Advances in Forage Legumes: Shrub Legumes

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Sesbania grandiflora on paddy walls, Lombok, Indonesia

"It is a humbling fact for grass pasture experts to realize that probably more animals feed on shrubs and trees, or on associations in which trees and shrubs play an important part, than on true grass-legume pastures"

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Abstract

Forage tree legumes benefit agriculture through their multi-purpose contributions to livestock feeding, to productivity of farming systems, and to protection of the environment.

Of the several hundred forage tree legume species regarded as having potential for forage only c. twenty are in common use. These are listed together with their agroecological range and tolerance of adverse environments including acid soils, cool temperatures, low rainfall, poor drainage and high salinity. The value of many species to ruminants is limited due to low nutritive value arising from low protein availability and low acceptability caused principally by high condensed tannin content. Only 10 of the 20 listed species are considered to have a high nutritive value viz. *Albizia lebbeck*, *Chamaecytisus palmensis*, *Cratylia argentea*, *Desmodium rensonii*, *Desmanthus virgatus*, *Gliricidia sepium*, *Leucaena leucocephala*, *Leucaena diversifolia*, *Sesbania grandiflora*,and *Sesbania sesban*.

The germplasm in commercial use worldwide is often inferior and with a narrow genetic base. The need for farmer access to a greater diversity of planting material and improved varieties through better distribution systems is highlighted. However, plant improvement is often limited due to taxonomic confusion in many genera e.g. *Albizia*, *Prosopis*, and farmer access to new varieties is limited by lack of information and lack of resources to purchase high quality seeds. There is debate over whether to use fast growing exotic species or slower growing native species. There are as many as 150-200 M people use *Gliricidia sepium* worldwide but there is minimal use in its native range. Conversely, native *Acacia* communities are over-exploited in their native range with minimal use elsewhere. Conservation of native range is critical and *in situ*, *ex situ* and *circa situm* approaches are suggested. Issues of weediness potential are paramount when using exotic species requiring greater care in the evaluation of risk factors.

Finally, the reasons for successes and failures in promotion of forage tree legume use in world farming systems are analyzed and suggestions made to extend the utilization of this important group of legume species.

Introduction

Multipurpose tree legumes (MPTs) offer many benefits to agriculture. Apart from their value as feed for livestock, tree legumes are recognised for their multi-purpose contributions to the productivity of farming systems, to the welfare of people and to the protection of the environment. It is the flexibility of their uses that makes them especially significant; they can be found on farms ranging from small-holder subsistence to large-scale commercial.

The history of tree legume use dates several millenia. In Mexico and Central America, where many of our most useful forage tree legume species originate, there was no tradition of tree forage use although they were used for other purposes. For example, Mesquite (*Prosopis* spp.) pods were a component of diets of inhabitants of the United States and Mexican border lands for several thousand years, and later on were consumed by the white pioneers of the 1800s (Ibrahim 1992). Its use as a browse has been more recent.

There is evidence of indigenous use of unripe *Leucaena* pods and seeds for human consumption in the Tehuacan Valley in Mexico dating back to 6800 BC. It seems that *Leucaena* cultivation may have begun about 2000 years ago (Hughes 1998) and continues to be cultivated for human consumption in Mexico today, but rarely for forage.

Current interest in MPTs is principally for forage. In developing countries, an increasingly affluent urban population is consuming more meat, and demanding higher quality meat. Smallholders are responding to this new and profitable opportunity with feeding strategies designed to fatten animals for slaughter at a younger age. This requires either high quality locally grown feeds or use of expensive concentrates. Farmers are finding that forage tree legumes meet this need enabling them to achieve increasing levels of profitability.

In Australia, large scale *Leucaena leucocephala* (leucaena) plantings are occurring because farmers appreciate that leucaena-grass systems are both sustainable and highly productive. This production system allows them to produce cattle for high value domestic and export markets in East and Southeast Asia (Larsen *et al.* 1998).

The purpose of this paper is to review the important issues for R & D on forage tree legumes in tropical and subtropical farming systems.

Taxonomic confusion

Accurate classification and documentation of genus and species relationships within important plant groups are a prerequisite for effective plant improvement programs. Accurate naming, and knowledge of the diversity available, influences the direction of plant evaluation (Hughes 1998b). Without this, key taxa may be omitted and uncertainty is often the main result. This has occurred with most forage tree legume plant improvement programs.

