Limitations and Opportunities for the Multi-Purpose Tree Legume Genera

The Future Role of Leguminous Multi-purpose Trees in Tropical Farming Systems

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Abstract

The history of research and development in multipurpose tree species (MPTS) is outlined, and the dual roles (production and service) of trees in agroforestry are defined. It is proposed that farmers will readily plant trees which produce marketable goods. The service roles of trees in reducing soil erosion, boosting soil fertility and giving shelter are seen as being of secondary importance to farmers. Practical aspects of advising farmers about MPTS are noted. Three successful projects are described in which small farmers are growing marketable trees on a large scale.

THE impetus for much of the research and development work on multipurpose tree species (MPTS) can be traced back to two crises of the 1970s — deforestation and the 'other energy crisis' i.e. fuelwood. Eckholm (1975) viewed with alarm the huge and growing demand for fuelwood endangering the world's forests, while Earl (1975) proposed using forests as a source of renewable energy. The World Bank focused on tropical deforestation and, in 1978, substantially discussed the fuelwood issue in its Sector Policy Paper (World Bank 1978). Later in the same year, the US Agency for International Development echoed the World Bank document in a strategic position paper on Tropical Deforestation (USAID 1978). The Eighth World Forestry Congress in Jakarta then voiced the need to augment forest resources with MPTS to provide continuing supplies of tree products. The primary focus was to be on household use and income generation in rural areas, based on active participation by rural people.

Following the 1978 Congress and an FAO paper on Forestry Research Needs in Developing Countries (FAO 1980), the 1981 International Union of Forestry Research Organizations (IUFRO) Congress in Japan adopted a resolution to review and promote forestry research activities in developing countries. As a result, in 1984 IUFRO organised a regional workshop on 'Increasing Productivity of Multipurpose Tree Species' in Kandy, Sri Lanka. Priority species were selected and research activities were identified (Shea and Carlson 1984).

New institutions were soon formed to address the problem — these included the Nitrogen-Fixing Tree Association (NFTA) in 1981, the Forestry/Fuelwood Research and Development Project (F/FRED) in 1985, and the Regional Wood Energy Development Programme in Asia (RWEDP) in 1986.

Seed collection and exchange programs were initiated, and these familiarised scientists and development specialists around the world with MPTS. Since then, leading programs have included the University of Hawaii/NFTA Cooperative Planting Program, the work of ACIAR and CSIRO on acacias, and the collaborative research program of the Oxford Forestry Institute (OFI) featuring Latin American species.

The concept of MPTS originated from the publications of Smith (1950) and Bene et al. (1977) on the role of trees in agriculture, of Singh (1982) on tree fodders, and of the US National Academy of Sciences (NAS 1980) on firewood crops. The literature on MPTS is now huge and there have been many efforts to synthesise it into species compendia (Table 1). Those published before 1987 have popularised MPTS, and are usually cited in the volumes published more recently.

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Table 1. Chronological list of 10 MPTS compendia.

1. National Academy of Sciences. 1980. Firewood Crops. U.S. National Academy of Sciences, Washington, D.C., USA. 237 p. Valuable compendium of 60 fuelwood tree species, by ecological zone. Contains a master list of fuelwood species, essays and case studies on the 'other energy crisis', and a good list of researchers, arranged by species.
2. Little, E.L. 1981? Common Fuelwood Crops. A Handbook for their Identification. Communi-Tech Associates, Morgantown, West Virginia. A USAID-funded dendrological compendium of 90 species. Considerable overlap with NAS (1980) acknowledged.
3. Panday, Kk. 1982. Fodder Trees and Tree Fodder in Nepal. Swiss Development Cooperation, Berne, Switzerland. 107 p. Interpretive study with colour pictures of major Nepali fodder species.
4. Singh, R.V. 1982. Fodder Trees of India. Oxford and IBH Publishing, New Delhi. 663 p. A definitive descriptive volume of 97 fodder trees. Now under revision by author.
5. NAS. 1983. Firewood Crops. Volume II. U.S. National Academy of Sciences, Washington, D.C., USA. 92p. Follow up to NAS (1980), contains description of 27 additional fuelwood tree species, following the editorial style and content of the first volume.
6. Turnbull, J.W. ed. 1986. Multipurpose Australian Trees and Shrubs. Australian Centre for International Agricultural Research. Canberra. 316 p. Five technical chapters plus descriptions of 100 Australian tree species representing 26 genera.
7. von Maydell, H.J. 1986. Trees and Shrubs of the Sahel. Their Characters and Uses. Gesellschaft fur Technische Zusammenarbeit (GTZ), Eschborn, Germany. 525 p. A colour-illustrated volume of MPTS of the Sahel, with summary interpretive chapters on uses.
8. Weber, F.R. and Stoney, C. 1986. Reforestation in Arid Lands. Volunteers in Technical Assistance. Arlington, Virginia, USA. 335 p. A field manual for extension workers, with illustrated Appendix of 165 dryland African tree species.
9. F/FRED 1992. Growing Multipurpose Trees on Small Farms. Winrock International, Arlington, Va., USA. 195 p. An extension document. Eight technical support chapters and compiled information on 41 multipurpose trees. Borrows heavily from previously published information. Currently under revision.
10. Hocking, D. ed. 1993. Trees for Drylands. Oxford and IBH Publishing Co. New Delhi. 370 pp. Swiss Development Corporation of 75 species for arid/semi-arid conditions, with emphasis on India. Seven supporting technical chapters.

Roles in Farming Systems

Agroforestry, the science of integrating trees into farming systems, was institutionalised in 1977 with the establishment of the International Council (now Centre) for Research on Agroforestry (ICRAF). Since then, a huge amount of research and development work has transformed the potential of MPTS into reality, and long lists of recognised agroforestry systems have been published. At the simplest level, however, trees play two basic roles in farming systems — service and production.

Service

Trees in farming systems affect the farming site itself, filling a service role that is either beneficial or detrimental to crop growth and farm stability, depending on the situation. For example, when properly managed in contour strips, trees and other perennial vegetation can reduce soil erosion. Trees affect soil nutrient status through litterfall and when used as green manure. Nitrogen-fixing trees (NFTs) can contribute substantial amounts of nitrogen to agricultural systems, depending on the site, species, and management. Trees also offer shelter, especially as windbreaks or as shade. Overstorey trees in traditional systems such as the *Faidherbia albida* / grain parklands of Africa and home gardens give considerable shelter to understorey vegetation and livestock, as do shade trees in plantations. Trees also make effective field and boundary fences, and are used widely for this purpose.

These service roles of trees in farming systems have always interested agronomists. However, a growing body of experience suggests that many farmers are far more attracted by the potential products of trees than by their potential effects on the site.

Production

Tree products are many and various — food, fruit and spices; fibre, lumber, tannin, resins, and other industrial raw materials; livestock fodder; wood for fuel, implements and housing. From the perspective of farming systems, there are several important aspects of MPTS production to consider:

Home consumption vs. sale

In many cases, the opportunity to grow trees for sale is a stronger incentive than growing trees for home consumption. An example is firewood where early projects, emphasising small firewood plantations for home consumption, did not meet expectations. Growing fuelwood for sale, however, has proved successful in many areas.

Value added products

For example, should the tree be marketed as fodder or fed to livestock? Either way, the tree product ends up in the market place in some form.

Substitution pricing

This is an economic tool to infer the value of MPTS products in one location based on similarity with other local or foreign products. Although useful, it is often misapplied. In an extreme example (actually published), the price of an MPTS fodder was equated with commercial protein concentrates in India when, in fact, the fodder of that species was not found in fodder markets.

Extending MPTS Use in Farming Systems

Ideal tree/crop systems should optimise both the production and beneficial service roles of trees. Most traditional farming systems featuring perennial vegetation (e.g. parklands, home gardens, traditional shifting cultivation) optimise both roles, as do many other tree/crop mixtures developed recently with farmers. However, there are many examples of designs that either over-emphasise and misrepresent the service role or try to pack too much into the production role of trees (e.g. 'agri-horti-silvipastoral' systems). The service functions of trees are of most benefit when they are subordinate to explicitly defined production roles.

There are many difficulties to be overcome when giving advice about MPTS, including:

(i) social aspects, such as negative impressions of trees, equity and gender issues and tenurial problems;
(ii) the legal problems of felling and transport restrictions;
(iii) technical difficulties — poor seed, improper species selection and management, lack of sound information and advice;
(iv) competition for cropland, and negative tree/crop interactions;
(v) low returns at market, no market access, no market;
(vi) investment (land, labour, capital) constraints.

Nevertheless, there have been some outstanding success stories, as indicated by the following examples from my own experience.

The poplars of Punjab

Declining forest reserves in northern India led to the creation of a dynamic partnership between industry and farmers to produce raw materials for wood processing factories. In the late 1970s the West Indian Match Company (WIMCO) initiated a cooperative tree growing system with farmers. The program is based on poplar clones and farming systems developed by innovative researchers in the Uttar Pradesh State Forest Service. As wheat is cultivated in winter, when the poplars are leafless, the crops suffer little through competition (l0-20%) depending on management, site, tree age, etc.). The poplars thrive on the high solar radiation, irrigation and fertilizer inputs typical of wheat farming in the region. The success of the program is evident in the altered landscape. Published internal rates of return (IRR) exceed 50%, based on actual production figures. The system is spreading into the Nepali terai and has been developed independently and simultaneously in Pakistan with equal success.

Rubberwood in Malaysia and Thailand

Rubber was introduced into the Malay Peninsula in the last quarter of the 19th century. Under conventional management systems, plantations are exploited for latex and felled for replanting when yields decline. Although rubberwood is inherently suitable for industrial processing, large amounts used to be stacked and burned on site. Aspects such as blue stain fungal disease and the relatively short bole lengths of modern rubber tree clones limited the actual use of rubberwood in wood processing industries. Two recent innovations — pressurised impregnation of fungicides and finger joining technology — have changed the picture. Today, the rubberwood furniture industry in Thailand and Malaysia turns over $500 million annually, and sawn rubberwood fetches as much as $\$130/m^3$. Since most rubber plantations are managed by smallholders, particularly in Thailand, substantial benefit is accruing to private landholders. Now many growers are choosing to plant old clones characterised by low latex yields and long straight boles.

Majjia Valley windbreaks

The Majjia Valley windbreak project in central Niger (West Africa) was started by Peace Corps Volunteers and Nigerian forestry officials in the early 1970s and managed by CARE. At first, farmers opposed the project because they lost cropland, and government retained ownership rights to the trees. Armed guards were employed to protect the seedlings. With persistence, however, attitudes softened until now some 400 km of fast-growing neem windbreaks have been planted in the narrow valley. However, studies of the shelter effects of the windbreaks have not been able to demonstrate any clear advantage to the millet crops. Since the mid-1980s the older windbreaks have been pollarded and the wood communally sold for fuel in heavily-subsidised marketing schemes. Recently, the CARE foresters reported that wood sales have attracted such favourable prices that subsidies have stopped. Now many farmers have stopped growing millet between the windbreaks and have established private neem plantations.

These projects have several features in common, perhaps the least consequential of which is the absence of leguminous MPTS! More importantly, in each case, a link has been forged between small farmers and industries or merchants. Also, farmers grow the trees *on their own land*. The two regional projects are examples of thinking big and doing small. In north India, ten thousand farmers have demonstrated that they can grow trees faster and cheaper than industry or government. In all three examples above, viable long-term markets are the key to sustainability.

