly found on soils with a high clay content, but may grow on deep sandy loam in areas of higher rainfall. It commonly grows close to waterways on seasonally flooded river flats and tolerates salinity well. It will grow in areas receiving less than 350 mm of rainfall to areas receiving more than 1,500 mm per annum. The species is reported to be very sensitive to frost, but will grow in areas where the mean monthly temperature of the coldest month is 16℃ (Gupta 1970).

In Australia, the major areas of *A. nilotica* are in Queensland with small infestations reported from the Northern Territory, New South Wales and South Australia. Frost limits the distribution of the plant in southern states. Data derived from Bolton and James (1985) show infestations of about 6.6 million hectares, or 25% of the Mitchell grasslands, with dense areas of about 0.6 million hectares. The distribution and density of the species is increasing (Reynolds and Carter 1990).

Uses

In Africa and the Indian subcontinent, *A. nilotica* is extensively used as a browse, timber and fire-wood species (Gupta 1970, Mahgoub 1979, New 1984). The bark and seeds are used as a source of tannins (New 1984, Shetty 1977). The species is also used for medicinal purposes. Bark of *A. nilotica* has been used for treating haemorrhages, colds, diarrhoea tuberculosis and leprosy while the roots have been used as an aphrodisiac and the flowers for treating syphilis lesions (New 1984). The gum of *A. nilotica* is sometimes used as a substitute for gum arabic (obtained from *A. senegal*) although the quality is inferior (Gupta 1970). The species is suitable for the production of paper and has similar pulping properties to a range of other tropical timbers (Nasroun 1979).

History of Invasion in Australia

Acacia nilotica was probably introduced into Australia in the late 1890s or early 1900s and the first recorded specimen in a herbarium was collected in 1914. The plant was actively spread as a shade tree along bore drains throughout central-western and northwestern Queensland. A series of above average wet years in the early to mid 1950s led to a spectacular increase in tree density especially on town commons. In 1957, the plant was declared a noxious weed following concern about its rapid spread in previous years. Landholders were required to remove all plants, but few did so and planting continued. Many plantings were along bore drains (long open drains distributing artesian water). These plants grew rapidly and the constant water supply ensured a large seed set. Seeds from these trees were spread by animals throughout properties and during above average wet years in the mid-1970s germination of this soil seed bank resulted in up to 1,000 fold increases in the number of plants on individual properties. The properties with greatest density of plants today, are those which had bore drains lined with trees prior to the wet years of the 1970s. Properties with cattle rather than sheep tend to have more serious infestations.

Although most germination and spread of new seedlings occurred in very wet years, some establishment occurred every few years. The recent prolonged drought has reduced tree density in some areas by up to 80%. However, soil seed banks are still large, and much larger than they would have been 20 years ago. A recurrence of above average summer rainfall could result in a further massive increase in plant populations. The pattern of invasion has been exponential in nature but in a stepwise fashion associated with wet years. Calculations of the area of land infested with *A. nilotica* in the early 1980s, estimates of infestation before 1970 and a projection for the future are presented in Figure 7.2.1.

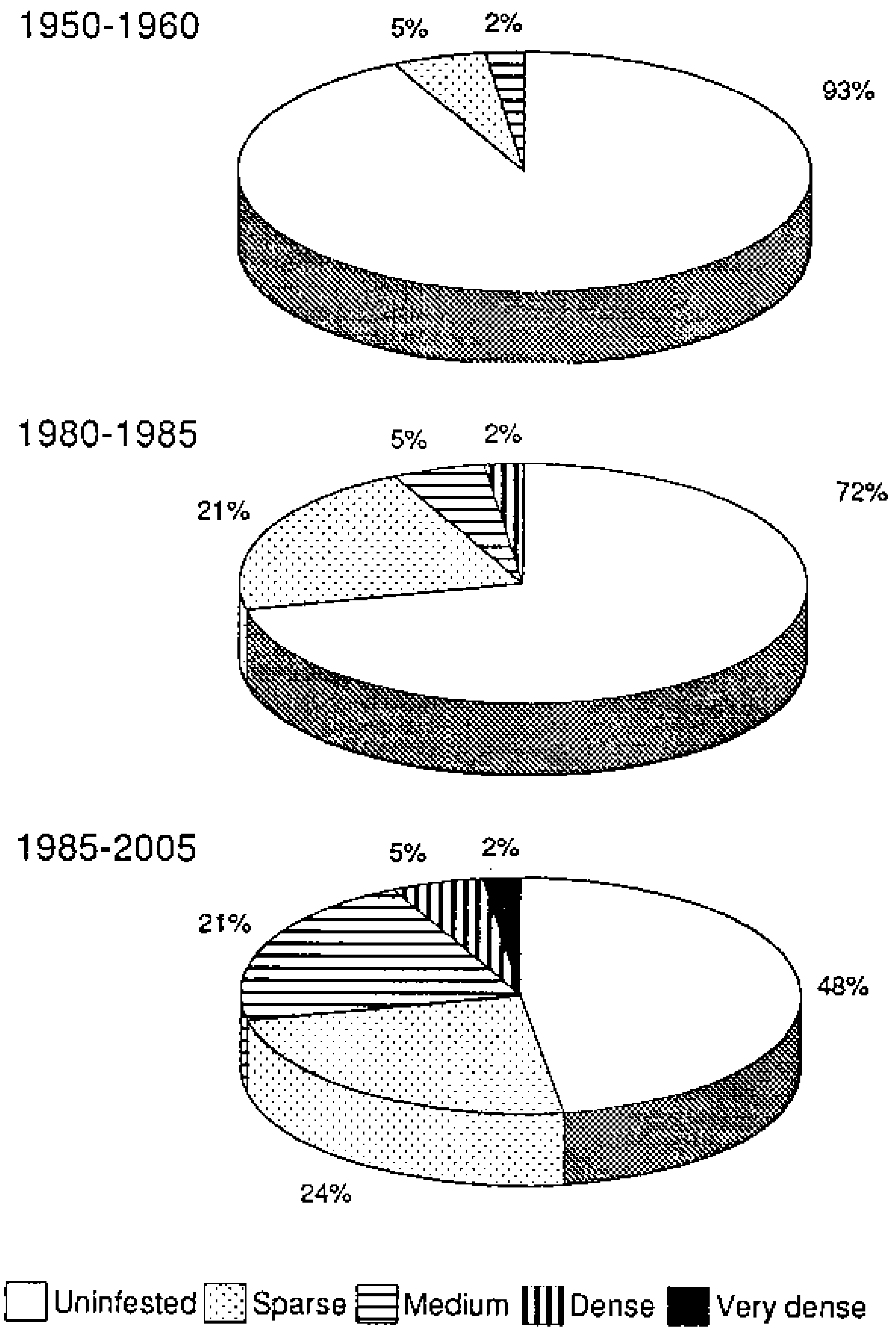
Ecology

There is some evidence that *A. nilotica* is a weed in its native habitat e.g. South Africa (Holm *et al.* 1979), but in other areas it is planted for forestry or reclamation of degraded land (Purl and Kybri 1975, Shetty 1977). In both Asia and Africa, the plant and seed pods are eaten by domestic grazers and browsers such as cattle, sheep, goats and camels (Gupta 1970). Other animal species which browse and eat seed pods are impala, Thompson's gazelle, dorcas gazelle, dikdik, elephant, giraffe, kudu and mountain goat (Lamprey *et al.* 1974). Seed dispersal is mainly via these browse animals. In Australia seed spread is via domestic animals. In Africa and India, there are also large numbers of insects which attack the mature seed.

Phenology

In Queensland, *A. nilotica* flowers from March to June with green pods being present in the driest part of the year, July to December (Figure 7.2.2). Leaf production and fall appears to be determined by availability of soil moisture (Carter and Cowan 1988) and up to 75% leaf fall occurs in the dry season. In contrast, in the Sudan, *A. nilotica* flowers irregularly but usually in the period June to September, with seeding occurring from January to May. Extensive leaf fall occurs in April-May with re-foliation in March-April. Leaf production and fall is similarly influenced by rainfall, whereas temperature affects flowering and fruiting (Khan 1970). In Australia, the intact ripe pods fall from November to February.

Fig. 7.2.1. Spread of *Acacia nilotica* in the Mitchell grass areas of western Queensland.



Seed Production

Seed production by *A. nilotica* is very high if trees are well watered. Trees planted along bore drains, dams or creeks produce large numbers of seeds every year. In areas with no permanent source of water, e.g. open downs, seed production is low (perhaps only a few pods per tree) unless there is significant winter rain. Along 3 km of bore drain at Toorak Research Station, estimated seed production in 1986/87 and

1987/88 was 18.6 and 24.0 million seeds respectively. Good relationships between tree basal area and seed production exist (Bolton *et al.* 1987). The half life of seed produced by trees on bore drains is between 10 and 12 months but may be longer for the smaller, harder seeds produced by trees with no permanent water supply.