After a long period of disagreement, *Leucaena* has finally been described in detail, agronomically and nutritionally (Shelton *et al*. 1998), and 22 species have been named (Hughes 1998a and b), compared with only 17 species in an earlier report (Hughes and Harris 1995). This is not the case with all important genera. Only a small proportion of the total diversity in *Albizi*a has been surveyed, and there is considerable unmapped potential in this genus (Hughes and Pottinger 1997). There is incomplete understanding and confusion regarding the taxonomy, genetics and ecology of *Prosopis* (Dutton 1992). Hybridisation, intra-specific polymorphism and heterogeneity make it very difficult to identify some *Prosopis* spp. (Ibrahim 1992).

Another source of taxonomic confusion arises when natural hybridisation occurs among taxa, normally well separated in their native range, that are brought together in evaluation programs. Hybrid seed is unknowingly collected and spread. Examples of this phenomenon have been documented in *Leucaena* (Hughes 1998a), *Erythrina* (Neill 1993), and *Gliricidia* (Lavin 1996). In Papua New Guinea, where *Leucaena leucocephala* and *L. diversifolia* were introduced separately, a vigorous inter-specific hybrid has appeared spontaneously. It is highly favoured and known locally by the incorrect name *L. mexicana*.

Further, our ability to describe variation in plant material has greatly improved, and this may warrant a re-investigation of some genera. Traditionally, morphological and agronomic traits have been used to characterise patterns of diversity in plants. It is now known that these represent only a small proportion of the genome. Such traits are influenced by environmental factors, thus limiting their use for description of genetic relationships and variability. Molecular approaches such as the use of isozymes, and other genetic markers, which may be more independent of environmental influence, are likely to provide a more powerful method to gauge species relationships and origins (Dawson and Chamberlain 1996). Macqueen (1996) confirmed that studies of molecular data, polyploidy and hybridisation research, rather than morphological work, were needed to understand the complex patterns of variation in *Calliandra*.

Unfortunately, in the present economic environment, it is difficult to find support for taxonomic studies, yet such activity underpins all plant improvement programs, and ultimately influences the quality of new varieties made available for farmers.

Diversity, quality and availability of planting material

Lack of diversity in original introductions

In most cases, the movement of tree legume germplasm around the world began more than a century ago. Original seed introduced into an area was usually harvested from a few readily accessible trees. This meant that the early developments were based on unimproved, inferior and often seedy varieties that contained little genetic diversity.

The movement of small amounts of seed of *Leucaena leucocephala* subspecies *leucocephala* from Mexico to Southeast Asia in the 1600s is the most celebrated example of this phenomenon. This species is a highly self-fertile polyploid, so that further movement of the introduced variety, was of almost identical genetic material. The spread of readily harvestable seed from country to country, region to region, organisation to organisation, farmer to farmer, has resulted in over-reliance on an extremely narrow genetic base (Hughes 1998a and b). This original leucaena, now known as the "common weedy type", has invaded disturbed sites, and become a weed in many countries. We now appreciate a much greater diversity in *Leucaena* from a range of ecological zones, some of which has significant potential value for agriculture, with much lower weed risk (Mullen *et al.* 1998b).

Similarly, Dutton (1992) reported that most seed of *Prosopis* planted around the world was of unknown origin and from a narrow genetic base. The thorny *Prosopis* shrubs, widespread in Africa and India, came from introductions of inferior germplasm, and this has lead to a poor appreciation of the genus. Research trials have shown that there is superior germplasm for different rainfall zones and soil types, and information on this new material needs to be disseminated.

The introduction of *Gliricidia sepium* from Trinidad to Sri Lanka was reported to be made with seed from one tree (Stewart *et al*. 1996). They suggested that the genetic diversity in many introduced populations will not be sufficient to ensure long-term stability.

There are other examples. Only two seed samples of *Calliandra calothyrsus* were first introduced into Indonesia (Java) from Guatemala in 1936 to provide shade for coffee. After 1974, seed was further spread by forest rangers for fuelwood use and now covers more than 30,000 ha in Java alone (Kartasubrata 1996).

There is an added problem as selection of best performing varieties by farmers has narrowed diversity. In Flores Indonesia, a wide diversity of tree legumes was grown in farming systems in the 1960s. Species such as *Acacia*, *Albizia*, *Calliandra*, *Cassia*, *Gliricidia*, *Pterocarpus*, *Sterculia* and *Tamarindus* were all grown in diverse mixed farming systems. With intensification and commercialisation, there was greater reliance on a few species notably leucaena (Djogo *et al*. 1995). The arrival of the psyllid in this region in the mid-80s was particularly devastating.