The Future Role of MPTS

The experiences of the past 20 years in tree extension are coming together to cause a fundamental change in the way trees are 'sold' to farmers and their families. Discussions I have had with many people in diverse disciplines during my tenure with the F/FRED program have included the following observations, which I pass on without editorial comment:

- A scarcity of household firewood, deficiencies in soil nitrogen and other 'alarming' issues are not sufficient reasons for farmers to plant trees.
- Agroforestry mixtures that work well on research stations rarely perform as expected when tried in the real world. All too often, they are under-productive, competitive and/or unmanageable.
- Using the findings of social and economic analyses, instead of arguing about them, can benefit biophysical scientists and development planners.
- The need has never been greater for development of extensible technical components, better planting stock, realistic systems and utilisation technology.
- Trees in farming systems need to be viewed as commodities like their crop counterparts. Trees, like any other commodity, must be treated as a complete production system which links markets with management decisions.
- No government or project can match the investment and innovative capability of a nation's farming, market and industrial sectors.
- As people move towards cities they leave marginal agricultural lands idle. There is an opportunity for tree farming these lands.

To define the future role of trees, leguminous, multipurpose or otherwise, one must distinguish between the types of problems they address. Here I discuss three types of problem — environmental, social and economic.

Environmental problems

Environmental problems confront us on a global scale. Tropical deforestation is now even more threatening than it was in the 1970s when it was first raised as a serious issue. Of equal concern are the threats facing whole populations in the tropics as a result of deteriorating soil resources, expansion of saline and other wastelands, degradation of watersheds and fresh water resources, and so on. There is clear scientific evidence that trees can lessen the impact of these trends. However, exploiting the service role of trees may prove to be prohibitively expensive. Distance from markets and services may hamper sustainability of efforts, and create extension problems. Correcting environmental problems with tree-based solutions will require large investments for incentives (subsidies, tax breaks, etc.), research, extension and policing.

Social problems

Great social problems also confront the tropics. Unemployment, poverty, population growth, resource tenure, income and gender inequality, among others, are (re)emerging as issues in their own right. Experience shows that the rural poor and landless can be effectively included in forestry programs. The huge amount of information gleaned from social science studies of forestry can be applied to advocate even greater use of forestry in social development schemes.

Production problems

The production role of trees should become more and more important as industry and markets search for alternatives to disappearing traditional supplies of raw materials. In my view, this will encourage (i) small farmers holding tenurial rights favourable to tree growing; (ii) active partnerships between farmers and industrial and market sectors; (iii) simple, competition-free tree/crop mixtures; (iv) food security; (v) value-added processing at the farm level; (vi) increased technological innovation in utilisation.

Conclusion

This paper has attempted to separate the service and production functions of MPTS and to provide support for the growing notion that the production role of trees is most important from the farmer's viewpoint. Researchers must force themselves to work in multidisciplinary teams, and should form alliances with industry, the marketplace, non-government organisations, and other groups. More effort must be made to give out the right information at the right level. Biophysical scientists need to develop better planting materials (seeds, clones) and competition-free agroforestry mixtures. MPTS market opportunities must be identified, and ways devised to avoid boom/bust pricing fluctuations. If policies based on natural forest management interfere with private tree growing, they must be reconsidered. Investment analysis models must be rethought and retooled.

Above all, the farmer's viewpoint must be the most important. As forests disappear, prices of wood and other forest products are increasing rapidly. Farmers are becoming aware of the opportunities, and when farmers perceive the economic advantages of growing trees, there will be more trees. Scientists must be prepared to help by providing state-of-the-art technical information.

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Opportunities and Limitations in Leucaena

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Abstract

Leucaena leucocephala continues to be one of the most productive multipurpose tree legumes available to tropical agriculture, yielding very high quality forage for ruminant production. However, the high expectations held for leucaena during the 1960s and 1970s have not been realised, primarily because of the narrow germplasm base available to producers. This is one reason why commonly used leucaena cultivars are poorly adapted to acid soils and cool temperatures, and lack resistance to damage by psyllid insects *(Heteropsylla cubana).* Other factors limiting the use of leucaena include poor seedling vigour, its potential to become a weed because of high seed production, and its moderate wood quality for fuelwood or construction purposes. International studies have shown that the sixteen or so other species of leucaena, with their wide diversity of characteristics, offer opportunities to develop germplasm which can overcome the above-mentioned limitations. The lesser-known species can be exploited directly or used to breed new hybrids which incorporate the beneficial qualities of two or more species.

THE genus *Leucaena* Bentham has its origins in Central America and Mexico where it has been used by humans for several thousand years and continues to be cultivated by present-day farmers (Hughes 1993). The genus is reported to contain either 16 species (Brewbaker and Sorensson 1993) or 17 (Hughes 1993), of which the most widely planted species is *Leucaena leucocephala* (Lam.) de Wit, known as leucaena. Its fodder value was recognised more than 400 years ago by the Spanish conquistadors who carried leucaena on their galleons to the Philippines to feed their stock (Brewbaker et al. 1985). From there leucaena has spread to most tropical countries of the world.

Leucaena has demonstrated wide environmental adaptability and a great variety of uses. It appears to possess combinations of attributes without parallel in other species. Brewbaker and Sorensson (1990) estimated that some 2-5 million ha of leucaena, almost entirely *L. leucocephala, are* planted world-wide. However, this estimate is difficult to verify because of the large areas of naturalised leucaena in Southeast Asian and Pacific regions.

Major limitations include poor tolerance of acid or waterlogged soils, poor adaptation to cool temperatures and frost, and susceptibility to the psyllid insect *Heteropsylla cubana* (Shelton and Brewbaker 1994). Indeed, the damaging effect of the leucaena psyllid has halted promotion and new plantings of leucaena in most regions. Unless these major limitations are overcome, leucaena's great potential, as predicted during the 1970s and 1980s, will not be realised.

Current Uses

Leucaena has always primarily been used as a high quality forage for ruminants, but it has also been valued for its fuelwood, charcoal, pulp and timber (Brewbaker et al. 1985). Its use in alley cropping systems is well-documented (Kang and Gutteridge 1994) so this aspect will not be discussed in this paper.

Leucaena is good forage. The leaves and young stems are highly palatable, and edible forage yields range from 3 to 30 t dry matter/ha/year depending on soil fertility, row spacing, rainfall and temperature, and psyllid challenge (Shelton and Brewbaker 1994). Leucaena also has special advantages,

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such as its strong perennial habit (half-life of 50 years; Jones and Harrison 1980) and its flexibility of use in animal feeding systems. Leucaena can be managed as hedge-rows in broad-acre grass-legume pastures for direct grazing, as hedgerows in alley-cropping systems, or as single trees in smallholder cut and carry systems. Once established, it is remarkably drought tolerant due to its deep-rooting system. During dry periods it is capable of producing small amounts of high value green shoots which are sufficient to maintain the microfloral activity of the rumen, enabling ruminants to digest the poor quality feeds commonly fed during severe drought.

Leucaena is also a valuable supplement to poor quality grasses and crop residues in smallholder systems where it has the effect of increasing intake and improving overall diet digestibility (Norton 1994).

Apart from its excellent palatability, leucaena is outstandingly good forage. Ruminants eat it readily and it has high digestibility. It supplies a balanced intake of protein, minerals (except sodium and iodine) and amino acids (Jones 1979), with low fibre content and a moderate tannin content which promotes by-pass protein value. The toxicity problem, caused by the non-protein amino acid mimosine, has been resolved (Jones and Lowry 1984).

In a broadacre system, cattle gained 1 kg liveweight/day and up to 300 kg liveweight/year while feeding on leucaena (in rows 5 m apart) interplanted with tropical grasses on fertile clay soils in Central Queensland, Australia (Wildin 1994). In the Ord River valley of northwestern Australia, steers have achieved annual liveweight gains of 1500-1730 kg/ha at a stocking rate of 6-7 steers/ha on irrigated leucaena/pangola *(Digitaria eriantha* spp. *penzii)* pastures in ideal growing conditions of fertile soil and high temperatures (Pratchett and Triglone 1989). These data indicate that leucaena has outstanding nutritive value among tropical legumes.

Limitations and Opportunities — Agronomic Aspects

Narrow germplasm base

Leucaena originally spread around the world as the germplasm of one species, *L. leucocephala,* often as seed from single trees. It has been described as one of the most extreme examples of a narrow genetic base in tropical tree planting (Hughes 1993). Clearly, farmers are over-dependent on this single species, and some of leucaena's limitations, such as susceptibility to psyllid attack, are partly caused by the lack of genetic diversity. *L. leucocephala* is a self-fertilised polyploid and therefore presents limited opportunities for genetic improvement.

We now know that, to date, we have used only a small fraction of the genetic resources of the genus leucaena. Table 1 lists 16 lesser-known species that present a wide variety of characteristics and potential opportunities for human use (Hughes and Harris, these Proceedings). Extensive germplasm collections

Table 1. Some descriptive data for sixteen Leucaena species (after Brewbaker and Sorensson 1993).

No.	Species	Chromosome number	Biomass	Psyllid tolerance	Elevation range	Mature height	Diam. at breast height
					(m)	(m)	**(cm)**
1.	*L. collinsii*	52, 56	Med	High	400-800	15	20
2.	*L. cuspidata*	—	V. Low	—	1800-2000	5	5
3.	*L. diversifolia*	52	High	High	700-2500	17	17
	L. diversifolia	104	High	Med	700-1500	20	30
4.	*L. esculenta*	52	Med	High	700-2000	15	27
5.	*L.* sp. "glossy"	112	V. Low	Med	1900-2400	7	15
6.	*L. greggii*	56	Low	Med	1200-1800	7	13
7.	*L. lanceolata*	52	Med	Low	0-800	13	25
8.	*L. leucocephala*	104	High	Low	0-900	20	40
9.	*L. macrophylla*	52	Low	Med	400-1500	8	13
10.	*L. multicapitula*	52?	Med	Low	0-200	17	30
11.	*L. pallida*	104	High	High	1500-2100	13	15
12.	*L. pulverulenta*	56	Med	Low	0-1500	20	35
13.	*L. retusa*	56	Low	High	500-1400	5	5
14.	*L. salvadorensis*	56	Med	Med	400-700	15	30
15.	*L. shannonii*	52, 56	Med	Med	0-900	15	30
16.	*L. trichodes*	52	Low	Low	0-600	12	17

of these species are available for direct use (Hughes 1993), and are held by the Oxford Forestry Institute (U.K.), the University of Hawaii (USA), and CSIRO (Australia). There is also scope for developing new interspecific hybrids (Brewbaker and Sorensson 1993; Sorensson, these Proceedings). In these hybrids, many of the desirable features of *L. leucocephala* could be combined with other desirable traits such as psyllid resistance, improved seedling vigour (Sorensson et al. 1994), higher yield (Castillo 1993), cool tolerance (Castillo 1993) and possibly even acid soil tolerance (Hutton and Chen 1993).

Pests and diseases

In the past, leucaena plants were notable for their relative freedom from insect pests, probably due to the insecticidal properties of the mimosine contained in actively growing young leaves. Two pests — the seed-boring beetle *Araecerus fasciculatus* and a flower moth *(Ithome lassula)* — did have particularly devastating effects on seed production (Walter and Parry 1994). However, it was the arrival of the leucaena psyllid *(Heteropsylla cubana)* that undermined the crop's reputation most effectively. The most positive result of the psyllid epidemic has been to catalyse the search for a suitable replacement from other tree legume genera.

Work in Hawaii has identified useful predators, such as the *Curinus* beetle, and parasites, such as the *Psyllaephagus* wasp, and there have been reports of several fungal pathogens providing control in Papua New Guinea (Hollingsworth et al. 1991). Although the initially catastrophic attacks by psyllids have become milder (Van Den Beldt and Napompeth 1992; Geiger, Van Den Beldt, these Proceedings), the leucaena psyllid remains the major limitation to continued use of *L. leucocephala.* However, experience in Australia has shown that the psyllid is not a serious pest in subhumid regions (600-800 mm rainfall) and commercial plantings are continuing there (Wildin 1994).