When seed pods fall they are rapidly eaten and seed is dispersed by domestic stock. The rapid consumption of the ripe seed reduces insect predation of seed to a low level. Insects such as *Caryedon serratus* (Coleoptera Bruchidae), a native seed boring beetle, and *Bruchidius sahlbergi* Schilsky (Coleoptera: Bruchidae), a seed boring insect introduced as an attempt at biological control, do not destroy seed if animals ingest seed soon after ripening (Lamprey *et al.* 1974). Consequently, biological control by these seed destroying insects will not be effective.

Fig. 7.2.2. Green pods on *Acacia nilotica* in November near Longreach, Queensland.

Seed Dispersal

Seed dispersal of *A. nilotica* occurs in several ways. Dispersal over long distances occurs when animals with ingested seed are moved by road transport over large distances (e.g. 1,000 km or more). Some spread of seed also occurs by wind and water.

Cattle are the most effective agents of seed dispersal and up to 81% of seed ingested passes through the animal intact. Tests have shown that at least 41% of this seed is readily germinable (Harvey 1981); furthermore, the presence of seed in a favoured environment (manure) can lead to a survival advantage compared with seed placed on the open ground.

Sheep spread seed by three mechanisms:

- spitting out of seed and pod breakage during eating (35%) (usually under existing trees),
- spitting out seed from regurgitated material (14%), and
- seed passing through the animal in faeces (2%).

Passage through the rumen takes at least 6 days and other ruminants probably have similar or longer retention times. Goats spread seed in a manner similar to sheep with spitting out accounting for 24% of seed ingested, and passage via the faeces only 2.3%. Seed regurgitated or passed by sheep and goats is more than 80% viable. Emus, a major spreader of *A. farnesiana* (a native thorny acacia) do not appear to eat *A. nilotica* and no seed has been found in droppings.

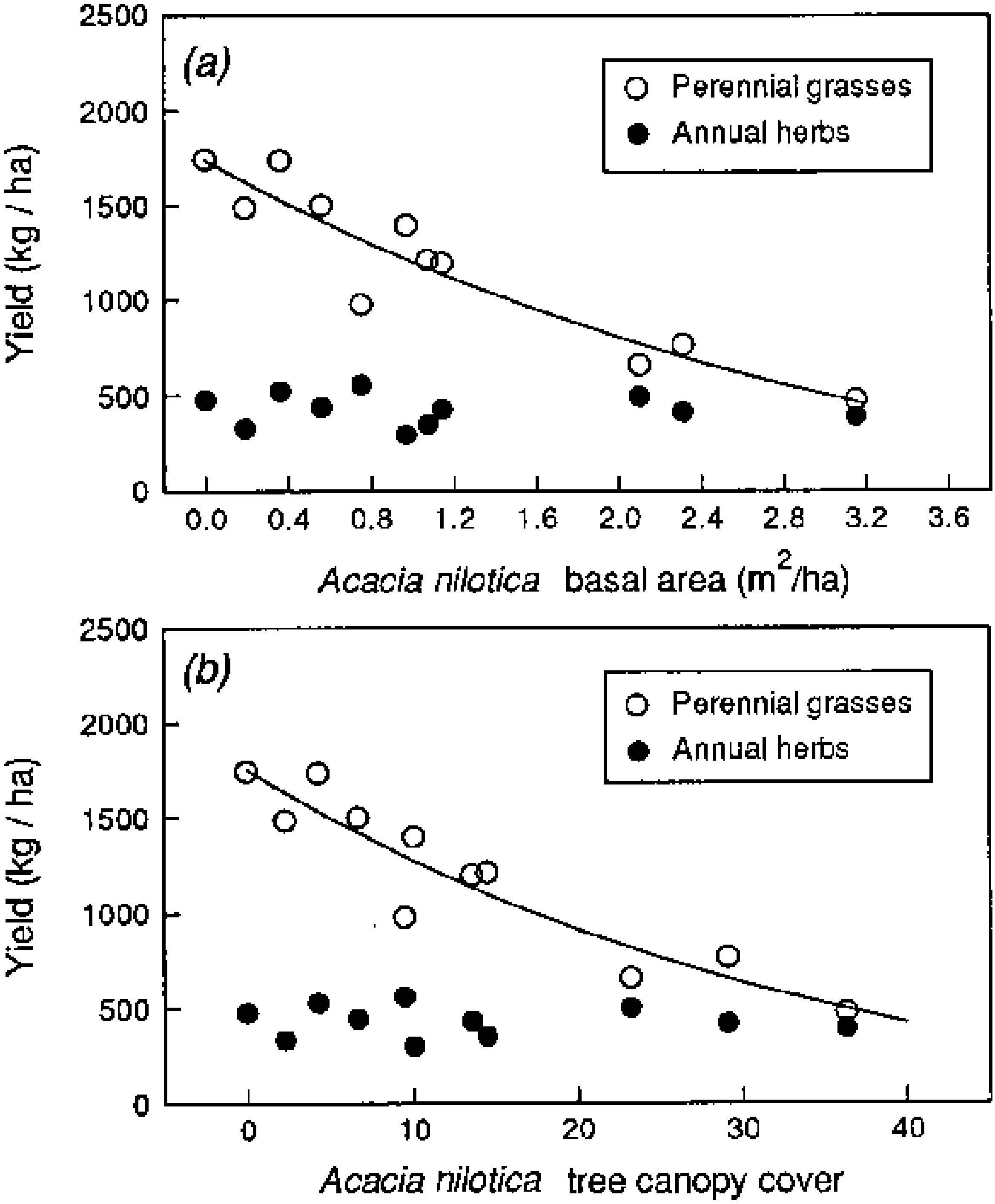
Short distance dispersal can be in mud packs formed on animals' hooves during wet periods, or by wind which may blow seed pods from tall trees for distances of up to 25 m. Flood waters can carry seed for significant distances. Many creeks in northwest Queensland have lines of trees which have grown from pods deposited at the edge of flood lines. River systems draining to the Gulf of Carpentaria and Lake Eyre are infested with drainage lines are a significant cause of inter- and intra-property spread.

Effect of Trees on Grass Production

In the Mitchell grasslands of northwest Queensland, *A. nilotica* suppresses pasture production by 50% at 25-30% tree canopy cover or 2 m^2 basal area per hectare (Figure 7.2.3). Maximum canopy cover and basal areas for *A. nilotica* in northwest Queensland are about 35% and 3.5 m^2/ha respectively.

These relationships for an average year, illustrated in Figure 7.2.3, are similar to those found in eucalypt and mulga communities and follow the form of a Mitscherlich equation $y = A + B * e^{-kx}$, where y is the yield of herbaceous species, x is the tree basal area and k is the slope of the line. The generalised relationship developed by Scanlan and Burrows (1990) shows that the slope of the curve (k value) can change with moisture and nutrients (site potential). Under ideal conditions the curve is flat, with suppression of grass being linear with tree basal area; however, as conditions worsen during drought, trees increasingly suppress grass production. The yields of annual and ephemeral plant species do not appear to be affected by tree density.

Fig. 7.2.3. Effect of *A. nilotica* on pasture production (kg/ha).



Acacia nilotica as a Browse Plant in Queensland

In the Mitchell grasslands, the plant is commonly browsed when there is an absence of green feed. The Mitchell grass system is driven by summer rainfall and in most years there is little green growth from May through to the first summer rainfall. The protein content of early green Mitchell grass leaf may be as high as 18%, but this rapidly declines and by the end of the season, ranges from 2.5 to 4.5% which is insufficient to maintain animal productivity. Mitchell grass pastures may also provide diets low in phosphorus, sodium and copper (McMeniman *et al.* 1986a). However, though old dry Mitchell grass will not maintain body weight in sheep or cattle, the presence of a robust grass species does provide a base diet during those months when more palatable feed is absent.

Browse and pod fall (November to February) can be an important supplement for animals grazing the low quality Mitchell grass pastures. Pod production occurs during the driest months of the year, and there is usually little pod set away from permanent water. However, trees growing along flowing bore drains can produce c. 1,000 kg of pods per kilometre. The average property in northwest Queensland has about 7 km of these drains.

In dry times, sheep, cattle and goats actively seek leaf and stem. Goats, and to a lesser extent sheep, also eat the bark of young trees, and sheep eat fallen flowers. Landholders cut trees down or lop branches to provide extra material for animals during drought, although leaf availability is at a minimum during these times.

Quality of Browsed Components of A. nilotica

Acacia nilotica leaf is very digestible and has high levels of protein. In some samples protein levels were higher than those for lucerne hay and much better than those for dry Mitchell grass (Table 7.2.1). Micronutrients, with the exception of sodium, are adequate for animal requirements.

The amino acid profile of *A. nilotica* leaf is similar to that of Mitchell grass leaf. However, the fruit is higher in glutamic and aspartic acid and lower in most other amino acids (Table 7.2.2). The amino acid methionine (an amino acid essential for wool growth) was absent from the fruit of Australian material but present in the seed of African material.