The current recommendation for selection of seed from a native range is to obtain seed from at least 25, and preferably 50 trees, with sufficient distance between them (50 m) to minimise the likelihood of co-ancestry (Allison and Simons 1996). This simple approach was not appreciated when the first introductions were made.

Accessing high quality germplasm

It is clear that many farmers are using inferior planting material and that overcoming this limitation will not be a simple matter. Cromwell *et al*. (1996), in surveys of farmers using multi-purpose trees (MPTs) in Honduras, Sri Lanka and Malawi, found that the quality and reliability of MPT germplasm supply was limited. Purchase from formal sources was often expensive, and seed was often obtained locally, as it was cheaper and more accessible. For this reason, germplasm was often:

- Of unknown genetic quality,
- Collected and distributed with weak protocols,
- Selected on timber criteria,
- Distributed with no knowledge or understanding of provenance quality, provenance origins, or the importance of genetic diversity,
- Not reliably available.

Other workers have found that the market is not discerning. Much of the demand for *Gliricidia* has been met with seed of inferior quality with no premium paid for quality (Simons 1996). A major and serious limitation for *Prosopis* spp., which is restricting adoption, is lack of availability of seed of well documented provenances or improved varieties. There is also no source of clones of best vegetatively propagated material (Dutton 1992).

This has not been the case with leucaena, as high quality seed is marketed under species, cultivar or provenance name.

There are difficulties when introducing new varieties to areas where inferior varieties are already well established. There are two reasons for this.

- Farmers may not be prepared to purchase seed of improved varieties e.g. of *Gliricida*, as they consider it a low value crop (Simons 1996). They can use existing material at no cost. New germplasm would need to be markedly superior. Although seed of the best provenances of *Gliricidia* is now becoming available from seed orchards around the world, much of the current demand for *Gliricidia* is being satisified by inferior unlabelled material, and it may be difficult to promote superior provenances such as Retalhuleu (Simons 1996). Simons (1996) suggested that new varieties will need to be at least 30% better in terms of woody and leaf biomass to interest farmers.

- When new material is introduced into existing areas, there may be hybridisation, loss of purity and therefore loss of advantage. This will be less of a problem for vegetative propagation and selfed seed. There may also be inbreeding depression if farmers collect seed from just a few trees for propagation eg. from those that seed prolifically.

However, other experience is that farmers will plant new varieties if they recognise key benefits. For instance, farmers in Batangas Province in the Philippines were immediately enthusiastic about the new F1 hybrid KX2 leucaena (A. Castillo, personal communiucation). They appreciated its improved growth potential and its resistance to psyllids. By contrast, K636 (cv. Tarramba) may not be accepted as quickly as it is similar to the giant leucaenas already present in the Philippines.

In order to introduce new varieties it may therefore be important to:

- Ensure that the variety has clear benefits e.g. insect / disease resistance, or greatly improved productivity,
- Create an appropriate local name for the new variety,
- Provide seed or planting material of high quality,
- Ensure that seed is readily available through traditional channels at a reasonable price, and promoting farmer level (smallholder) seed production schemes to provide income for farmers, and local availability of seed.

The principal species and their agroecological range

Principal species

There are several hundred species of leguminous trees with potential for forage listed in the literature (Houérou 1980, Atta-Krah 1989). Most have not been investigated and few are in current use in any significant way. Of the 5000 known nitrogen fixing woody species, Brewbaker (1986) suggested that only about 80 leguminous tree and shrub species may have potential multipurpose agroforestry roles, including fodder, in tropical farming systems. Roshetko *et al.* (1996) listed 46 species suitable for fodder, but many fewer have found significance in world animal production systems.

Twenty species and key references are given in Table 1. There may be additional species which have forage potential, and within each species there is genetic variation which can be exploited. However, in this brief review only those species in significant use for forage are listed.

Other species may have potential but are not yet in significant use. Examples include the *Leucaena pallida* x *L. leucocephala* KX2 hybrid, *L. collinsii* and *L. trichandra*, the latter species for the high altitude tropics (Shelton *et al.* 1998).

Agroecological range

Agroforesters require forage tree legumes adapted to a wide range of environments. Species are needed for climates ranging from the humid tropics of some Pacific Island countries, the seasonally dry tropics of Southeast Asia, the cooler high altitude tropics of East Africa, and the arid zones of the Sahel in North Africa. Similarly, adaptation to a great range of edaphic conditions is sought from the alkaline vertisiols of the brigalow soils in Central Queensland to the very acid high aluminium grasslands of South America.

A summary of the general ecological adaptation of key species is given in Table 1.