The leucaena psyllid is most likely to be controlled by use of resistant leucaena varieties. There are resistant provenances of *L. pallida, L. diversifolia, L. collinsii* and *L. esculenta* that may be used directly or through selected hybrids with *L. leucocephala* to retain the desirable features of that species (Brewbaker and Sorensson 1993). For example, resistant Fl hybrids have been successfully developed, as have advanced generation, open-pollinated lines from the interspecific cross of *L. leucocephala* with *L. pallida*, known as KX2 (Brewbaker and Sorensson 1990). Great scope exists to continue this aspect of research.

Diseases such as *Camptomeris* leaf spot, gummosis in leucaena stems, stem canker *Pirax subvinosus*, and pod and root rots, have also reduced leucaena productivity (Lenne and Boa 1994). This underscores the need for greater genetic diversity in leucaena plantings to reduce the risk of destructive epidemics (Boa and Lenne, these Proceedings).

Environmental tolerances

Opportunities to increase the use of *L. leucocephala* are limited because the species cannot tolerate cool temperatures and frost, nor soils that are acid (below pH 5.0) or waterlogged.

However, several species of leucaena do possess varying levels of cool and frost tolerance because they originate from higher altitudes in Central Mexico. These include *L. pallida, L. diversifolia, L. esculenta* and *L. pulverulenta,* while *L. retusa* and *L. greggii* even show tolerance of frequent frosts to –15°C (Hughes 1993). Data from southeast Queensland demonstrated the cool season growth potential of *L. pallida*, *L. diversifolia* and hybrids with *L. leucocephala* (Table 2). Using these species, growers should be able to expand plantings of leucaena into subtropical areas and to the high altitude tropics, where year-round cooler temperatures greatly restrict the utility of *L. leucocephala.* However, the frost tolerance of these species requires further study. For example, Williams (1987) reported that *L. diversifolia* has no more frost tolerance than *L. leucocephala.*

Table 2. Mean seasonal growth rate (cm/month) of three *Leucaena* species involving 11 lines (after Castillo 1993).

Species/Hybrids	No. of lines	Season			
		Autumn[1]	Winter[2]	Spring[3]	Summer[4]
L. leucocephala	(4)	3.2[b]	0.9[c]	10.6[c]	44.7[c]
L. pallida	(5)	14.6[a]	19.6[a]	54.5[a]	68.2[a]
L. diversifolia	(2)	13.2[a]	13.2[b]	32.0[b]	52.6[b]

Means with the same letter in a column are not significantly different ($P < 0.05$)
[1] 16 April-16 June 1992; [2] 17 June-16 Sept. 1992; [3] 17 Sept.-13 Nov. 1992; [4] 14 Nov.-16 Dec. 1992

We now know that leucaena's intolerance of acid soils was overstated in the past and that *L. leucocephala* can tolerate moderately acid soils of pH >/= 5.2 (Ruaysoongnern 1989). However, genuine acid soil tolerance is required to cope with the more severely acid soils of the tropics (pH < 5.0). Progress is being made with hybrids involving *L. diversifolia* (Hutton and Chen 1993). Diploid *L. diversifolia*, *L. esculenta*, *L. pallida* and *L. shannonii* may also have genes for tolerance to acid soil infertility (Brewbaker and Sorensson 1993, Blarney and Hutton, these Proceedings).

Leucaena leucocephala seedlings do not tolerate waterlogging, although a mature tree can survive intermittent waterlogging. Brewbaker and Sorensson (1993) suggested that *L. diversifolia* and *L. multicapitulata* may be sources of tolerance to waterlogging. Conversely, *L. leucocephala* is quite tolerant of dry conditions. Other species with potential drought tolerance include *L. collinsii* and *L. pallida*, which originate in dry areas (Hughes 1993).

Establishment

Slow establishment of *L. leucocephala* is still considered a major limitation to expanded use of leucaena in Australia (Lesleighter and Shelton 1986). The slow early growth of seedlings makes them vulnerable to predatory wildlife and weed competition, and it can take up to three years before leucaena can be used for grazing. Recent work has shown that young seedlings grow slowly partly because of inadequate weed control, partly because it takes time for roots to achieve effective symbioses with vesicular-arbuscular mycorrhizae and *Rhizobium* species (Brandon and Shelton 1993), and partly because leucaena has inherently low seedling vigour (Piggin, Shelton and Dart these Proceedings). However, *L. pallida* and its hybrids show better seedling vigour and faster early growth than *L. leucocephala* (Sorensson et al. 1994). Hybrids which combine psyllid resistance with improved seedling vigour and cool tolerance while retaining the high forage quality of *L. leucocephala* are an exciting prospect.

Weed Potential

A major concern with the promotion of *L. leucocephala* is the risk that it will become a weed if it invades protected areas or ecosystems where demand for foliage and wood is low. Leucaena is already a declared weed in 20 countries (Hughes 1993) although it has not been reported to invade undisturbed vegetation. The species' weed potential is related to its abundant production of seeds, which remain viable in the soil for a long time. The risk of leucaena becoming a weed is minimised in areas where human demand for leucaena products is high or where livestock are grazing. With the exception of *L. diversifolia*, other leucaena species are less likely to become weeds because of their reduced seed production (Hughes 1993). However, when species are brought into close proximity for evaluation they may hybridise spontaneously and produce vigorous new hybrids with unknown weed potential (Hughes 1993).

Brewbaker and Sorensson (1993) reported the production of seedless sterile triploid hybrids from the interspecific hybridisation of diploid and tetraploid species. While this strategy would eliminate weed risk it requires other effective clonal propagation (Osman these Proceedings) or effective hybrid seed production techniques.

Limitations and Opportunities — Forage Quality

Nutritive value of 'new' leucaenas

Not all leucaena species have as high a nutritive value as *L. leucocephala*. The limited information available (Table 3) suggests that psyllid-tolerant

Table 3. Average crude protein (CP), neutral detergent fibre (NDF) and acid detergent fibre (ADF) contents, in vitro dry matter digestibility (IVDMD) and condensed tannin (CT) level of three *Leucaena* species involving 11 lines (after Castillo 1993).

Species/Hybrids	No. of lines	Parameter (DM basis)				
		CP(%)[1]	NDF(%)[1]	ADF(%)[1]	IVDMD(%)[1]	CT(%)[2]
L. leucocephala	(4)	22.8[a]	32.0[c]	18.1[b]	66.3[a]	6.6[c]
L. pallida	(5)	17.5[c]	37.3[a]	20.6[a]	56.4[b]	8.5[b]
L. diversifolia	(2)	20.6[b]	34.1[b]	20.5[a]	54.2[b]	12.0[a]

Means with the same letter in a column are not significantly different ($P < 0.05$)
[1] Leaf fraction only; [2] Condensed tannin (Free-CT + bound-CT)

species, such as *L. pallida* and *L. diversifolia*, contain higher tannin and fibre levels and have lower in vitro digestibilities than *L. leucocephala* (Bamualim 1981; Norton, Lowry and McSweeney, these Proceedings).

Condensed tannins probably occur in all leucaenas, though in varying amounts. The levels of 4-6% found in *L. leucocephala* may be sufficient to prevent excessive protein breakdown in the rumen without over-protecting the protein from digestion in the small intestine. Higher levels of tannins, as found in *L. pallida* and *L. diversifolia* (Wheeler, Norton and Shelton, these Proceedings), may adversely affect animal production potential, although this has not been tested. To complicate the problem, drying can greatly reduce both the in vitro and in vivo digestibility of tree legumes, especially in species containing high levels of tannins (Mahyuddin et a1. 1988; Palmer and Schlink 1992).

It is essential that high forage quality be maintained in new leucaenas intended for use by livestock. The challenge is to produce psyllid-resistant cultivars of high quality.

Opportunities to exploit exotic rumen microflora

Researchers are optimistic that they can manipulate rumen microbial populations to improve digestion and utilisation of tree legume forage (Jones 1985). Cattle and sheep, which are not natural browsers, should benefit from the introduction of microbes from browsing animals. Already there are indications that sheep can digest tree legume foliage better when first given rumen contents from goats (Palmer and Minson 1994). Browsers that eat only tree foliage, such as giraffe and kudu, may be better donors. Their more effective utilisation of tree legumes seems to be associated with possession of rumen bacteria capable of degrading material containing tannins (Mathew et al. 1991). Even more effective micro-organisms may be found in termites.

Increasing the rates at which ruminants digest cellulose might be accomplished through genetic engineering. For example, genes from wood-degrading fungi might be introduced to the rumen in modified rumen bacteria or anaerobic rumen fungi (Orpin and Xue 1993).

Opportunity for developing low-mimosine leucaena

For ruminants, the mimosine in leucaena need no longer be considered an anti-nutritive factor. Specific rumen bacteria *(Synergistes jonesii)* are now available to detoxify this amino acid (Jones 1994). However, mimosine is still a problem when leucaena is fed to monogastric animals. Although mimosine can be removed from fresh material by immersion in hot water (Lowry et al. 1983), the degradation product DHP can also have deleterious effects, mainly by reducing feed intake (Tangendjaja and Lowry 1984).

While there is some scope for selecting and breeding leucaena for reduced mimosine levels (Gonzalez et al. 1967), it has already been found difficult to combine high vigour with low mimosine (Jones and Bray 1983; Bray, these Proceedings).

Prospects are not good for including leucaena meal in poultry rations, although the meal's high xanthophyll content imparts colour to egg yolks and pigment to broilers. Recent work has found that chicks perform poorly more because of the low apparent metabolisable energy value of leucaena meal rather than because of high mimosine content (D'Mello and Acamovic 1989). The presence of tannins, trypsin inhibitors, galactomannan gums, saponins and flavonols may also reduce leucaena's nutritive value for poultry (D'Mello and Acamovic 1989) and other monogastric animals.

Ensiling leucaena lowers the concentration of mimosine (James and Gangadevi 1990), but probably converts it to DHP. Adding *Synergistes jonesii* to leucaena silage may enable DHP to be degraded, but this has not been tested.

Meat and milk quality

The high liveweight gains of leucaena-fed cattle mean that cattle can be marketed at a younger age, a major factor affecting beef quality for specialised markets. Excessively yellow-coloured carcass fat was noted in earlier work with Hereford cattle, but is not as marked in Brahman cross cattle (Jones 1994), and goats fed 100% leucaena have no yellow fat.

Consumers have readily accepted beef from cattle fattened on irrigated leucaena in northwestern Australia (Ryan et al. 1992). Milk from leucaena-fed cows has a distinct taint. Although Hamilton et al. (1969) claimed that this taint was removed by pasteurisation, Stobbs and Fraser (197 1) disagreed. However, Mexican consumers are said to prefer milk from leucaena-fed cows. There is some concern about mimosine accumulation in the tissues of chickens fed rations containing leucaena (after Meulen et al. 1984). Mimosine and DHP could also be excreted in milk if they are not degraded in the rumen. Clearly the presence of these toxins in animal products is unacceptable.

Limitations and Opportunities — Wood Quality

Wood is a valuable additional product of *L. leucocephala* in smallholder systems. In its native range in Mexico and Central America, leucaena is widely grown and managed to produce wood for fuelwood and poles (Pottinger and Hughes, these Proceedings). The wood is of medium density (SG = 0.36 to 0.52) and the giant varieties are most valuable (Van Den Beldt and Brewbaker 1985). Leucaena wood compares favourably in quality with that of many other fast-growing tree legumes (Ryan 1994) and has also been used industrially for the production of pulp and energy.

The principal limitations of leucaena wood are its low durability, susceptibility to termite attack and moderate density. However, it should be possible to select for improved tree form, wood quality and durability. This is probably especially true within the species *L. collinsii* and *L. salvadorensis* (Hughes 1993) which are preferred for firewood in their native range. However, the specific gravity, heartwood production, fuelwood characteristics and durability of the lesser-known leucaena species should also be studied (Pottinger and Hughes, these Proceedings).