In the Mitchell grass/A. *nilotica* system, the tree legume acts primarily as a protein supplement. When pasture conditions deteriorate the pasture protein content falls to a level where nitrogen supply to the rumen microbes limits their activity. Provision of rumen digestible nitrogen will correct this situation, improve the protein status of animals and probably increase intake. However, the low digestibility of Mitchell grass pasture may limit energy availability and significant improvement in animal production may also demand additional energy supplements. The protein: ME ratio in drought affected pasture is often below the 6.5 g/MJ needed for maintenance and well below the 12:1 ratio needed for optimum wool production (McMeniman *et al.* 1986b). This compares with a ratio of 16:1 for *A. nilotica* leaf and 12:1 for pod material. An intake of about 1 kg of leaf or 0.9 kg of pods would be needed to supply the energy requirement of sheep for maintenance at 0.22 MT/kg W/day (McMeniman *et al.* 1986b).

Table 7.2.1. Nutrient levels in *A. nilotica* leaf and fruit.

	Leaf		**Fruit (pod and seed)**	
Parameter	**Mean ± SD**	**Samples**	**Mean ± SD**	**Samples**
Protein (%)	13.92 ± 2.53	29	12.30 ± 2.03	28
Fat (%)	6.63 ± 3.41	13	1.93 ± 1.14	23
NFE (%)	60.99 ± 3.41	19	63.68 ± 7.35	22
CF (%)	10.35 ± 2.85	13	15.36 ± 5.85	23
ADF (%)	20.38 ± 6.35	8	25.44 ± 4.16	2

Ash (%)	9.29 ± 2.95	22	5.26 ± 1.29	23
Tannin (%)	7.62 ± 1.00	13	5.45 ± 1.48	2
Lignin (%)	6.95 ± 2.17	6		
P (%)	0.23 ± 0.22	15	0.26 ± 0.21	18
Ca (%)	2.53 ± 1.13	15	0.64 ± 0.19	18
Mg (%)	0.18 ± 0.08	11	0.13 ± 0.02	70
Na* (%)	<0.32	5	<0.01	4
K (%)	1.25 ± 0.79	9	1.28 ± 0.22	5
Si (%)	0.45 ± 0.47	4	0.24 ± 0.21	9
S (%)	0.26 ± 0.03	4	0.59 ± 0.11	2
Cl (%)	0.70 ± 0.26	3	0.36 ± 0.04	2
Cu (mg/kg)		6	6.43 ± 0.90	4
Zn (mg/kg)	25.63 ± 9.20	4	28.50 ± 9.76	2
Mn (mg/kg)	90.25 ± 19.00	4	2650 ± 0.71	2
Fe (mg/kg)	428 ± 205	4	100.00 ± 86.27	2
ME (mg/kg)	8.69 ± 1.09	9	10.19 ± 0.16	2
OMD (%)	69.9 ± 5.20	3	67.2	1

*Some values below limit of detection (0.05%)

NFE	nitrogen free extract
Fat	ether extract
ADF	acid detergent fibre
CF	crude fibre
OMD	organic matter digestibility
ME	metabolisable energy

Condensed tannins are high in all browsed components. The relative tannin levels in *A. nilotica* from least to most are pods (5.4%), leaves (7.6%), bark (13.5%) and twigs (15.8%). Total polyphenolics in the fruit range from 32 to 34% (Kumar 1983) and in leaf range from 30 to 60% (Ehoche *et al.* 1983, Reed 1986, Tanner *et al.* 1990). The high levels of tannins in plant parts may bind protein and, at high levels, suppress animal production. Bullocks fed 45% oil-extracted seeds of *A. nilotica* in their diet showed reduced weight gain (68 g/day to 16 g/day) and a 5% decrease in intake (Pande *et al.* 1982). *Acacia nilotica* tannins have been used to treat cottonseed cake to prevent rumen degradation of protein. At 5% inclusion of tannin (probably total polyphenolics), liveweight gains of lambs were increased by 36% and feed intakes by 6%; however, at 10% inclusion average daily gain was reduced by 18% and intake reduced by 4% (Ehoche *et al.* 1983). Sheep fed *A. nilotica* pods and roughage at 204 and 347 g/day respectively had lower growth rates than control feeds (Tanner *et al.,* 1990).

Table 7.2.2. Amino acid composition (%) of *A. nilotica* and *Astrebla lappacea.*

	Amino acid composition (%)						
Amino add	**Green fruit**	**Fruit**	**Leaf**	**Kernel**	**Hull**	**Seed**	**Grass**
Lycine	4.98	4.08	6.17	6.38	11.92	7.69	6.90
Histidine	2.63	2.57	2.34	2.34	12.03	5.28	2.30
Arginine	5.07	2.64	5.92	10.39	3.80	10.04	6.90
Aspartic acid	28.69	36.53	11.19	9.54	16.95	10.72	11.40
Threonine	3.20	2.74	4.92	3.16	3.65	3.10	4.70

Serine	4.58	4.27	5.03	4.91	8.99	5.59	4.90
Glutamic acid	8.97	6.57	11.87	15.06	10.43	14.01	12.40
Proline	11.81	15.52	5.73	5.81	3.90	4.72	4.70
Glycine	4.05	3.17	5.71	0.00	0.00	0.00	5.60
Alanine	4.59	3.71	6.62	4.33	3.81	3.87	8.90
Valine	5.00	4.65	6.10	4.05	3.47	3.19	5.50
Methionine	0.00	0.00	1.86	6.89	0.78	5.22	2.30
Isoleucine	3.06	2.51	4.92	3.62	2.81	2.97	4.40
Leucine	5.45	4.12	9.41	8.79	5.12	7.41	8.90
Tyrosine	2.34	2.12	4.00	3.11	2.47	2.99	3.40
Phenylalanine	3.23	2.47	5.52	4.23	2.93	3.33	5.30
Cysteine	2.35	2.34	2.66	5.91	6.95	9.87	2.40

Grass is Mitchell grass dead leaf (McMeniman *et al.* 1986c). Kernel' hull and seed (Kumaresan *et al.* 1974)

Management of Grazing Systems with a Browse Component

The ecological implication of using *A. nilotica* as a browse source while maintaining inappropriate stocking rates is land degradation. Trees compete with grasses for limited soil moisture, reducing feed supply and increasing stocking pressure on the remaining pasture, particularly the palatable perennial grasses. Small amounts of tree legume stimulate rumen function resulting in reduced weight loss and probable increased intakes. However, maintenance of animals through dry periods leads to reduction in ground cover and high animal numbers at the beginning of the growing season, putting maximum pressure on new grass tillers and seedlings.

The mulga (*A. aneura*) lands of southwest Queensland are an example of over-use of browse trees contributing to species change and soil erosion. Failure to adjust stocking rates to available feed is a common management problem in these continuously grazed savannah pastures. Managers often do not realise that competitive effects of woody plants are magnified as growing conditions become harsher.

There is some evidence from field monitoring sites which suggests that strategic heavy grazing by sheep can control small seedlings of *A. nilotica.* Cattle have less effect on seedlings but can utilise browse to a greater height. A survey by Bolton and James (1985) indicated that sheep-only properties have shown significantly less rapid increase in *A. nilotica* than cattle-only or mixed animal enterprises. A recent trial using goats to control *A. nilotica* showed that, in drought times, goats reduced seedling numbers and tree canopy cover with little effect on enterprise profitability (Carter *et al.* 1990). There is clearly potential for optimising the mix of domestic species to use *A. nilotica* more effectively while still providing some control of seedling recruitment.

Anticipating Weediness Problems

Planned and unplanned introductions of exotic tree legumes can sometimes lead to environmental disasters. The reasons for the invasion of *A. nilotica* are summarised below together with some suggestions for minimising the chance of similar invasions of other species in other areas.

Acacia nilotica was able to spread rapidly because:

- seedlings and young trees are protected from grazing by thorns,

- there was active propagation by landholders in early years,
- it has long distance dispersal mechanisms (domestic stock and floods) allowing uncontrollable spread,
- there is large seed production (up to 175,000 seeds/tree),
- it has long-lived seeds,
- the young plants grow rapidly,
- it is tolerant of grazing, drought, fire and salinity,
- there was a treeless, fire-free habitat to invade,
- the trees are long-lived (30-60 years),
- growth is possible over an extensive climatic range, and
- the useful characteristics of the plant and slow initial spread led to complacency among producers and government authorities.

The lessons learnt from this invasion and many others worldwide suggest that all plant introductions should be screened with great care. This screening should involve observations in the native homeland environment and other areas of introduction including:

- measurements of seed production and longevity,
- monitoring of methods of seed dispersal,
- examination of susceptibility of seedlings and small trees to grazing (e.g. whether thorny or not),
- a bioclimatic and soils analysis to predict potential in new country,
- investigation of the effects of insect predators, plant pathogens and fire on control of the plant in its native environment, and
- investigation of practical methods of chemical and biological control in the case of weediness problems.

There are numerous difficulties with screening of plants in this way. These include:

- unpredictable behaviour after removal from native pathogens, insects and browse animals,
- unpredictable behaviour under new climatic, management and fire regimes (the full genetic potential of a plant is not necessarily expressed in areas in which it is endemic), and
- genetic drift or hybridisation which may change the character of the plant introduced.

Once species are introduced there should be:

- long-term monitoring (problems may not show for 50-100 years), and
- rapid action if weediness appears a problem.

Once a plant has established as a weed it is usually impossible to eliminate it, and action usually involves control of further spread (an expensive and often futile process) and evolution of new management strategies to cope with and minimise the effect of the weed. Biological control is rarely a complete success and should not be relied upon as a last resort. I believe all plant introductions should be presumed weeds until proven otherwise.