Limitations and Opportunities — Adoption

Despite three decades of research on leucaena, and a multitude of research papers and other more general publications, adoption worldwide has been much lower than expected. This can be partly attributed to earlier concerns about mimosine toxicity, followed by the psyllid challenge, and more recently, to environmental concerns. Even in subhumid northern Australia, where there is no major obstacle to expanded plantings and the benefits are substantial, adoption has been surprisingly slow. In Africa, disappointingly few farmers have taken up the widely promoted alley-cropping technology. Poor adoption is blamed on the farming systems being unsuitable and farmers not being ready for alley-cropping methods. Brewbaker and Sorensson (1993) suggested promoting leucaena's versatility in farming systems by on-farm demonstrations and better education of rural practitioners.

Conclusions and Research Opportunities

Leucaena has failed to fulfill its predicted potential, primarily because of the narrow germplasm base used in the majority of plantings. Whilst we understand how to establish leucaena, and methods are available to protect ruminants against mimosine toxicity, we still do not understand the mechanisms of 'psyllid resistance and cold tolerance.

But there are now opportunities to diversify the germplasm available to farmers by using other species in the genus, either directly or by interspecific hybridisation. There is scope for breeding new leucaena varieties with psyllid resistance, cool tolerance, improved seedling vigour and perhaps even acid soil tolerance. Such diversity will help protect farming systems from new outbreaks of pests and diseases.

However, we must guard against leucaena spreading as a weed when new varieties are introduced. Use of sterile triploids of leucaena would prevent that problem, if ways can be found to propagate them vegetatively.

High priority must be given to studying the nutritive value of the new leucaenas, especially the effects of high tannin content on forage quality. There may be opportunities to modify rumen microflora to improve the digestibility of high tannin foliage.

There are opportunities to improve animal production of ruminants by feeding leucaena, but we are less optimistic for monogastric animals.

Provenances are needed which produce more durable wood of higher density.

Adoption of leucaena has been lower than expected. Its benefits need to be demonstrated on farms. This versatile plant can be exploited in many ways to make farming systems more productive and sustainable in both developing and developed countries.

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Opportunities and Limitations in Sesbania

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Abstract

Within the genus *Sesbania, S. grandiflora* and S. *sesban* show the greatest potential for use in agriculture. Both species tolerate waterlogging and soil salinity, making them suitable for use in reclaiming inhospitable, unproductive sites. Seedlings grow rapidly and with vigour, early biomass production is high, and seed production is prolific. Sesbania forage has a high nutritive value for ruminants and is best used as a supplement to low quality basal diets such as crop residues or standing grass. The method of harvesting forage from these species is an important consideration in their management: S. *grandiflora* does not tolerate frequent defoliation at low cutting heights. Opportunities and limitations of these species are discussed in this paper.

THE two most important species within the genus *Sesbania* are *S. grandiflora* and *S. sesban*. They are perennials, with great potential for agricultural use as fodder, fuelwood and mulch. Several annual *Sesbania* species, such as *S. rostrata* and *S. cannabina*, are used as green manures, particularly in rice cultivation, but have little other agricultural value.

Although the exact origin of the perennial species is not known, *S. grandiflora* is considered native to many countries in Southeast Asia while *S. sesban* is widely distributed throughout tropical Asia and Africa. There are two main varieties of *S. grandiflora*, a white flowered type and a red flowered type. *S. formosa* is a closely related species native to northern Australia. Five varieties of *S. sesban* are recognised botanically, but their breeding systems and taxonomy remain unclear in spite of some cytological studies (Bir et al. 1975). *S. sesban* var. *sesban*, *S. sesban* var. *bicolor* and *S. sesban* var. *nubica* are all quite similar and are 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 paper indicates the variety *S. sesban* var. *sesban*.

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Environmental Adaptation

Sesbania grandiflora is well adapted to hot humid environments. It does not grow well in the subtropics especially where temperatures fall below about 10°C (Wood and Larkens 1987). *S. sesban*, however, shows some cool tolerance and grows well in the subtropics and at elevations up to 2000 m in the tropics provided there is no frost.

Both species are outstanding in their tolerance to salinity and highly alkaline soil conditions (Hansen and Munns 1985), and to waterlogging. They appear to thrive in seasonally flooded environments. Very few other trees or shrubs grow well in saline waterlogged environments, making *Sesbania* species ideal for improving the productivity of such sites (Rekib and Shukla 1993).

Agronomic Characteristics

The perennial *Sesbania* species are usually established from seed. This is produced quite prolifically (Gutteridge and Stur 1994) and can be stored at room temperatures for up to 3 years with little deterioration (Pathak et al. 1976). Extensive plantings are sown at rates of 3-4 kg/ha, but better establishment is often obtained by transplanting seedlings early in the wet season (Patil et al. 1979). One of the major advantages of these species over other shrubs and trees is their seedling vigour and rapid early growth rate. Dutt et al. (1983) report that *S. sesban* attained a height of 4-5 m in 6 months in India. This characteristic confers an advantage in situations where weed competition is a problem during establishment (Maasdorp and Gutteridge 1986). The species' early vigour also enables the production of high yields in the first year under favourable growing conditions. Yields of more than 20 t/ha of dry matter have been recorded at several locations in the tropics (Gill and Patil 1983; Evans and Rotar 1987a; Rekib and Shukla 1993).

Cutting management has a very important influence on the productivity of perennial *Sesbania* species. *S. grandiflora* does not tolerate repeated cutting at heights of about 1-1.5 m; stands subjected to this type of management show high plant mortality (Horne et al. 1986; Evans and Rotar 1987b; Akkasaeng et al. 1989). This major limitation of *S. grandiflora* can be overcome, to some extent, by not cutting the growing apex and only removing the side branches. Plant survival is then much greater. By contrast, *S. sesban* appears to thrive under repeated cutting and coppices readily, with many branches arising from the main stem below cutting height. About three to four cuts per year have given dry leaf yields ranging from 4-12 t/ha/year depending on location (Dutt et al. 1983; Galang et al. 1990). Rekib and Shukla (1993) harvested *S. sesban* at 0.75 m which induced more branching and reduced mortality.

There are few studies on the response of perennial *Sesbania* species to direct grazing by livestock. Several researchers report both species being browsed but give no indication of their rate of recovery after browsing (Gillett 1963; Lamprey et al. 1980). Young *S. grandiflora* trees were destroyed by goats grazing in the dry season in Sumbawa, Indonesia (P.R.D. Philp, personal comm.). In southeast Queensland, goats grazing an 8 month old stand of S. *sesban* stripped the bark from the main stem 10-15 cm above ground level causing 75% plant mortality (Kochapackdee 1991). The goats inflicted damage as soon as they were exposed to the trees. In a follow-up study, Callow (1993) found that sheep caused similar damage only after three or four weeks access to the sesbania.

After a 15 month study, Gutteridge and Shelton (1991) reported that cattle grazing on *S. sesban,* in 4 m wide rows interplanted with *Brachiaria decumbens*, caused breakage and splitting of many of the side branches of *S. sesban* trees, because the branches were brittle. The damage may have been responsible for the trees' reduced longevity, from 5 or 6 years under cutting to 2 or 3 years under grazing. Thus a limitation of these species is their apparent susceptibility to direct grazing. 'Cut and carry' systems may be more appropriate for sustained, longer term forage production. Appropriate management systems need to be devised if sesbania is to be grazed directly.

Nutritive Value

Sesbania species are a potential source of high quality forage, with generally low crude fibre and high phosphorus content. The leaves and fine stems of both *S. grandiflora* and *S. sesban* are readily eaten by ruminants such as cattle and goats (e.g. Gohl 1981; Hutagalung 1981). Djogo (1994) observes that many smallholder farmers in Timor Indonesia prefer *S. grandiflora* foliage for their stock as it seems more palatable and more nutritious than leucaena.

Akkasaeng et al. (1989) measured in vitro dry matter digestibilities (IVDMD) of *Sesbania grandiflora, S. sesban* and *S. sesban* var. *nubica* as 66%, 75% and 66% respectively. These values were higher than those of 15 other tree legumes tested. *S. grandiflora* has been reported to contain more crude protein but less fibre than *Gliricidia sepium* and *Leucaena leucocephala*, with IVDMDs of 73.3%, 65.2% and 62.2% respectively (van Eys et al. 1986). Singh et al. (1980), Ahn et al. (1989), Ash (1990) and Mozumdar et al. (1987) also report high digestibility of sesbania foliage.

Animal Production

There are few data on animal productivity when perennial *Sesbania* species are used as feed. In most instances, the herbage of sesbania has been fed as a supplement for low quality straws or grasses and for relatively short periods.

The only long-term grazing study is that of Gutteridge and Shelton (1991) who reported liveweight gains of 0.7 kg/head/day over 15 months for young heifers grazing a mixed *Sesbania sesban/Brachiaria decumbens* (signal grass) pasture in southeast Queensland. This compared with liveweight gains of 0.4 kg/head/day for similar cattle grazing signal grass alone fertilized with 200 kg N/ha/year (Fig. 1). The heifers were reluctant to graze *S. sesban* at first but after three months became accustomed to it and consumed it readily at up to 20% of their diet. In penned feeding trials, Singh et al. (1980) found that goats fed a diet of *S. sesban* forage ad lib for a period of eight weeks gained an average 17.1 g/head/day compared to an average gain of 30.3 g/head/day when 20% of the forage was replaced with a concentrate mixture. Robertson (1988) found growth rates of 66 g/head/day in goats fed dried *S. sesban* as a 30% supplement to rice straw over a period of four weeks.

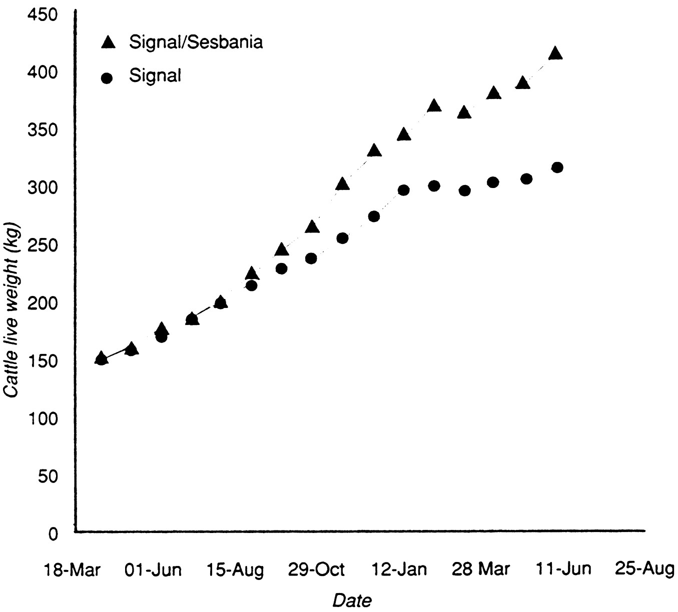

Figure 1. Liveweight gain of cattle grazing a *Sesbania* sesban/signal grass mixture or signal grass alone fertilised with 200 kg N/ha/year.

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 some feeding experiments have been no better than for other tree forages (van Eys et al. 1986; Anon. 1987; Semenye et al. 1987). This may be associated with anti-nutritional factors in the sesbania forage. 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 but the concentration of total phenolics was 2.8% and 2.5% in fresh and dried material respectively.

The most economically efficient and safe use of perennial sesbania forage for ruminants may be as a protein supplement with low quality roughages such as crop residues or grasses. This dilutes the effects of anti-nutritional factors and greatly improves the utilisation of the roughages (Rekib et al. 1987; Ash 1990). Even so, Gutteridge and Shelton (1991) found no toxic or anti-nutritive effects on the heifers in their 15 month grazing study.

Perennial sesbania forage is less suited to the diets of monogastric animals. S. *grandiflora* leaf meal progressively depressed chicken feed intake and body weight when fed at rates of 0, 5, 10 and 15% of total ration (Prasad et al. 1970). Williams (1983, cited by Evans and Rotar 1987b) 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 there were no signs of toxicity in those fed *S. formosa.* However, 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 when using perennial sesbania species in the diets of monogastric animals.

Soil Fertility Improvement

The perennial *Sesbania* species, particularly S. *sesban,* have been used successfully as green manures and sources of mulch for improving the N and organic matter status of degraded soils (Sivaraman 1951; Weerakoon 1989). Incorporation of up to 13 t/ha dry matter of S. *sesban* improved maize and bean yields by 78% in Kenya and residual effects lasted up to 3 years (Onim et al. 1989).

Yamoah and Getahun (1989) suggested that S. *sesban* is a promising tree for alley cropping systems because it is easy to establish, grows rapidly, coppices readily and provides mulch of high nutrient content. They cautioned, however, 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. However, *S. grandiflora* has been declared inappropriate for alley cropping in Nigeria because it has shown up to 80% mortality and produced less biomass than leucaena and gliricidia (Duguma et al. 1988).

Fuelwood

There is limited information on the wood yields of perennial *Sesbania* species. Onim et al. (1989) reported a yield of 16 t/ha of sun-dried wood from a four year old stand of S. *sesban* at a density of 1600 plants/ha in Kenya. Much higher yields of 63.5 t/ha are reported for S. *sesban* grown under rainfed conditions in Haryana, India (Singh 1989). von Carlowitz (1989) pointed out that S. *sesban* is popular for fuelwood because it produces a high woody biomass in a short time. Although soft, this wood provides a relatively smokeless, quick, hot-burning kindling. The wood of S. *grandiflora* is not highly valued for cooking as it has poor burning qualities and produces much smoke.

Conclusions

There are several features of the perennial sesbania species which make them attractive for use in agricultural systems. These include their tolerance of waterlogging and soil salinity, their rapid early growth and their high digestibility and high nutrient content which make them excellent high quality forage. Their high nutrient content also makes them a good source of high quality green manure and mulch. These species also have several limitations, including their weak perenniality and poor cold tolerance.

The species' tolerance of waterlogging and soil salinity could be exploited to a greater extent in the many environments where periodic inundation and/or saline encroachment severely restrict agricultural productivity. Research on how Sesbania species could best be used to help reclaim such sites should be a matter of high priority. In other sites, Sesbania species could be combined with slower growing plants, providing early and more sustained yields because of Sesbania's rapid early growth rate and ability to compete with weeds.

Appropriate management systems are needed to exploit these *Sesbania* species fully for fodder. We need to understand how direct grazing affects plant longevity before deciding when *S. sesban* should be first grazed. However, the anti-nutritive factors in the foliage limit sesbania's potential for use as feeds for monogastric animals, and even ruminants may suffer when fed diets high in sesbania for long periods. Research could determine the types of anti-nutritive factors present and whether they can be controlled, altered or reduced by management practices.

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Opportunities and Limitations in Calliandra

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Abstract

Calliandra calothyrsus is the best known species of the genus *Calliandra,* which has its centre of diversity in South America. Although rarely used in its area of origin, *C. calothyrsus* (calliandra) provides fuel, shade, soil stabilisation and feed for ruminants in the humid tropics, especially in Indonesia. Calliandra outyields *Leucaena leucocephala* and gliricidia on acid, low fertility sites and shows continuous growth throughout the year when regularly cut. Calliandra is not attacked by the leucaena psyllid. Preliminary comparisons of yields and tissue nitrogen in several accessions of calliandra have been made. Recent research in Australia showed that the digestibility and voluntary feed intake of *C. calothyrsus* was higher for fresh than for dried or wilted material, which has implications for feeding C. *calothyrsus* in cut-and-carry systems. Modifying the rumen microflora improved the digestibility of dried calliandra leaves, overcoming some of the adverse effects of high tannin content. The high condensed tannin levels (11% of DM) appeared less of a problem in fresh material. The Oxford Forestry Institute has a range of calliandra material now available for evaluation.

THE genus *Calliandra* (Mimosoideae, Ingeae) has its centre of diversity in South America, and also occurs in Central and North America, Madagascar, and India. The best known species, *Calliandra calothyrsus,* occurs naturally in Mexico, the secondary centre of diversity of the genus. This species is one of seven in the genus that fall within the subgroup Racemosae, all members of which are found in Mexico and Central America. Several other species from this region have been placed in a new genus, *Zapoteca* (Hernandez 1986). The taxonomy, botanical description, phenology and breeding system of *C. calothyrsus* have been well covered in the literature (Meissner 1948; Wiersum and Rika 1992). Macqueen (1992, 1993a) has given detailed information on C. *calothyrsus* and related species.

Although C. *calothyrsus* (calliandra) is rarely used in its centre of origin, it has been introduced to many tropical regions where it is used in agroforestry systems for fuelwood and plantation shade, and as an intercrop hedgerow shrub to improve soil fertility and soil stability. More recently it has been used as livestock feed (NAS 1983; Lowry and Macklin 1989; Wiersum and Rika 1992; Palmer et al. 1994). Calliandra is particularly favoured in Indonesia, where more than 170 000 ha have been planted for the reforestation of eroded, poor quality land around villages.

Calliandra calothyrsus provides a possible alternative to Leucaena. Many soils in newly developing areas of southeast Asia are infertile and acidic and unsuitable for growing *Leucaena leucocephala* unless considerable quantities of lime are applied. The damage caused by the leucaena psyllid in recent years gives another urgent reason to find alternative shrub legumes (Palmer et al. 1989; Bray and Woodroffe 1991).

In Indonesia, animal production is practised mainly on subsistence farms, where forage is cut and carried from small holdings of land, usually with no input of fertilizer. In these systems, the shrub legumes offer energy and plant protein to supplement low quality grasses, as well as providing fuel, shade and fences.

In this paper we summarise recent information on some of the characteristics perceived to limit the usefulness of *C. calothyrsus* as a multipurpose shrub legume. We comment on the opportunities for, as well as on, the *actual* limitations to use of calliandra in agroforestry in the newly developing countries.

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Agronomy

In its native habitat, *C. calothyrsus* grows at altitudes from sea level to 1800 m in areas where the annual precipitation range is 700-3000 mm. Although able to withstand dry periods, the species is reputedly not very drought tolerant.

Growth

The growth of *C. calothyrsus*, *L. leucocephala* and *Gliricidia sepium* (gliricidia) has been compared at one site in Indonesia and two sites in Australia (ACIAR projects 8363 and 8836). At the 'Silkwood' site in north Queensland, *C. calothyrsus* had a similar growth rate in both the wet and dry season, while growth of G. *sepium* was negligible in the dry season (Fig. 1). This low fertility site has a pH of 5.3 and an aluminium saturation of 85%.

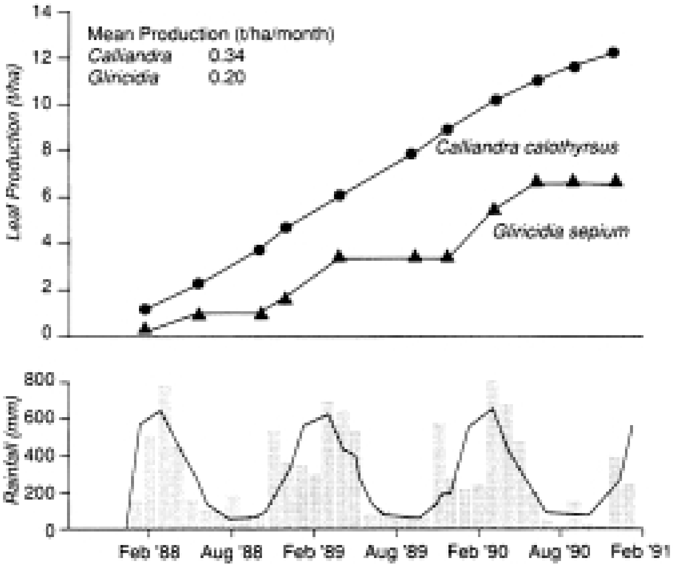

Figure 1. Cumulative leaf dry matter production (t/ha) of calliandra and gliricidia with no fertilizer application, and monthly and long term average rainfall (—) at Silkwood.

The ability of *C. calothyrsus* to maintain production throughout the year is recognised as a most desirable attribute and was evident at all three sites ('Sei Putih', 'Silkwood' and 'Utchee Creek'). Calliandra out-yielded leucaena and gliricidia in monthly leaf yield at the three sites both with and without fertilizer (Table 1). At less fertile sites ('Silkwood' and 'Sei Putih') fertilizer applications would be recommended to sustain economically viable animal production.

Clearly *C. calothyrsus* grows well in a range of environments. It has the potential to complement leucaena and extend the range over which shrub legumes are grown in forage production systems in the humid tropics. Within the genus *Calliandra* there is the potential to select material to improve productivity not only for forage but also for multipurpose traits.

Genetic diversity

Bryan (1991) used isoenzyme analysis to examine storage protein banding, and confirmed considerable genetic diversity within provenances of C. *calothyrsus* collected by the Oxford Forestry Institute. Least variation was found in San Ramon, Nicaragua (11/91), which may represent a colonist population from a Sandanista fodder plantation. The data suggest that, as expected, land race or planted material contains less variation than wild populations — an observation supported by the apparent uniformity of material growing in the Indonesian archipelago.

Production and forage quality

Although *C. calothyrsus* has been the focus of attention for agroforestry, there are signs that other species, even within the Racemosae, also have potential. In Papua New Guinea, *C. houstoniana* has shown impressive production in hedgerows (Brook 1992) and in Australia an accession of C.

Table 1. Leaf yield (DM t/ha/month) for calliandra, gliricidia and leucaena at three sites, plus and minus fertilizer.

Site	Soil PH	Calliandra		Gliricidia		Leucaena*	
		fertilizer		fertilizer		fertilizer	
		minus	plus	minus	plus	minus	plus
Silkwood	5.3	0.34	0.63**	0.20	0.36**	0.06	0.27**
Sei Putih	5.3	0.71	1.10**	0.55	0.60	0.38	0.62**
Utchee Creek	5.3	1.01	1.05	0.60	0.56	0.49	0.63

* Leucaena data obtained while plant sprayed for insect control (first 22 months only) at Utchee Creek and Silkwood
** Significant response to fertilizer application ($P < 0.05$)

houstoniana ranked in the top ten amongst 30 accessions (mostly of *C. calothyrsus).* At higher altitude sites *C. longepedicellata* may also have potential (Macqueen 1993a). In the wider context of the genus, many as yet untested species may prove useful for agroforestry.

The performance of a range of calliandra germplasm, mainly from the Oxford Forestry Institute collection, is being compared in two experiments in North Queensland. The accessions include C. *calothyrsus* (19 entries), *C. grandiflora* **(1),** C. *houstoniana* (1), *C. juzepczukii* (1), *C. physocafyx* (1), *C. acapulcensis* (3), unidentified calliandra species (2), and a *Zapoteca* species (formerly *Calliandra) tetragona* (1).

One site ('Lansdown') has a fertile alluvial soil (pH 7) and a longterm mean annual rainfall of 870 mm. In the 1993 drought year (annual rainfall 400 mm) trickle irrigation was used. 'Utchee Creek' is a high rainfall site (mean annual rainfall 3500 mm) with a slightly acid soil (pH 5.5). The experiments were established in December 1992. To estimate yield, all plants were cut back to 75 cm in May 1993 and harvested again in October 1993 (4.5 months later). Some preliminary results are shown in Table 2; the yields obtained (about It/ha/month) are similar to those from our previous experiments at these sites.

Among the best entries were *C. calothyrsus* 134/91 from La Puerta, Nicaragua (although this had relatively low tissue nitrogen) and 147/91 from Madiun, Indonesia. *Calliandra houstoniana* also yielded well but had low tissue nitrogen, while C. *grandiflora* and *C. physocalyx* yielded very poorly (Table 2). The differences between entries in the ratio of leaf to stem were not correlated with yield.