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7.3 Beef Production from Broadacre Leucaena in Central Queensland

J.H. Wildin

Introduction

The forage value of leucaena (*Leucaena leucocephala*) has been recognised for decades but commercial plantings for extensive grazing only commenced in central Queensland in 1980 (Wildin 1981). Commercial plantings increased from 24 ha in 1979 to an estimated 20,000 ha in central Queensland by early 1992. Cattle owners now see this permanent forage system as a sound investment and have been adopting it readily. This section discusses the commercial use of rainfed leucaena for grazing beef cattle in central Queensland.

Leucaena in Central Queensland

The outstanding attributes of leucaena which have been mentioned in Section 2.1 include:

- high palatability, digestibility, dry matter production and nitrogen content,
- adaptation to a range of soils including clays but best performance on deep fertile soils,
- adaptation to wide climatic range including the semiarid regions (5001,000 mm rainfall) of the tropics and subtropics,
- rapid regrowth following grazing if soil moisture is available,
- excellent persistence once established (20+ years) and competitive dominance over associated grasses,
- easy management under controlled continuous or rotational grazing without trampling and fouling losses,
- high liveweight gains of about 1 kg/head/day under dryland conditions (>250 kg/ha/year), and
- high economic returns.

Strategic continuous or rotational grazing management of leucaena is compatible with the extensive operations on Australian beef ranches (Wildin 1981). Leucaena plantings offer flexibility to graziers for whole property pasture and livestock management. Leucaena can be used for ensuring high conception rates in breeders, for growing weaners or for fattening cattle for slaughter. With experience, cattle owners may modify leucaena management to suit their particular requirements. Inoculation of cattle grazing leucaena with the DHP detoxifying rumen bacteria (Section 4.4) allows animals to ingest a high percentage of leucaena in their diet without toxicity effects.

Dryland plantings

Many individual plantings have been in excess of 100 ha in rows spaced by >5 m with adapted grasses planted in the cultivated weed-free inter-row spaces. Weed control for 12 months after sowing has been the key to rapid successful leucaena establishment under rainfed conditions in Queensland (Figure 7.3.1). Deep ripping (>400 mm) for aeration, moisture infiltration and accumulation from rains, has been observed to boost early leucaena seedling growth. Preplanting seed treatment, high density seeding along the row and accurate seed placement into good soil moisture followed by rolling with dual press wheels to apply side pressure to ensure good seed/soil moisture contact have markedly improved the success rate for commercial establishment of leucaena.

Beef production

Central Queensland cattlemen with more than 200 ha of leucaena-grass pasture have recorded annual steer liveweight gains of 250-300 kg at stocking rates of 1-1.5 ha/steer. By comparison, pastures of buffer/green panic/Rhodes grass (>10 years old) stocked at 3.5 ha/steer give liveweight gains of 140-180 kg/steer/year. One cattleman with 500 ha of rainfed leucaena-grass pastures in a 550-600 mm annual rainfall region has achieved a liveweight gain of 317 kg/ha/year in 300 days of grazing (S. McGhie, personal communication). His stocking rates in the first few months of grazing from late summer were relatively high (0.4 ha/steer) and progressive turnoff of prime cattle balanced stock numbers with available forage so that a liveweight gain of around 1 kg/steer/day was achieved. His mean annual stocking rate on leucaena pastures has been 1-1.5 ha/steer. Unfertilised rainfed leucaena pastures have increased beef production 6-7 times that previously produced on aged unfertilised improved grass pastures.

In other examples, steers have gained 333 kg liveweight in 272 days near Clermont (G. Farmer, personal communication). Forty weaner steers grazing buffer grass at 2 ha/weaner and another 40 grazing leucaena-buffel at 0.75 ha/weaner during the dry season between 29 May and 13 November 1990 at Minnie Plaines, recorded mean liveweight gains of 0.35kg/weaner/day (28 kg/ha) and 0.77 kg/weaner/day (150 kg/ha) respectively (S. McGhie, personal communication).

Fig. 7.3.1. Leucaena established in weed free conditions prior to sowing of grass.

Carcass weights of 300-350 kg at 30 months of age have been achieved by leucaena growers even in relatively dry years. Prime cattle fattened on leucaena pastures and fetching A$700-800 per beast are presently more lucrative than grain growing in central Queensland.

Such commercial successes have increased the adoption rate. Some of the successful leucaena growers have extended their plantings to more than 1,000 ha, and several others have at least 500 ha. Leucaena has been used for growing and fattening beef cattle but several cattle operators have concentrated on the prime cattle market. In these hot drier regions, the leucaena psyllid (*Heteropsylla cubana*) has had little impact on leucaena growth and farmer confidence in leucaena pastures has increased.

Future Research Needs

Establishment

The relatively slow establishment of leucaena in central Queensland has been a concern of some cattle owners. To hasten seedling growth, more effective *Rhizobium* strains have been incorporated into commercial inoculants but mycorrhizae and the use of faster growing cultivars may also improve establishment. More supporting evidence on the benefits to establishment of deep ripping under the leucaena row during seed-bed preparation is warranted. Leucaena growers now accept that trees and shrubs take a longer time to establish than grasses.

Cultivars

New cultivars may complement the present commercial cultivars available for forage systems in cooler environments. Desirable attributes include faster growth at temperatures below 18℃ and some frost resistance. Resistance to the leucaena psyllid, soft brown scale and *Ithome* moth larvae in flower heads are other characteristics which would improve the productivity of leucaena. All these attributes may not be found in *Leucaena leucocephala* and new selections within the genus *Leucaena* and synthetic hybrids should be evaluated for beef cattle productivity. Other tree and shrub legumes may also be useful in improving forage production systems (Shelton *et al.* 1991).

Alley farming

Grain crude protein levels from many of the grain cropping lands in central Queensland are becoming unacceptably low (Garside *et al.* 1992) and leucaena planted in parallel rows up to 30 m apart may have a role in restoring the fertility of these soils. The leucaena could be used in an alley cropping/alley grazing rotation to provide high quality forage during the grazing phase and nitrogenous mulch and erosion control during the alley cropping phase.

Conclusions

Commercial leucaena pastures have consistently produced high liveweight gains in central Queensland and have allowed cattle owners more flexibility in developing their cattle enterprise including highly profitable fattening options. Continuing research on the use of leucaena in pastures (alley grazing) and in cropping systems (alley cropping) will further improve land management and enhance profitable and sustainable grazing farming systems.

The central Queensland experience may be of benefit to other parts of Australia and to other countries with similar soil and climatic conditions.

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7.4 Management Options for Leucaena in the Burnett Region of Queensland

M.F. Quirk

Introduction

The tree legume, leucaena (*Leucaena leucocephala* cv. Peru) initially attracted attention in the Burnett region in the 1960s. Its major attraction was its ability to persist on the clay soils of the region. Prior to leucaena, lucerne (*Medicago sativa*) was the only suitable legume for clay soils, but it rarely persisted for more than 3-5 years. Subsequent experiments confirmed the high beef production potential from leucaena-based pastures. Seed treatment, establishment methods, weed control, planting density, fertiliser requirements, grazing management and cattle production were all studied in subsequent experiments at the Brian Pastures Research Station. The synthesis of this work into possible production systems for the Burnett region will be described in this section. Problems encountered in the transfer of this technology to commercial enterprises will also be discussed.

Suitable Sites for Leucaena

The inland Burnett (latitude 26°S) is not an ideal environment for growing leucaena. Soil moisture is often limiting during the growing season as the mean annual rainfall of 700 mm is quite variable. Cold temperatures prevent growth from April to September, frosts cause leaf-drop and most soils are shallow and infertile. Hence, good site selection is crucial for successful leucaena production in this environment.

Availability of soil moisture is the major determinant of leucaena growth. Hence, growth is markedly influenced by soil characteristics, especially the water holding capacity and depth of rooting. Cooksley *et al.* (1988) found that production of edible leucaena was much greater on deep, fertile alluvial/colluvial plains than on shallower soils located on low to medium slopes (Table 7.4.1). This occurred despite the greater frost damage to leucaena plants on the plain, suggesting that in such situations, the advantages of a deep and fertile soil outweigh the disadvantage of frosting.

Table 7.4.1. Effect of soil type on growth and height of leucaena at Brian Pastures (from Cooksley *et al.* 1988).

	Alluvium (black earths, brown clays)	Colluvium (brown clays, prairie soils)	Andesite (prairie soils, brown clays)	Basalt (brown clays, black earths)
Growth (including leaf fall) (kg/ha)	1,515	2,375	1,215	1,145

Height (cm)	165	235	155	145

For sites where leucaena grows well (1,500 - 3,000 kg edible material/ ha/year), leucaena-based pastures are likely to give much higher and more persistent benefits to cattle growth than other pasture improvement options. However, on sites of lower growth potential, leucaena-based pastures may not give greater benefits than other development options (e.g. sowing stylos). As sowing leucaena is usually more risky and more costly than other development options, using leucaena on such sites is unlikely to confer advantage. Thus, for the Burnett region, only fertile soils with good drainage and at least 60 cm in depth, are considered suitable for leucaena.