In general, C. *calothyrsus* yielded better than the other *Calliandra* species, although the noticeable variation between the accessions suggests potential for improvement. Accession CPI 115690, which has been widely tested by Palmer and Bray in Indonesia and Australia, showed considerable potential. It had close to average dry matter yield (3.28 t/ha) with a relatively high leaf nitrogen content.

Use by Animals

In recent work, Palmer and Schlink (1992) found that fresh C. *calothyrsus* CPI 115690 has high forage value. Sheep fed fresh leaves of C. *calothyrsus* voluntarily ate 59 g DM/kg metabolic weight ($[\text{liveweight}]^{0.75}$) compared to 37 g of dried (wilted) leaves per kg metabolic weight. The higher level of voluntary intake was associated with a higher in sacco digestibility of fresh material compared with oven dried, wilted or freeze dried material (Fig. 2).

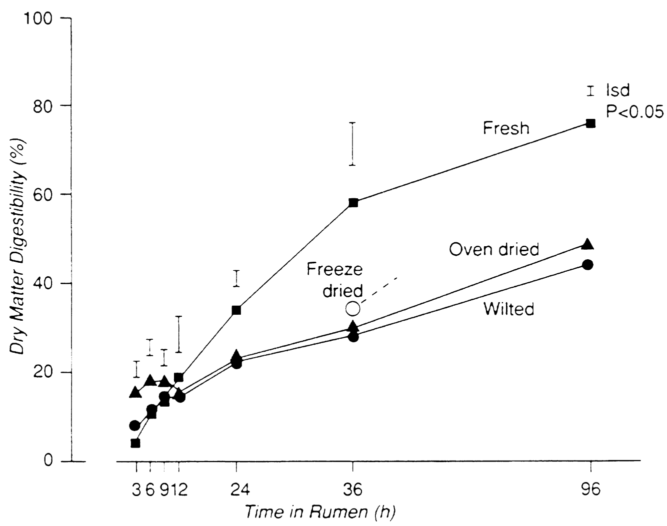

Figure 2. Relationship between in sacco digestibility of *Calliandra calothyrsus* and the length of time in the rumen of steers.

Table 2. Yields from cutting trials of the calliandra collection at two sites (DM t/ha), and tissue nitrogen (g/kg) at the initial cutting.

Accession	Lansdown				Utchee Creek			
	Leaf		Stem		Leaf		Stem	
	Yield	N	Yield	N	Yield	N	Yield	N
C. calothyrsus 115690	3.28	33.7	2.07	8.5	3.23	38.4	2.30	11.5
C. calothyrsus 134/91	4.36	24.1	2.93	6.7	3.74	33.8	2.96	12.7
C. calothyrsus 147/91	3.80	33.4	2.39	9.6	4.68	42.7	3.45	14.6
C. calothyrsus 40/92	2.78	27.9	1.86	8.0	1.92	32.5	1.57	12.9
C. grandiflora 39/92	0.34	30.2	0.18	12.9	0.02		0.00	
C. houstoniana 58/92	4.03	27.9	2.46	8.8	4.05	32.7	2.80	17.2
llsd 5%	0.93		0.88		1.00		0.90	

na = not available

Sheep made significantly different daily liveweight gains when fed ad lib low quality hay supplemented with fresh *C. calothyrsus* leaves at four levels, namely 0, 16, 28, and 35% DM. The resulting liveweight gains were -35, 6, 41 and 70 g/day respectively (Fig. 3). Extra wool was produced too, at rates of 30, 55, 70 and 95 mg/l00 cm^2/day on these feeds, indicating extra bypass protein.

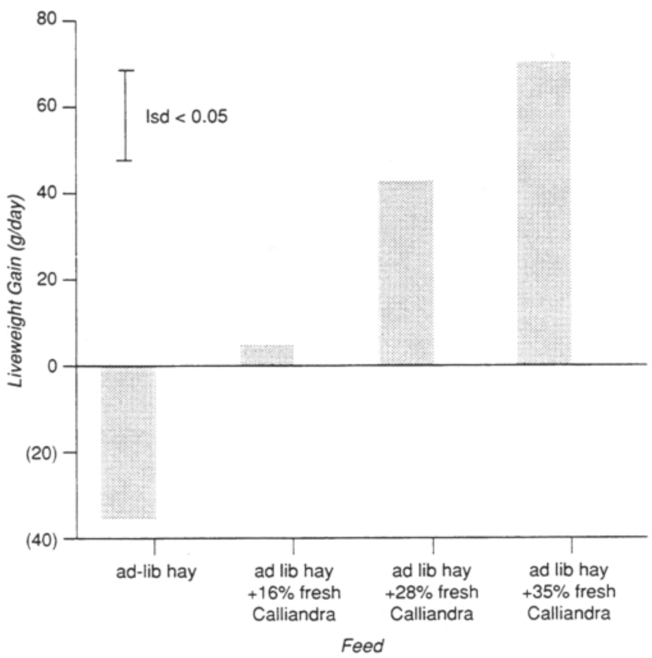

Figure 3. Daily liveweight gain of sheep fed fresh calliandra leaf over a 65 day period.

Anecdotal information suggests that the palatability and fodder quality of C. calothyrsus are inadequate, possibly due to tannins. Ahn et al. (1989) reported high concentrations (up to 11%) of condensed tannins but no toxic substances. C.S. MacSweeney (pers. comm.) extracted tannin (approximately 11%) from *C. calothyrsus* CPI 115690 and used NMR spectroscopy to show it was predominantly condensed.

The tannins (phenols) present in fresh C. *calothyrsus* may not be as harmful as those in wilted or dried material. In the fresh state they may be less polymerised and so less able to bind with plant protein or other components. This hypothesis is supported by data reported by Tangendjaja et al. (1992), who measured tannin activity by precipitation of bovine serum albumin. They found tannin activity was more than doubled by wilting. Recently, Palmer has demonstrated significant improvements in the digestibililty of dried C. *calothyrsus* leaf (fed, dried or fresh, as 40% of the diet, with 60% *Brachiaria humidicola* hay) by the addition of up to 20 g of polyethylene glycol (PEG) to complex any free tannin. However, the PEG did not improve the digestibility of the fresh material.

In a cut-and-carry system it is very difficult to maximise calliandra's feed value by feeding it fresh to animals. Even six hours after cutting, calliandra's in sacco digestibility can fall by up to 50% (Palmer and Schlink 1992). We suggest two ways of overcoming this problem. One way is to select or develop lines of calliandra in which the tannins are less affected by drying — we are investigating this approach in the current collection of accessions held by the Oxford Forestry Institute. An alternative solution may be to modify the rumen microflora, as Palmer and Minson (1994) have tried to do by introducing rumen liquor from feral goats to sheep. They found an improvement in dry matter digestibility (Table 3). The dry matter digestibility of dried *C. calothyrsus* leaf, resident in the rumen for 96 h, improved by 12%, while the crude protein digestibility improved by 20%. These results demonstrate the potential for this line of research.

Table 3. Effect of inoculating the rumen of sheep on the percent in sacco disappearance of dry matter and crude protein from fresh and dried *C. calothyrsus.*

Time in rumen	Dry matter			Crude protein		
	Sheep		Goat	Sheep		Goat
	Control	Inoculated		Control	Inoculated	
Dry Material						
48 h	34^b	38^a	40^a	40^b	45^b	58^a
96 h	47^b	53^a	53a	59^b	72^a	72a
Fresh Material						
48 h	60^b	68^a	72a	58^b	72a	73^a
96 h	72a	73a	72a	79^a	85^a	82^a

Values in the same row with different superscripts were significantly different (P<0.05)

Opportunities and Limitations

Opportunities

Calliandra calothyrsus CPI 115690, the accession used in most of this work, grows well in a range of environments and appears to have potential as an animal feed. It is palatable and no problems of poor intake have been observed so far in animal trials. The fresh material has high in sacco digestibility and there is potential to improve the digestibility of dried material by modifying the rumen microflora. This accession is currently being studied in field grazing experiments and has been shown to persist under harsh cutting or grazing regimes. Improved agronomic practice should overcome most of the accession's field establishment problems, which are caused by extreme competition from tropical grasses. In Australia, this accession has been sown successfully using a minimal disturbance band seeder.

The Oxford Forestry Institute's trial network is collecting data on the performance of different seedlots of calliandra. Researchers throughout the world will be able to use the resulting database to match calliandra accessions to the specific needs of user groups. Apart from being good fodder *C. calothyrsus* is good fuelwood, is suitable for making charcoal and can be used as a smoking fuel for producing smoked sheet rubber. The multipurpose attributes of this genus suggest its potential both for smallholder farmers in developing countries and for niche specialty pastures in more extensive systems. Genetic diversity within the genus can be exploited through the use of different species, or selections of populations within species, to improve quantity, quality and stability of production.

Limitations

Some words of caution are in order.

- *Calliandra calothyrsus* is an outcrossing species, with specific pollination requirements (bats and hawkmoths) in its native environment (Macqueen 1992), and poor seed production may occur if pollinators are not present.
- At present there is wide use of material from a narrow genetic base, and thus possible susceptibility to inbreeding depression and future pest/disease attack are of concern. Maintenance of the genetic integrity of accessions or selections may prove difficult, especially in countries with land races of inferior material.
- Little is known about the pest/disease status of calliandra, although there have been reports of plant damage by borers and moths in the Philippines (Braza 1991) and Sumatra and Northern Australia.
- Although *C. calothyrsus* is a multipurpose shrub, not all ideotypes suit all uses, just as in any other species. For example, a fodder ideotype with good branching and high leaf production may not be suited to fuelwood production, where a single-stemmed form with high wood production is ideal (Macqueen 1993b). Breeders need to plan carefully which traits to improve for a given area, and improved varieties must be released and maintained in such a way as to maintain their genetic integrity.

Many of the perceived limitations have probably been observed in a very limited range of germplasm, possibly as a result of using inappropriate feeding techniques. We believe calliandra has a valuable role to play in the tropics, based on the opportunities outlined above.

Conclusions

The agricultural productivity of members of the genus *Calliandra* can be improved using a variety of approaches. In areas where the species is not widespread it may be best to select and breed a broadly based population of calliandra with medium production, rather than a high-risk, narrowly based high-performance variety. In areas where the species is commonly found, selection and breeding techniques may not be appropriate. Rather it may be more useful to improve the utilisation of the existing material as forage through improved postharvest handling methods and modification of rumen microflora.

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Opportunities and Limitations in Gliricidia

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Abstract

The genus *Gliricidia* Kunth. comprises two species which are often confused because of their very similar appearance. This paper describes opportunities and limitations for the development of *G. sepium* (Jacq.) Walp., the more common species, which has been introduced to most parts of the tropics. The leaves of this species provide animal fodder of apparently high nutritive value, though they are toxic to some monogastric species, and unpalatable to ruminants in some countries. The wood has several uses. Gliricidia can grow extremely quickly in a wide range of soil types, resprouts vigorously after cutting, and is easily propagated vegetatively. By using these characteristics, growers can benefit from the tree even in the dry season or in slightly frosty areas. Researchers have now identified outstanding provenances from gliricidia's native range, but even when bulk seed becomes available from seed orchards, growers will have to avoid having the genetic superiority of these provenances swamped by the abundance of local landrace genes already established in most countries.

THE genus *Gliricidia* Kunth. currently comprises only two species, *Gliricidia sepium* (Jacq.) Walp. and *G. maculata* (H.B.K.) Steud. (Lavin 1987). The two species are very similar, but *G. maculata* is characterised by white flowers while those of *G. sepium* are pink. *G. maculata* also tends to have more rounded leaflets than *G. sepium.* Because they look alike, there has been long-standing confusion surrounding the identity of the two species, and the names have often been treated as synonyms. However, the existence of two distinct species has been confirmed by chloroplast DNA analysis (Lavin et al. 1991), as well as by studies of diversity in seed storage proteins (Chamberlain and Galwey 1993).