Agronomy of Leucaena

Reliable and rapid establishment of legumes in the inland Burnett is often difficult due to the unreliability of summer rainfall. With leucaena, good sowing methods are even more crucial than for other legumes, for two reasons. Firstly, leucaena seedlings are slow-growing, making them susceptible to both moisture stress and weed competition. For example, Cooksley (1981) found that vigorous weed competition reduced the growth of leucaena seedlings by 87% in the first 40 days after emergence. Clearly, such slow growth will greatly increase the time before leucaena is able to provide useful grazing.

Secondly, the early productivity of leucaena in this environment is dependent on achieving an adequate plant population in the first year. Improvement in the population of mature leucaena plants with time may occur but will be slow.

Essential practices

To help overcome these problems special emphasis should be placed on the following:

- seedbed preparation,
- storage of soil moisture prior to sowing,
- seed scarification and inoculation,
- fertiliser use (N,P),
- weed control, and
- control of marsupials, rabbits and hares.

Given attention to the above, leucaena can be expected to reach a height of 0.5-1.5 m at the end of the first growing season.

Plant density and row spacing

As with any crop, yield of leucaena per hectare increases with plant density. Cooksley and Goward (1988) found that leucaena yield increased from 640 kg/ha at 6,000 plants/ha, to 2,260 kg/ha at 62,500 plants/ha. In practice, leucaena is grown in rows, with a distance between rows of at least 3 m. This facilitates cultural practices such as fertilising, sowing and weed control. When grown in rows 3 m apart, plant populations stabilise at around 10,000 plants/ha (3-4 plants/m of row) (Addison *et al.* 1984).

Varieties

The cultivars Peru and Cunningham are used in the region although there is little difference in yield of edible material between the two (Cooksley 1979). However, Cunningham flowers 1 month later than Peru, which may limit its seed production in years with early frosts.

Fertiliser requirements

Leucaena is considered only for the higher fertility soils in the Burnett. Hence, maintenance fertiliser is generally not required to maintain good production (Cooksley *et al.* 1984). Sulphur deficiency, however, has been detected in older stands of leucaena growing on clay soils (Prinsen *et al.* 1992). For example, from January to May 1990, leucaena yields increased from 450 to 1,100 kg/ha of edible herbage when it was fertilised with 15 kg S/ha.

Pests and diseases

Prior to the arrival of the leucaena psyllid in 1986, there were no major insect pests or disease problems on leucaena in Queensland. Minor pests include long soft scale (*Coccus longclus*), which lives on the stem, and *Ithome* larvae, which can reduce seed set. Leucaena plants in the Burnett are often covered by sooty mould growing on an exudate from the scale insects.

The effects of the leucaena psyllid in the Burnett have been far less dramatic than in more humid areas. Occasional outbreaks have occurred which may have reduced growth but it is not considered a major problem. Control would be considered only for young, establishing stands and for seed crops.

Grazing Systems and Cattle Production

Using leucaena as a protein supplement for cattle grazing native pasture

In most paddocks of native pasture, only a portion of the total area may be suitable for leucaena. One option is to grow leucaena on the better soil, fence it off from the rest of the paddock and allow cattle access to it only when the native pasture is deficient in protein. The use of leucaena as a protein bank in this way formed the basis for all of the early work with leucaena in the region. As native pasture suffers its greatest protein deficiency in the cool dry season (April to October), most studies combined year-round grazing of native pasture with cool season grazing of leucaena.

Addison *et al.* (1984) grazed steers on paddocks with 25% of the area sown to leucaena (in rows 3 m apart) and the remainder as native pasture. The growth of these steers during autumn and winter was compared with those of steers grazing native pasture only, steers grazing native pasture and supplemented with protein meal (690 g/head/day of peanut meal) and steers grazing native pasture plus leucaena that were also supplemented with peanut meal. The leucaena was grazed rotationally (four plots, 1 week grazing, 3 weeks rest) in an attempt to ration the leucaena. Steers with access to leucaena were 57 kg heavier than steers on native pasture alone (Table 7.4.2). This response was better than the response obtained from feeding protein meal. When steers had access to both leucaena and protein meal, there was an additional response in weight gain, particularly during winter (Table 7.4.2). The autumn grazing depleted the amount of leucaena available in winter. As a result, steers with access to leucaena responded to additional dietary protein at this time. There was little or no compensatory gain during the subsequent spring-summer grazing. These results demonstrate the value of leucaena as a protein supplement for cattle grazing native pasture.

Table 7.4.2. Liveweight changes of weaner steers in autumn and winter when grazing native pasture only, and when grazing native pasture supplemented with either leucaena, peanut meal, or leucaena plus peanut meal (from Addison *et al.* 1984).

	Liveweight change (kg/head)		
	Autumn	**Winter**	**Total**
Native pasture (NP) only	-5	-23	-28

NP + leucaena	27	2	29
NP + peanut meal	16	6	22
NP + leucaena + peanut meal	36	20	56

Foster and Blight (1982) compared weight gains from year-round grazing of native pasture with year-round grazing of native pasture combined with winter-spring grazing of leucaena. In the latter paddocks, leucaena pasture (rows 3 m apart) made up 25% of the area, and was divided into four blocks so that it could be rotationally grazed during the winter/spring. Cattle grazing the native pasture plus leucaena paddocks gained 226 kg/head from 9 to 30 months of age, compared with only 142 kg/head for cattle grazing only native pasture.

Mimosine toxicity

When leucaena was used for seasonal grazing with native pasture, there were rarely signs of mimosine toxicity. Apparently, the cattle were not eating enough leucaena to suffer any side-effects from either mimosine or its ruminal break-down product, 3-hydroxy-4(IH)-pyridone (DHP). This was confirmed when cattle dosed with DHP degrading rumen bacteria did not gain more weight than unclosed cattle when leucaena was used as a supplement (Quirk *et al.* 1988).

The emphasis in the early work in the Burnett was on integrating relatively small areas of leucaena with larger areas of native pasture. This gave a boost in growth rate of 20-40 kg/head/year to all the cattle in the paddock. However, another option is to use leucaena pasture by itself, since a good leucaena pasture produces 1,500-3,000 kg/ha of edible foliage and also 4,000-6,000 kg/ha of inter-row grass annually. How should leucaena be managed in such a role, and what productivity would it give? Also would this intensive grazing of leucaena lead to problems with mimosine toxicity?

A grazing trial was designed to assess the need for DHP degrading rumen bacteria when cattle grazed leucaena pasture only (Quirk *et al.* 1988). Steers were grazed on either native pasture (year-round), native pasture (year-round) with seasonal access to leucaena, or year-round on just leucaena pasture. Within each pasture type, there were paddocks grazed by cattle dosed with the DHP degrading bacteria and paddocks with unclosed cattle.

Results showed that dosing with bacteria had no effect on liveweight gain of steers grazing native pasture and leucaena together, but doubled weight gain in steers grazing leucaena-only pasture (Table 7.4.3). In the latter case, unclosed steers were consuming sufficient mimosine to cause a DHP-induced depression in serum thyroxine concentrations. However, with dosed steers, DHP was broken down in the rumen and serum thyroxine levels were normal.

Table 7.4.3. Average daily gains (kg/head) of unclosed and dosed (with DHP degrading bacteria) steers grazing either native pasture with seasonal access to leucaena pasture, or leucaena pasture only for the 0-6 and 6-19 week periods following treatment (from Quirk *et al.* 1988).

Treatment	**Liveweight gain (kg/head/day)**	
	0-6 weeks	**6-19 weeks**
Native pasture + leucaena		
Untreated steers	0.95	0.62
Dosed steers	0.80	0.63
Leucaena pasture		
Untreated steers	1.06	0.52

Dosed steers	1.19	1.03

The annual production from the three pasture systems was also measured (Table 7.4.4) (Quirk *et al.* 1990). Steers on native pasture with access to a small area of leucaena gained an extra 37 kg/head/year, while steers grazing only leucaena pasture (same total area as other systems) gained twice as much weight as those on native pasture alone (205 versus 90 kg/head/year). Clearly, the more leucaena available, the better the liveweight gain, provided the DHP degrading bacteria are present.

Using leucaena to finish cattle for market

Notwithstanding the above results, year-round grazing of leucaena is not recommended in this region, as the trees need an opportunity to regrow. Best production is obtained when periods of intensive grazing are combined with periods of rest, the latter occurring when growing conditions are favourable.

Table 7.4.4. Seasonal and annual liveweight gains of steers grazing either native pasture, native pasture with seasonal access to leucaena, or leucaena pasture (from Quirk *et al.* 1990).

	Liveweight change (kg/head)				
	Spring	**Summer**	**Autumn**	**Winter**	**Annual**
Native pasture	53	39	26	-27	90
Native pasture + leucaena	73	34	42	-21	127
Leucaena pasture	107	64	47	-11	205

This management system is now used on Brian Pastures to finish cattle for market. The leucaena pasture is used as a permanent forage crop. Leucaena pastures are not grazed for several months during the growing season, to allow accumulation of a large amount of foliage, and then grazed for short periods (about 80 days) by forward store steers (about 500 kg liveweight, 2.5 years old) during the late summer/autumn/early winter months. Stocking rates vary from 1.5 to 3 steers/ha, depending on the amount of leucaena pasture on offer. Steers gain weight quickly (0.75-1.3 kg/head/day) and most are then ready for sale (Table 7.4.5) at the end of the grazing period.

Which system is best?

The choice between using leucaena pasture in conjunction with native pasture and using leucaena pasture as the sole feed source will depend on the desired level of liveweight gain. For example, allowing breeding animals limited access to leucaena (i.e. using leucaena as a seasonal protein supplement) may give sufficient boost in liveweight to ensure high conception rates. On the other hand, quick finishing of sale cattle may require grazing solely on leucaena pasture.

Commercial Adoption of Leucaena

There has been a very low level of adoption of leucaena by cattle producers in the Burnett. Lesleighter and Shelton (1986) found that the three major barriers to increased use of leucaena in Queensland were: low level of awareness, lack of information and high failure rate among leucaena growers. The latter problem appeared to be linked to the low level of use of essential cultural practices such as seed scarification and inoculation. The small size (<4 ha) of most first plantings would also have increased their vulnerability to damage by wildlife (e.g. marsupials, rabbits and ducks).

Table 7.4.5. Productivity of a 5 ha block of leucaena pasture used for finishing steers for market (J.D. Mullaly, unpublished data).

Period	Number of steers	Age of steers (years)	Length of grazing (days)	Average steer weight at start (kg/head)	Stocking rate (AE/ha)	Average LWG (kg/hd/day)	No. sold off leucaena
1987 summer/autumn	15	2	146	428	2.6	0.73	7
1988 autumn/winter	11	2	78	434	1.9	1.30	9
spring/summer	7	2.6	82	525	1.5	0.74	7
1989 summer/autumn	12	2.5	74	513	2.5	0.82	12
1990 autumn	15	2.6	57	541	3.1	0.82	13

AE = animal equivalent = 400 kg liveweight
LWG = liveweight gain

Other factors which also limit the potential for leucaena pasture in the Burnett region are:

- Limited areas suitable for leucaena - i.e. sites with arable soils that are sufficiently deep and fertile to compensate for erratic summer rainfall and frost damage. Such sites are also open to other options e.g. cropping.

- Unreliable and slow establishment - to overcome erratic summer rains and weed growth requires an intensive approach to establishment. Producers may not be able to afford or risk the costs associated with such development.

Despite these problems, leucaena remains an option for pasture development on some properties in the Burnett. The successful use of leucaena on Brian Pastures over the past 20 years provides good evidence of its potential.

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7.5 Sloping Agricultural Land Technology (SALT) in the Philippines

W.A. Laquihon and M.V. Pagbilao

Introduction

The strategy of using tree legumes to improve the fertility and stability of agricultural soils is receiving increased attention in developing countries. It provides a means for resource-poor farmers to achieve sustainable production without the use of expensive, and often unavailable, chemical fertilisers.

In the southern part of the Philippines, the Mindanao Baptist Rural Life Center (MBRLC), a non-government organisation based in Kinuskusan, Bansalan, Davao del Sur, has developed a conservation farming scheme called Sloping Agricultural Land Technology (SALT), based on the use of tree and shrub legumes.

SALT is a simple, applicable, low-cost method of upland farming. It is a scheme developed for small farmers with few tools, little capital and little knowledge of modern agriculture.

SALT is a form of alley farming in which field and perennial crops are grown in bands 4-5 m wide between contoured rows of leguminous trees and shrubs. The latter are thickly planted in double rows to form hedgerows.

When the hedge reaches 1.5-2.0 m in height, it is cut back to 40 cm and the cuttings are placed in the alleys between the hedgerows to serve as mulch and organic fertiliser or green manure.

The species used in the hedgerows include *Leucaena leucocephala, L. diversifolia, Calliandra calothyrsus, Gliricidia sepium, Flemingia macrophylla* and *Desmodium rensonii.* Farmers are encouraged to use a combination of these species or other fast-growing, fast-coppicing and high-biomass leguminous trees or shrubs found to be suitable on their respective farms. Presently, the MBRLC is testing the performance of over 20 species of shrub and tree legumes for hedgerow and forage use.

Rows of perennial crops such as coffee, cacao, citrus and banana are planted on every third alley created by contoured hedgerows. The alleys not occupied by permanent crops are planted alternately to cereals (e.g. com, upland rice or sorghum) or other crops (e.g. sweet potato, melon or pineapple) and legumes (e.g. mungbean, string bean, soybean or peanut). This cyclical cropping provides the farmer with several harvests throughout the year. The average monthly income to one family from 1 ha of SALT farm is approximately P1,300 (1 US$ = P25).

On a SALT farm, a farmer can grow varieties of crops familiar to him. SALT can be adapted to incorporate new or traditional farming techniques. If farmers leave the land fallow for one or two cropping cycles, the leguminous trees and shrubs will continue to grow and may be harvested later for firewood and charcoal (Tacio 1991).

Historical Background

In the early 1970s, MBRLC staff members heard numerous complaints of low and declining farm income from upland farmers in Kinuskusan, Bansalan, Davao del Sur. In one area, corn production had declined from 3.5 to about 0.5 t/ha in a span of 10 years. Yields of other crops had also declined to unprofitable levels during the same period. It was found that the main reason for these low yields was depletion of soil and nutrients through erosion.

At first, the Center tried many standard ways to stop erosion and rebuild soil fertility. Nothing worked. Then, MBRLC obtained seeds of *Leucaena leucocephala* from the Nitrogen Fixing Tree Association (NFTA) in Hawaii. Double hedges of *Leucaena leucocephala* were planted on contours 4-5 m apart and crops and fruit trees were grown between the hedges.

This technique appeared to be successful. Soil erosion was minimised, soil fertility restored, crop yields were sustained and improved income for upland families was generated. Because of SALT's initial success, three more SALT variants have been developed. These are Simple Agro-Livestock Technology (SALT-2), Sustainable Agroforestry Land Technology (SALT-3) and Small Agro-fruit Livelihood Technology (SALT-4).

SALT-2 is a goat-based agroforestry project with a land use comprising 40% agriculture, 20% forestry and 40% livestock. SALT-3 is a small-scale reforestation technology with 40% of farm area devoted to agriculture and 60% to forestry (Figure 7.5.1). SALT-4 is a system of planting fruit trees and short-term crops at a ratio of 75%:25%. All of these variants utilise shrub and tree legumes in contour hedgerows.

The Extension of SALT Nationwide

Many public and private organisations in the Philippines believe in the potential of SALT for upland development (Table 7.5.1). These organisations have voluntarily disseminated the technology to their clientele. SALT farms, established with the help of these organisations, now occupy over 5,000 ha throughout the country.

Fig. 7.5.1. Sustainable Agroforestry Land Technology (SALT-3).

Table 7.5.1. List of organisations using SALT since 1981, and the estimated number of cooperators.

Adopting organisation	Category*	Year	Estimated no. of cooperators
Federation of Free Farmers	NGO	1981	15
US Peace Corps Volunteer	NGO	1981	30
Forest Management Bureau[a]	GO	1981	15
Southern Philippines Dev. Authority	GO	1982	15
Kilusang Kabuhayan at Kaunlaran[b]	GO	1982	100
Phil.-Australian Dev. Assistance Program	GO	1982	700
Department of Agrarian Reform	GO	1982	10

British Volunteers	NGO	1982	10
Agric. Education Outreach Project[c]	GO	1983	150
Farm Systems Dev. Corporation	GO	1983	30
Davao Medical School Foundation	NGO	1983	20
Farmers Training Center for Rural Development	GO	1984	50
Department of Agriculture	GO	1984	500
Overseas Missionary Fellowship	NGO	1984	20
National Electrification Administration	GO	1985	503
Save the Children Foundation	NGO	1985	25
Support Technology Assisting Rural Transmigration	NGO	1985	10
Cotabato Rural Upliftment Movement	NGO	1985	15
International Human Assistance Program	NGO	1985	15
Catholic Santa Cruz Mission	NGO	1985	50
Regional Rainfed Development Program	GO	1985	30
Philippines Business for Social Progress	NGO	1986	50
Resources Ecology Foundation for Regeneration of Mindanao, Inc.	NGO	1987	100
DAR-UNDP-FAO	GO	1988	150
Central Visayas Regional Project	GO	1988	50
Meralco Foundation, Inc.	NGO	1989	200
Kapwa Upliftment Foundation, Inc.	NGO	1989	30
Mag-Uugmad Foundation	NGO	1989	50
Muslim-Christian Agency for Rural Development Inc.	NGO	1989	15
Soil and Water Conservation Foundation	NGO	1991	150

* NGO = non-government organisation
GO = government organisation

[a] Then known as Bureau of Forest Development

[b] This was under the Ministry of Human Settlements

[c] In collaboration with the United States Agency for International Development (USAID) and the Ministry of Education, Culture and Sports

The Department of Agriculture used SALT as the basis for its extension effort on sloping uplands. The Department of Environment and Natural Resources endorsed the concept for its social forestry pilot projects. A significant training effort for extension personnel was launched by the Philippine Government and demonstration plots of SALT were installed on farmers' fields throughout the country.