Gliricidia sepium is by far the more common of the two species, both in natural populations and as an exotic. Although its native range is limited to the Pacific coast and to seasonally dry inland valleys of Mexico and Central America, it is naturalised throughout much of Central America and the Caribbean, and is now pantropically distributed. In contrast, *G. maculata* is much less common, restricted in its native range in Mexico to the Yucatan peninsula. Thus although much of the literature, particularly from India, refers to *G. maculata*, most of the landrace material around the world is in fact *G. sepium.* Interestingly, in a trial in Honduras, wood biomass production was found to be four times greater in *G. sepium* than in *G. maculata.*

In view of the much greater importance and potential of *G. sepium,* this paper discusses only this species, referred to from here on as 'gliricidia', and opportunities and limitations for its future development.

Gliricidia leaves are used for animal fodder and green manure, and the wood is used for fuel and charcoal as well as for poles, construction timber and agricultural implements. Within its native range gliricidia's most important use is as live fencing; other important uses include shade and support for perennial crops, soil stabilisation and improvement through nitrogen fixation, and several medicinal uses. The products and services provided by gliricidia have been described in detail elsewhere (e.g. Falvey 1982; Withington et al. 1987; Glover 1989; Simons and Stewart 1994).

Opportunities for developing gliricidia's role in tropical farming systems, as well as limitations to such development, are defined to a great extent by its inherent biological attributes. Until very recently, gliricidia has been spread around the world in an almost entirely unplanned and undocumented way,

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without consideration of any genetic aspects. This history has several important implications both for the future of gliricidia and, by extension, for the development of other non-industrial species.

Biological Advantages and Limitations of Gliricidia

Gliricidia's many uses exploit its special properties, which are central to any discussion of ways in which its value could be enhanced by further research and development.

The most striking attributes of gliricidia are physiological. It has the potential for very fast growth (up to 6 m in 12 months), it can resprout vigorously after lopping or pollarding, and it can easily be established from cuttings.

Its potential for fast growth gives Gliricidia an important role in the control of weeds such as *Imperata cylindrica* (Anoka et al. 1991), as well as providing early returns after planting. Rapid resprouting is an essential attribute of any tree used for leaf production, and is also useful for manipulating the shade over crops grown alongside gliricidia, such as tea, coffee and pepper.

Gliricidia is commonly propagated vegetatively, from cuttings, and this has several important implications. Plants grown from stakes have root architecture quite different from that of seedlings. The latter display much stronger taproot development which is a definite advantage on sites where water is limiting for part of the year, particularly where gliricidia competes with crops. Liyanage and Jayasundera (1988) found that plants grown from seedlings, despite slower establishment, were ultimately hardier and more productive than vegetatively propagated plants.

Natural populations of gliricidia occur on a wide range of soil types, from pure shifting sands including slightly saline coastal dunes, to deep black vertisols and unstratified rocky regosols (Hughes 1987). On most of these sites pH is in the range 5.5-7.0, although gliricidia will not tolerate acid sites where aluminium saturation is high. It thrives on degraded and eroded skeletal soils, and improves them through biological nitrogen fixation — clearly one of its major strengths.

Gliricidia tolerates a wide range of climatic conditions, including rainfall which varies from 600 mm to 3000 mm in its native range. To set seed, however, it requires a dry season of 6-8 weeks following flowering, and dry weather is needed for flower initiation to occur. In areas where rainfall continues throughout the year (e.g. Indonesia: Seibert 1987), farmers must rely on vegetative propagation from stakes.

Rainfall distribution also has an important effect on gliricidia's leaf phenology. In seasonally dry climates the trees are deciduous in the dry season, and they flower and set seed while leafless. Clearly, this phenomenon reduces gliricidia's value as a fodder crop in such areas, where the main role of fodder trees is to provide green forage during the dry season, when fresh herbaceous vegetation is not available. This limitation can be overcome by management, since resprouts do not lose their leaves in the dry season. When cut regularly, gliricidia produces leaf material throughout the year.

Many studies have investigated the optimum spacing, height and frequency of cutting for leaf production (e.g. Duguma et al. 1988; Ella and Blair 1989). In general, total biomass production per unit area increases with closer spacing, increased cutting height and longer intervals between cuttings. However, when the trees are cut less frequently, the leaf: wood ratio decreases.

Gliricidia does not tolerate frost, and the limits of the species' natural distribution in Mexico follow the frost-free limits. Even minimum temperatures as high as 15°C can cause leaf loss (Whiteman et al. 1986), and dieback will occur at lower temperatures. However, a light frost will not kill the plant's roots, and its vigorous resprouting ability allows it to be used as an forage crop, managed on an annual cutting cycle with new growth removed before frost damage can occur (Foroughbakhch et al. 1987).

Opportunities and Limitations in the Future Development of Gliricidia

In view of its wide range of useful traits, it is not surprising that G. *sepium* is one of the most researched tropical multipurpose trees. Because of the restricted natural distribution but almost pan-tropical naturalisation of the species, most research is done outside the native range, using landrace material of unknown origin (which in many cases is likely to have a very narrow genetic base).

During the 1980s, well-documented range-wide provenance collections were assembled by the Oxford Forestry Institute (Hughes 1987) and tested in multilocational field trials around the world (Pottinger 1992), often with the local landrace as a control. In every trial, the landrace yielded much less than the best provenances from the native range.

On most sites, a provenance from a small riverine population from a high rainfall area of Guatemala, Retalhuleu, emerged as the best for both wood and leaf production, even on dry sites. At any given site, this provenance typically produced double the mean yields of other provenances tested. Another Guatemalan provenance, Monterrico, occurring on shifting sands, also yielded abundant foliage. Isoenzyme and DNA studies have revealed high genetic diversity in both these provenances (Chamberlain 1993; Dawson et al. 1995). This has two important implications. Firstly, they should be adaptable to changing environmental conditions, such as new pests and diseases. Secondly, their genetic diversity provides scope for further improvement by farmers through selection.

Genetic improvement of any species is only possible where there is heritable variation and efficient selection, yet intense selection will reduce the extent of genetic variation. For a non-industrial species such as gliricidia, it is logical to allow end-users to make their own selections from the variation present in a superior provenance. Since Retalhuleu yields so much more biomass than other provenances, the gain (typically 100%) from using this provenance is higher than could be obtained from intense phenotypic selection within a population, without the concurrent loss of genetic diversity. This diversity can then be exploited by farmers to meet their own requirements.

An example of one such requirement might be high quality animal fodder. The use of gliricidia as animal fodder is problematic and not well understood. From proximate analysis, the leaves appear to have high nutritive value, with high protein levels (20-30% of dry matter), in vitro dry matter digestibility of 60-65%, and low crude fibre and tannin levels (Gohl 1981; Hunter and Stewart 1993). However, toxicity of leaves or bark has been reported in several monogastric species including rodents (Standley and Steyermark 1946), poultry and rabbits (Cheeke and Raharjo 1987). There is little evidence of toxicity to ruminants, but in some parts of the world (e.g. Somalia: Madany 1992) the use of gliricidia for ruminants is limited by unpalatability (Lowry 1990). Elsewhere, for example in Sri Lanka and Colombia, there appears to be no problem at all with palatability. The reasons for the variation are not well understood, but Larbi et al. (1993) have demonstrated provenance differences, so selection of palatable genotypes might overcome the limitation. Current research at the Oxford Forestry Institute is also investigating genetic variation in fodder quality.

However superior a provenance appears in research trials, the knowledge is of little practical value until enough seed is available for wide distribution to growers. At present, planting programs tend to use inherently inferior local seed or cuttings because no alternative is available. This practice is limiting the future of *Gliricidia sepium*, but the problem is being addressed by several countries which have set up seed orchards to produce seed of superior provenances in bulk.

In countries such as Malawi, where no landrace currently exists, it should be possible to influence the composition of future landraces by releasing material which is superior in both yield and product quality. Where a landrace is already established, however, the much more plentiful local genepool will tend to swamp the superior introduced genes, through outcrossing. The genetic quality of the first introduction is therefore of paramount importance, but unfortunately this factor is rarely considered by forestry practitioners in the field.

Clonal propagation by cuttings of gliricidia offers at least the possibility of maintaining superior genetic material. Genotypes can be kept discrete by vegetative propagation after their release, for instance for wood and for fodder production. However, researchers should be wary of making several introductions to one area for different end uses, at least until it is known how provenance hybrids would perform. In industrial trees, negative heterosis has frequently been observed in provenance hybrids.

Conclusions

We now have information comparing the performances of gliricidia provenances and patterns of intraspecific variation (Lavin et al. 1991; Chalmers et al. 1992). This provides scope for breeding gliricidia germplasm which performs well, and has a genetic base broad enough to confer environmental tolerance and avoid inbreeding depression. As with any multipurpose species it is essential that researchers understand farmers' needs for both quality and yield and how these are determined biologically. For security and flexibility it is more important to maintain diversity than to maximise production through intense selection.

As superior genetic material is identified, its multiplication, dissemination and management must take high priority. Unlike industrial plantation species, control over germplasm of multipurpose trees may be lost after the first release, because subsequently it tends to be spread informally, from farmer to farmer (Simons et al. 1993). It is important to recognise that this practice will probably dilute any improvement, although gliricidia has the great advantage that preferred (e.g. palatable) individuals can be readily propagated by cuttings.

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Opportunities and Limitations in Other MPT Genera

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Abstract

In the past, traditional farming systems of the tropics grew combinations of tree and shrub legumes to help maintain diversity and provide a range of products and services throughout the year. The system was often difficult to manage so it was replaced in some areas by a system relying heavily on one or two species. The folly of this practice was highlighted by the devastation caused to leucaena-based systems by psyllids in the mid-1980s. The disaster has prompted a search for alternative species and a return to broader-based, more diverse systems. This paper discusses the opportunities and limitations of several selected tree and shrub species that could be used in such systems.

THE devastation caused by the psyllid insect *(Heteropsylla cubana)* in the mid-1980s had a major impact on farming systems that relied heavily on *Leucaena leucocephala.* It highlighted the vulnerability of systems based on a single species and stimulated a search for alternative tree and shrub legumes from the wide range of species occurring naturally in many regions of the world. Brewbaker (1986) identified about 80 leguminous tree and shrub species which have potential multipurpose roles in farming systems in the tropics. Many of these species are already quite widely used, but opportunities exist for their expansion into other farming niches.

It is not possible to examine all 80 species in this paper. Instead, we discuss several species representative of the genera *Acacia, Albizia, Cassia, Desmanthus, Desmodium, Erythrina* and *Flemingia* that are currently in use or have shown some potential. *Calliandra, Gliricidia* and *Sesbania* species are discussed elsewhere in this volume.

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Traditional Uses of Tree and Shrub Species

In the past, traditional farming systems of the tropics were based on a range of different species resulting in much greater diversification than occurs in modern commercial farming systems. For instance, observers in Flores, Indonesia, noted that farming systems in the 1960s grew a wide range of plant species for staple foods, vegetables, fruit and spices. Bamboo, teakwood, *Pterocarpus, Stercufia foetida, Tamarindus indicus, Albizia lebbeckoides, Albizia chinensis, Cassia siamea* and *Cassia fistula* were among species grown for timber. Other local species were used for fuelwood, fodder and other purposes. In the 1990s, many fewer species are in use and many are under threat of extinction in the region.

Farmers realise that, as a result of land degradation and population pressure, the food crisis is now greater than it was in the past. The trend towards monocultural cropping and farming practices has made the land more productive, but although apparently economically safer these new practices are ecologically more fragile.

A step back to more traditional practices, using a wider range of tree and shrub species, would provide greater diversity in farming systems and greater resilience in the face of challenges by pests or diseases. Where possible, the species discussed in this paper (Table 1) should be grown as part of a mixed range rather than being used in monoculture.

Table 1. Limitations and opportunities of selected species.

No.	Species	Limitations	Opportunities
1.	*Acacia angustissima* *A. boliviana* *A. villosa*	Low palatability and possible poor nutritive value, potential weed problem	Fast growing and adaptable to infertile sites; reclamation of degraded areas; pioneer plants
2.	*Acacia auriculiformis*	Limited value as a fodder	Drought resistant and fast growing, adaptable to wide range ecological conditions from dry to humid tropics
3.	*Acacia nilotica*	Very fast growing and prolific; potential weed problem; difficult to control; thorny	Potential fodder, fuelwood, timber charcoal and resin; good for land reclamation
4.	*Acacia leucophloea*	Poor tolerance to coppicing	Drought resistant; good supplemental fodder during dry periods
5.	*Albizia chinensis*	Low digestibility; poor wood quality	Fast growing and therefore potential for reafforestation on degraded lands; coppicing ability makes it suitable for alley cropping and hedgerow grazing system
6.	*Albizia falcataria*	Big tree suitable only for mixed garden or plantation; suitable only in humid areas	Fast growing species; potential for shade trees with very good humus
7.	*Albizia lebbeck*	Very slow establishment phase	Good nutritive value; no toxins or antinutritive factors; beneficial effect on pasture growth; potential for use in silvopastoral systems; good fuelwood
8.	*Cassia fistula* and *Cassia javanica*	Slow growing, low biomass production	Good quality fuelwood and charcoal; wide range adaptation from low rainfall to humid tropics
9.	*Cassia siamea*	Low palatability; possibly toxic foliage; slow early growth; non-nitrogen fixing species	High biomass production; use in rehabilitation of degraded lands; fuelwood plantations
10.	*Desmodium rensonii*	Not very resistant to drought, suitable only to humid or wet areas	Potential for live hedgerows and fodder
11.	*Desmanthus virgatus*	Low biomass production particularly in dry region	Potential fodder as supplement
12.	*Erythrina species*	Alkaloid content of foliage may reduce its feeding value; its use should be restricted to ruminants; poor quality fuelwood	High biomass production favours its use in alley cropping and as a green manure; low alkaloid lines could be exploited and developed for forage production
13.	*Flemingia macrophylla*	High fibre content of leaf therefore low digestibility; slow release of nutrients when used as a mulch	Good potential for alley cropping in combination with other species; long lasting mulch suppresses weeds and aids moisture retention; rehabilitation of acid, infertile sites; some potential for fuelwood production

Acacia

Several *Acacia* species are widely grown in farming systems, including *A. villosa*, *A. nilotica*, *A. farnesiana*, *A. leucophloea*, *A. auriculiformis* and *A. oraria*. Many other acacias native to Australia have been tested and developed in other countries, including *A. ampliceps*, *A. holosericea* and *A. mangium*.

Choosing where to use a given species depends on a farmer's planting niches. *A. mangium*, for instance, is a tree which can be directly incorporated into farming systems, while *A. angustissima* and *A. villosa* are grown as live fencing, hedgerows and as fuelwood. Other species, such as *A. nilotica*, *A. auriculiformis*, *A. leucophloea*, *A. oraria* and *A. aneura* are used in their native range but rarely incorporated into other farming systems.

Some species can become serious woody weeds. *Acacia nilotica*, a thorny species, is a useful multipurpose tree for farming systems in northern India, but in other areas is considered a significant weed. In Timor, Indonesia, it has covered 70% of the 30 000 ha Bena alluvial plain, replacing the previously dominant grasses in five years. In Queensland, Australia, large areas of formerly treeless Mitchell Grass *(Astrebla* spp.) plain are being invaded by *A. nilotica*, creating problems for sheep and cattle management. Although it is serious weed, the species does produce reasonable quality browse, high in tannins (Carter 1994).

Acacia angustissima, *A. boliviana* and *A. villosa* are closely related and there is considerable confusion over their taxonomy. They are native to Central America but are now common in Southeast Asia. Seed production is prolific. They are well adapted to free-draining acid infertile soils and show excellent drought tolerance. They have been tested as hedgerows, live fencing and fuelwood and are acceptable to farmers. However, there are some concerns about their potential to become weeds as they are not very palatable and therefore not favoured by livestock.

Albizia

Several species of *Albizia* are very important in traditional farming systems in Southeast Asia. The major species currently used are *Albizia falcataria (Paraserianthes falcataria)*, *A. chinensis*, *A. lebbeck*, *A. lebbeckoides*, *A. saman* and *A. procera*.

Albizia lebbeck is indigenous to the Indian subcontinent, Southeast Asia and Australia and is now naturalised in many tropical regions with monsoonal climates. It is a medium to large tree reaching 20 m in height with a widely spreading habit. Isolated mature trees can grow 5 m in one year and produce 100-120 kg edible dry matter/year (Lowry 1989). Leaf fall under plantation conditions can exceed 5000 kg/ha/year (Pradham and Dayal 1981). Leaves, flowers and pods, which drop sequentially during the dry season, can be consumed directly by grazing animals as a supplement to the low quality grasses usually on offer. The protein content in green leaf ranges from 16-23% while in vitro digestibility values have been reported in the range 45-70% and are usually around 50% for mature leaf. In addition to providing feed directly, the tree also appears to enhance pasture production and quality (Lowry et al. 1988).

Albizia lebbeck has almost disappeared from Timor and only a few stands can be observed in certain areas, mainly because it has been overused as a fodder in traditional farming systems.

Albizia chinensis used to be very important for soil fertility management in Sikka on the island of Flores in Indonesia. In Ngada Flores, this species, together with Bamboo, was an important timber species for most of the traditional houses. It is currently difficult to find and rarely cultivated.

Cassia

Most *Cassia* species are not nitrogen-fixing legumes, but can nevertheless make a significant contribution to farming systems and landscape protection programs. Several species such as C. *siamea*, *C. fistula* and *C. spectabilis* also show potential as sources of timber, fuelwood and charcoal.

Cassia siamea is the best known of these three because of its fast growth and widespread adaptation to most tropical and subtropical regions. It also shows considerable drought tolerance. Even though this species does not fix nitrogen, there is increasing interest in using it to produce mulch in alley cropping because of its high biomass production (Yamoah et al. 1986). Although sometimes used as a fodder for sheep and goats, the leaves are not very palatable and can be toxic, particularly to non-ruminants (Maheshwas 1988). An excellent source of fuelwood and charcoal, this species is also noted for its dark heartwood, and prized as a cabinet timber. The leaves and flowers are usually very susceptible to insect attack and caterpillars growing on the leaves and flowers can be very destructive to crops below.

Cassia fistula and *C. javanica* grow more slowly while *C. spectabilis* has almost the same functional characteristics as *C. siamea*, though preferring a more humid environment. So far, *C. alata* is not widely used in farming systems, but it will grow in dry zones and has potential as fuelwood and fencing material.

Desmant hus

Species of *Desmanthus* display a range of morphology and habits, from erect shrubs 2-3 m tall to prostrate herbaceous types less than 50 cm in height (Allen and Allen 1981).

The genus is native to Central and South America, but is now naturalised in many tropical regions. It tolerates acid infertile soils and has drought tolerance similar to that of leucaena. *Desmanthus virgatus* is naturalised in Timor but is rarely deliberately planted in that island's farming systems. Farmers usually let their cattle browse this species on forest margins or on areas near their farm plots. Biomass production is usually low especially during the dry season, when most of its leaves fall. However, it may grow vigorously in the wet season.

Little is known about the feed value of *D. virgatus*, although Kharat et al. (1980) found crude protein contents in the range 24-30% while protein digestibility was 58%. Productivity is reasonably high under good growing conditions. Dense stands cut close to ground level yielded 23 t/ha/year and 35 t/ha/year in Hawaii and northwestern Australia respectively (Takahashi and Ripperton 1949; Par berry 1967).

In the last 4-5 years, *D. virgatus* has been widely promoted as an alternative to leucaena in other regions of Indonesia and in other parts of the tropics. The Queensland Department of Primary Industries has recently released cultivars Marc, Bayamo and Ulman for use on the heavy black cracking clay soils of central Queensland, Australia.

Desmodium

Desmodium rensonii is the most important shrub species in this genus. It usually grows better in humid regions. Under drier conditions such as in Timor, growth is significant only during the wet season. It has been extensively used in the Sloping Agricultural Land Technology (SALT) system developed in Mindanao in the Philippines for land stabilisation (Laquihon and Pagbilao 1994).

Erythrina

Species of *Erythrina* can be found in most regions of the tropics or subtropics with the possible exception of the Kalahari desert of southwest Africa. *E. edulis* is found at high elevations in the Andes while *E. fusca* occurs throughout the coastal regions of the tropics, where it shows considerable tolerance to flooding and saline conditions. *E. berteroana* and *E. peoppigiana* are widely used in Central and South America and have shown tolerance to soils with high aluminium saturation (Kass 1994).

E. urophylla performs better at higher altitude and is easily propagated from cuttings although seeds are usually viable. It was once the most important shade species for coffee plantations in Indonesia, and was also used as live fencing in Flores and Timor. Large cuttings are generally used to establish *Erythrina* species for live fences or for shade in plantations, while seed is preferred when it is grown as a support for vine crops such as pepper and vanilla (Kass 1994).

E. variegata and *E. ovalifolia* are species that grow at lower altitudes and in drier conditions in Indonesia (Timor and Flores islands).

Flemingia

Flemingia macrophylla is an erect woody shrub to 4 m in height which is native to Asia where it occurs in brushwood, forest margins and along waterways. A hardy plant, it can withstand long dry periods but also tolerates some waterlogging. In Indonesia it has grown well on acid soils (pH 4-6) with high soluble aluminium levels (80% saturation) (Budelman 1989).

During the dry season *F. macrophylla* retains most of its trifoliate leaves, making it suitable as a dry season browse (Gutteridge 1990). Although in vitro dry matter digestibility was less than 40%, Asare (1985) found that palatability of young growth was adequate and much higher than that of older herbage. Productivity is moderate with leaf yields of around 12 t/ha from four cuts per year (Budelman 1989).

F. macrophylla has been used as an alternative to Leucaena in Indonesia, usually as live hedgerows or for fodder. Because its leaves are relatively tough and fibrous, they resist breakdown in the soil and therefore have potential for suppressing weeds in alley cropping systems. Budelman (1989) found that 40% of a *F. macrophylla* leaf layer remained after seven weeks on the soil, compared with only 20% for leucaena leaf. The mulch from *F. macrophylla* formed a solid layer that effectively prevented germination of weed seeds for 100 days. Alley cropping with a mixture of *F. macrophylla* and leucaena or gliricidia may be ideal, providing longer lasting mulch for weed control and soil moisture retention as well as sustained release of nutrients.

Although *F. macrophylla* does not produce a large woody biomass, Yamoah et al. (1986) obtained 6.8 t/ha of dry stems from a two-year-old stand indicating some potential for fuelwood production.

Other Genera

Other important leguminous or nitrogen-fixing genera are *Casuarina, Tephrosia, Tamarindus, Parkinsonia, Peltophorum, Pterocarpus, Prosopis, Caesalpinia, Moringa, Pithocellobium* and *Parkia.* Species from all these genera may fill productive or service functions in farming systems. Their suitability for use can be assessed from several perspectives including:

(i) their ecological adaptation;
(ii) morphological characteristics;
(iii) potential and constraints for use in productive and service functions;
(iv) the farm size and type of farming system in which they will be used; and
(v) their social acceptability.

Conclusions

A wide range of tree and shrub legume species is available for use in tropical farming systems, providing a diversity, flexibility and resilience that could not be achieved by using only one or two species. All species have some limitations, but by using mixtures the limitations of one may be overcome or counterbalanced by the positive features of another. Problems with seed production, supply and distribution are common to most species and need to be addressed by researchers when developing more productive and sustainable systems. It is important that researchers and extension workers encourage farming communities to use mixtures of species to develop the potential benefits of diversity more fully.

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