Soil Erosion Control

To verify the effectiveness of the SALT system for controlling soil erosion, an experiment was established in 1984 to compare the SALT system with a non-SALT system used by local farmers. There were two replications of each system with individual plots measuring 800 m^2.

Soil losses in both systems were assessed using a staking method which measured changes in soil levels throughout the plots. This method was found to be relatively inaccurate and tended to overestimate erosion in the SALT treatment. A correction factor (E. Paningbatan and S.A. El-Swaify, personal communication) was applied to all measurements and the final results of the study are presented in Table 7.5.2.

Table 7.5.2. Soil losses In SALT* compared with non-SALT systems.

Months from start of test	SALT. (mm)	Non-SALT (mm)	SALT. (t/ha)	Non-SALT (t/ha)
0	0.0	0.0	0.0	0.0
5	0.5	4.0	6.2	53.8
34	0.8	20.9	10.6	278.0
45	1.2	46.5	15.6	618.1
50	1.6	58.4	21.3	776.2
57	1.7	71.4	22.0	950.1
60	1.7	77.1	23.1	1025.4
68	1.6	82.8	21.4	1101.1
72	1.5	87.4	20.2	1162.4
Mean loss/year	0.25	14.6	3.4	194.3

* SALT soil loss calculated with a correction factor

The SALT system was very effective in controlling soil erosion as there was almost 58 times less erosion in the SALT system than in the non-SALT treatment.

The annual rate of soil loss from the SALT system was 3.4 t/ha which is well within the tolerable limits for soil loss. Palmer (1991) suggested that acceptable soil loss limits for the tropics were within the range 10-12 t/ha/year.

Crop Productivity

MBRLC has also conducted tests on crop productivity with emphasis on corn, a traditional upland crop in the Philippines, particularly in Mindanao. The influence of leucaena mulch on corn yields and the effect of minimum inputs of inorganic fertiliser on productivity were of interest to MBRLC.

One trial studied the effect of organic and inorganic nitrogen sources (leucaena mulch and fertiliser) on DMR-2 corn production over eight croppings. There was a significant increase in corn yields when either leucaena or fertiliser was used with the fertiliser being more effective than leucaena (Table 7.5.3). However, the leucaena mulch treatment produced double the yield of the no-fertiliser plots. Fertiliser treatments increased yield three-fold.

Table 7.5.3 Effect of nitrogen sources on DMR-2 corn production over eight croppings.

Treatment	Corn yield (t/ha)
No fertiliser	1.3
Leucaena mulch from hedgerow*	2.7
Fertiliser** + leucaena mulch	3.7
Leucaena mulch = fertiliser	2.6
Fertiliser only*	3.7
LSD 5%	0.7

* 8.7 t dry matter/ha/year
** 100 kg N. so kg P/ha

Another trial was conducted to determine if continuous corn production on the same piece of land (using leucaena mulch as fertiliser) would eventually deplete the soil of nutrients. Results revealed that after ten continuous crops of corn over a period of 39 months, the yield was slightly lower than at the start but significantly higher than the national average. This indicated that leucaena mulch can sustain reasonable yields of corn over time.

A ten-year economic study (1981-1990) conducted at the MBRLC farm showed that a 1 ha SALT area can increase an upland farmer's income substantially. The average net annual income for upland farmers in the Bansalan area was about P4,000 (US$1 = P25) with most farmers tilling more than 1 ha of land. After adopting SALT, farmers' net incomes increased from P4,595 to P15,981 ha/year.

Labour Management

Based on observations of the first few years of implementation of SALT, MBRLC staff estimated that management of 1 ha of SALT required much more labour than management of a 1 ha farm planted to corn.

MBRLC's observations were based upon the relatively high amount of labour required to establish a SALT project (locating contour lines, seedbed preparation, planting the leguminous trees and shrubs, trimming the hedgerows, etc.). However, further studies showed that when averaged over a longer period of time, 1 ha of SALT may involve less labour input than 1 ha of corn under the traditional management system.

Several factors contributed to the decrease of labour requirements in SALT with time. Firstly, there was a build-up of rich organic mulch from the trimmings of the hedgerows. This helped in control of weed growth and reduced labour requirement for weeding. Also, as the permanent crops on the SALT farm became established, there was less area for planting, harvesting and caring for annual crops. This reduced labour input as less labour was required for permanent perennial crops than for seasonal crops such as corn.

A cost and return analysis for 5 years for the Simple Agro-Livestock Technology (SALT-2) showed that the system generated a monthly net profit of P5,320/ha, which was 7-8 times higher than the traditional method of upland farming. In addition to this financial benefit, the farming family became more self-sufficient growing a wider range of food crops and producing approximately 4,700 litres of goat's milk per year for sale or consumption. The soil was protected and fertilised with up to 16 t of goat manure per year thus further enhancing productivity and sustainability.

The small-scale, long-term, 2 ha reforestation model called Sustainable Agroforest Land Technology (SALT-3), in its fifth year realised a net profit of P2,393.33 per month. The return on investment was 42%. Like the first two SALT schemes, SALT-3 controlled soil erosion and provided food, fuelwood and timber to the farmers.

Conclusions

Despite the many benefits of this shrub and tree legume-based alley farming system (e.g. soil protection and amelioration, landscape stability, sustained production and economic benefits), there are still many upland farmers in the Philippines who are not adopting the SALT scheme. Thus, Watson and Laquihon (1985) stressed:

'There is not and never will be one system for all farmers. SALT is not a miracle system or a panacea To establish a one-hectare SALT farm requires much hard work and discipline. It took many years to deplete the soil of nutrients and lose the topsoil; no system can bring depleted, eroded soils back into production in a few short years. The price of soil loss is poverty, but we have seen land restored to a reasonable level of productivity by using SALT.'

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7.6 The Use of Forage Tree Legumes in Timor, Indonesia

A.P.Y. Djogo

Introduction

Timor Island is a unique biophysical area of Indonesia in terms of its environment and agricultural production systems and human ecosystems. It is part of the province of Nusa Tenggara Timur and lies between 7°and 10° S. The climate is characterised by an extended dry season of 8-9 months caused by the southeast monsoon, a hot dry outflow from the Australian continent. A relatively short and unpredictable wet season occurs from December to March due to the influence of the northwest monsoon. Rainfall varies from less than 1,000 mm in some locations to over 2,500 mm in others largely due to orographic effects.

Soils on the island are derived from uplifted coral terraces surrounding volcanic ejecta laid down in a marine environment. They are generally shallow, of alkaline reaction and susceptible to erosion.

The major agricultural production system in Timor is based on maize and livestock production which provides a source of cash income for almost all villagers.

Most farmers raise chickens, goats, pigs and cattle. Cattle are grazed on natural savannah grasslands on forest margins, on roadsides and fallow cropping areas. Pigs, chickens and goats scavenge around villages.

Traditionally, livestock were killed and eaten only on ceremonial or festive occasions and contributed little to the nutrition of the rural population. However, over the last two decades, cattle have been increasingly sold to local, provincial and national markets.

Most of the natural forests on the island have been denuded or severely reduced by decades of 'slash-and-burn' agriculture. This has resulted in an increase in the area of grasslands and unproductive degraded lands. As a result, increasing use is being made of local, naturalised and introduced tree and shrub species as sources of forage, placing some strain on this resource.

This section outlines the use of naturalised tree and shrub species in livestock production in Timor, the historical background to their use and progress towards use of exotic species introduced specifically for forage production. The benefits and shortcomings of planting forage trees and shrubs will be highlighted. The dependency of local cattle production on one major species, *Leucaena* *leucocephala,* has provided an excellent insight into the drawbacks of over-reliance on a monocultural system.

Historical Perspectives

In Timor, livestock production is the major source of cash for villagers. This is in contrast to other parts of Indonesia where farmers rely upon cash crops or plantation agriculture for their major source of income. Livestock husbandry is relatively recent in Timor as Bali, Ongole and Madura breeds of cattle were first introduced at the beginning of this century.

The introduction of cattle has had a profound impact on the Timorese way of life. Bali cattle in particular were given to rulers and chiefs and due to their high calving rate, even in the harsh conditions, numbers expanded rapidly. This placed great pressure on fallowed 'slash-and-burn' lands and food crops cultivators had to invest a great deal of time to protect their fields against damage from straying livestock (Suryanata *et al.* 1986). Ormeling (1955) estimated that farmers spent up to one third of their labour on fence construction.

Unfortunately, with the introduction of Bali cattle in 1912, a fast-growing shrubby weed, *Lantana camara,* was also introduced. It rapidly spread over the island and covered much of the grazing and cropping lands. To help combat this problem, and to provide a source of high quality feed for the cattle, the Dutch authorities introduced the drought resistant leguminous tree *Leucaena leucocephala* (Ormeling 1955, Fox 1988).

The introductions of Bali cattle, *L. leucocephala* and weed species to Timor had both positive and negative impacts on the environment and the stability and sustainability of livestock production systems. These are discussed below.

Leucaena, a Miracle Multipurpose Tree in Timor - its Rise and Fall

The first introductions of leucaena occurred mainly in the Amarasi district, southeast of Kupang where a powerful local ruler delineated grazing and cultivation areas within his domain. This was the first step of its kind in Timor to prevent the intrusion of animals into fields and to limit the need for extensive fencing (Fox 1988).

The grazing areas were planted to leucaena and a local Amarasi farmer noticed that Bali cattle could be successfully fed on an exclusive diet of this species. The local ruler then instructed that all cattle be tethered and fed leucaena. Within a decade Amarasi achieved the most equitable distribution of cattle ownership in the whole of Timor (Fox 1988) and it became the most important source of high quality animals. In other parts of Timor, there was also a shift from extensive cattle raising on native rangelands to stall-fed cut-and-carry systems. These changes have been supported by the increasing cattle market and extensive plantings of leucaena. In the past, large cattle herds were owned by elite groups representing only 2-10% of the population. In stall-fed systems, families rarely tended more than 3-4 cattle, thus improving the distribution of benefits.

Although leucaena was promoted by the government, it was not always used by local farmers. For example, in the Humusu district, even though leucaena was extensively planted, farmers did not feed it to their cattle, relying instead on more traditional species such as *Sesbania grandiflora* and *Acacia leucophloea.* In 1985, the psyllid insect (*Heteropsylla cubana*) arrived in Timor and devastated most of the leucaena plantations on the island. Some stands were killed outright and most have not recovered even today. The farmers of the Amarasi district, whose cattle depended almost exclusively on leucaena, had to find alternative species and many discontinued cattle raising as a result. The Indonesian government has taken urgent action to combat this problem but alternative species, until recently, have been confined to research stations.

The destruction of leucaena by the psyllid was a disaster for cattle production systems in most parts of West Timor. However, it did provide a good lesson for governments and development agencies of the dangers of over-reliance on single multipurpose trees.

Local Utilisation of Forage

In the traditional livestock production system (swidden pastoral) the major source of animal feed was natural rangelands. Forage supply and quality, water supply and the prolonged dry season were the main constraints to productivity and stability of the system.

Due largely to overgrazing of most of the rangelands during the last few decades, the quality, biological diversity and botanical composition of the rangelands have been considerably degraded. Farmers have resorted to the forests and woodlands in search of forage for their livestock. This, in combination with traditional slash-and-burn agriculture, has placed significant strain on forest resources and the whole ecological balance on the island is under threat.

In most parts of Timor Island, turi (*Sesbania grandiflora*) is now the most important multipurpose tree. This species is utilised as forage, as a vegetable for human consumption, for firewood and light construction materials and for soil fertility improvement. *Sesbania grandiflora* is one of the few species that is widely accepted throughout Timor as a good source of forage (Figure 7.6.1).

Fig. 7.6.1. Bundles of *S. grandiflora* foliage for sale on the roadside in Timor.

In drier areas of West Timor, kabesak (*Acacia leucophloea*) is a second important forage species. It grows naturally in open fields and forest margins. It is resistant to drought and fire and regrows well after coppicing or pollarding. It is one of the few sources of forage during the dry season, however, considerable pressure has been placed on *Acacia leucophloea* and it is declining in the natural grasslands and forest ecosystems. Farmers appear not to have the knowledge or capability to grow this species and very few efforts have been made to replant it in its natural habitat.

Also important are the banyan trees (*Ficus* spp.). There are more than 30 species of *Ficus* in Timor and many of them are edible and used as livestock feed (Dress 1951).

Many other species (Table 7.6.1) are also traditionally utilised as forage but some are not widely recognised for their forage value. *Melia azedarach,* for instance, is not commonly used for forage in Indonesia as its leaf is somewhat bitter but in certain areas of Timor (Seki, Oemofa and Bismark regions), this species is routinely used as a source of forage.

Table 7.6.1. Local species utilised as forage sources in traditional farming systems in West Timor (Djogo, 1992).

Species	**Vernacular name**
Acacia farnesiana	Bakuro
Acacia leucophloea	Kabesak, Besak
Acacia villosa	Lamtoro/Petes Merah
Adenanthera pavonia	Saga Pohon, Kaikenahawu
Albizia chinensis	Samatuku, Angkai
Albizia lebbeck	Pusine

Albizia lebbeckioides	Pusine, Pusinat, Pusienta
Albizia saponaria	Araek, Kaben, Kbena, Kabena
Artocarpus integra	Nangka
Bambusa spp.	Bambu
Bauhinia malabarica	Pohon Daun Kupu-kupu
Bauhinia sp.	Pohon Daun Kupu-kupu
Borasus sundaicus/flabelifer	Tuak, Lontar
Breynia cernua	Buah tinta, Mekon
Cajanus cajan	Kacang Turis
Callotropis gigantea	Kolengsusu, Widuri
Ceiba petandra	Kapok
Cordia dichotoma	Kukbai
Cordia subcordata	Nunak
Cordia subpubescens	Haukukbai, Nanukukbai
Corypha gebanga	Gewang, Gebang
Desmanthus sp.	Petes Utan
Erythrina ovaliafolia	Nenes, dadap
Erythrina urophylla	Dadap
Erythrina variegata	Nenes, Neonsae, Dadap Duri
Ficus spp.	Ara, Beringin
Gosampinus malabarica	Kapok Utan
Grewia koordersiana	
Hibiscus tiliaceus	Waru, Fao
Ipomoea batata	Ubi tatas
Justicia ganderussa	Gandarusa
Macaranga tanarius	Bafkenu, Kfenuk
Manihot esculenta	Ubi Kayu
Melia azadarach	Kme, Kame, Akmel
Melochia umbelata	Busi
Musa spp.	Pisang
Parkinsonia aculeata	Adjao kase
Passiflora foetida	Buah putri, Markisa utan
Peltophorum innerme	Kaukolo, Kayu Laru
Phaseolus sp.	Arbilla
Pipturus argentus	Ramkoa
Pongamia pinnata	Sikam, Waringi
Psidium guajava	Jambu
Schleichera oleosa	Kosambi, Usapi
Sesbania grandiflora	Kane, Gala-gala
Sesbania sesban	Gala-gala kecil
Sesbania sp.	Gala-gala utan
Tamarindus indica	Kiu, Tambering
Tarena incerta	Mengkudu
Terminalia microcarpa	Nismetan
Thevetia peruviana	Tunmolo
Timonius timon	Timo

Trema orientalis	Loam, Deo
Uvaria rufa	Koknaba
Zizyphus mauritiana	Kabuka, Bidara, Kom

At present in Timor, there are only a very few individual trees of *Albizia lebbeck* left in the landscape. It is thought that this species was originally widespread but has been overexploited; it is slow growing and difficult to propagate, hence its occurrence has declined markedly. *Albizia lebbeckioides,* a similar species which is highly regarded as a forage source, is also under threat.

Farmers utilise many of the local plants quite extensively but they seldom try to propagate or replace species in replanting programmes (Djogo 1992). It may be that they do not have sufficient knowledge to do this or that they regard the trees as an exploitable, unlimited resource.

Introduced Species

Apart from *L. leucocephala* and the many local species, there are a number of introduced species of trees and shrubs that have been utilised as sources of forage in Timor. However, many of these species are still under investigation in experimental plots on research stations and only a few have been widely used by farmers.

Acacia catechu was introduced into Timor in the 1930s. It is fast growing and, in two decades, it has spread over the island as a useful forage and fuelwood species. It has been variously known as *Acacia arabica* or *Acacia polyacantha* and it appears to be closely related to *Acacia nilotica* which is growing extensively in the dry zones of Queensland, Australia (Section 7.2).

Since the devastation of *L. leucocephala* by the psyllid in 1985, there has been considerable research activity on suitable alternatives. Several research institutes have focused on other leucaena species or interspecific crosses with *L. leucocephala,* such as KX1 (*L. pallida x L. diversifolia*), KX2 (*L. pallida x L. leucocephala*) and many others.

Other government and non-government organisations are promoting species from other genera such as *Calliandra calothyrsus, Calliandra tetragona, Gliricidia sepium, Desmodium rensonii, Flamingia macrophylla, Cassia siamea, Desmanthus virgatus, Sesbania sesban* and several other species. These efforts, however, are still in the initial stages focusing on experimental observations. The basic objective is to stabilise the various agroecosystems.

Conclusions

This section has illustrated the use of forage tree species in both the traditional systems and the more modern economically driven livestock production systems.

The traditional pattern of utilisation of forage trees and shrubs has provided a sound basis that can be remodelled to fit the modern or improved animal production system. However, there are a number of key issues facing small-scale farming systems of Timor which should be addressed by developmental schemes of this nature. Some of the issues include:

- There are a wide range of species that could be utilised as forage but there is insufficient information on their value or most appropriate management.
- Farmers' plots are usually very small, so that there needs to be careful

consideration given to the introduction of species which have minimal impact on their main cropping enterprise.

- Land tenure issues have become an important factor in the promotion and planting of new species. In the past, farmers in Timor exploited forage resources on communally owned land, but this opportunity has become more limited.

- More information is required on the combined use of local species with introduced species to provide an ecologically and economically sound fodder production system.

- Seed production of local and introduced tree and shrub species is a major constraint to the expansion of the programme of planting of these species.

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