There is a wide range of ecological adaptation among tree legumes, although there are no single species suited to the entire range of conditions. Managers must select carefully to ensure successful growth of tree species in their environment. The topic of environmental adaptation is treated in detail elsewhere (Shelton 1994a). The vexed question of suitable leguminous trees for acid soils continues to be an important research objective for many workers (Evans and Szott 1995). Several species such as *Cratylia argentia*, *Desmodium velutinum* and *Flemingia macrophylla*, are valued in South America because of their acid soil tolerance, but need to be more thoroughly tested for nutritional quality for ruminant feeding (Kexian *et al*. 1998). No tolerance of severely acid soils (pH < 5.0, with high aluminium saturation) was found in *Leucaena* (Mullen *et al*. 1998a).

Animal productivity

Management

Once established, forage legume systems can deliver sustainable high productivity. This has been shown in Australia where the oldest leucaena / grass systems have been grazed for over 30 years and remain productive. In Central Queensland, liveweight gains of 1.26 kg/day have been achieved over 100 days in leucaena - buffel grass pastures (Larsen *et al.* 1998). This greatly exceeds that obtained from herbaceous grass/legume pastures in similar environments.

Other advantages of the leucaena/grass system compared to herbaceous grass/legume pastures in Australia include:

- Relative ease of maintaining a suitable grass – legume balance as the two components are separated spatially.
- High level of nitrogen cycling leading to strong grass growth, or ingress of desirable grasses, between leucaena rows,

- Insulation of farms against the worst effects of droughts, provided conservative stocking rates are employed. This arises due to the deep rooted character of leucaena enabling it to produce high protein sprouts during dry periods.
- Control of run-off during heavy precipitation and excellent infiltration thus minimizing soil erosion.

In the drier regions of the world, e.g. the arid and semi-arid zones of the Sahel and North Africa, tree legumes, principally *Acacia* spp., provide a proportion of total herbage intake, and most of the protein intake, for livestock. This proportion increases during dry periods (Baumer 1992).

Nutritive value, palatability, toxicity and preference

High nutritive value for livestock is an essential pre-requisite for successful adoption of forage species. Without high quality, commercially oriented farmers may not achieve the economic animal responses to justify their investment. On the other hand, in areas where feed resources are grossly inadequate, or other uses are equally important, farmers may accept a more modest contribution from browse, especially if the species is indigenous and does not require specific introduction and management.

New varieties, promising because of their agronomic and ecological adaptation, must then be assessed for nutritive value (Dicko and Sikena 1992). Plants which grow well but contribute little to livestock production are of little value as forage species. For instance, the species *Cratylia argentia*, *Desmodium velutinum* and *Flemingia macrophylla*, are valued in South America for their acid soil tolerance, but *Flemingia macrophylla* has low intake, high condensed tannin content, low digestibility and protein quality (Kexian *et al*. 1998).

The most important measure of forage quality is intake of digestible dry matter (nutritive value), and ultimately the production of animal product. Whilst this is known for well researched species such as *Leucaena leucocephala* (Middleton *et al*. 1995), *Sesbania sesban* (Gutteridge 1994b), *Calliandra calothrysus* (Shelton *et al*. 1996), and *Gliricidia sepium* (Stewart 1996), there is much less information on other species. Much of the data available are chemical composition only, and therefore of limited value. The concepts of nutritive value of tree legumes are described in detail in Norton (1994a,b,c).

Tannins

One aspect of forage quality that deserves special mention is the secondary plant compounds which are common in tree legumes. They appear to have no functional role, although they may impart ecological advantage by limiting or preventing damage from insects, fungi, bacteria, protozoa or grazing animals.

In particular, many tree legumes species contain condensed tannins (CT). These compounds are highly polymerised proanthocyanidins composed of flavanoid units with molecular weight from 1000-20,000. Tannins may have positive and negative effects on feed quality for ruminants. They bind with protein (astringency) reducing digestibility of dietary protein in the rumen, but the effect may be positive if protein is released post-ruminally.

It is clear that high levels of CT are detrimental to forage quality. Dalzell *et al*. (1998) showed that there was a strong relationship between *in vitro* digestibility and the ratio of crude protein to CT in tissues of *Leucaena*. Levels of CT above approx. 5-6% reduced digestibility. The relative binding capacity of CTs varies among species eg. *L. leucocephala* CT is less astringent than *L. pallida* CT (McNeill *et al*. 1998). The concentration of CT in plant tissue varies seasonally with variables such as radiation, moisture supply and soil fertility (S. Dalzell, unpublished data). The astringency of the CT may also vary seasonally although this has not been investigated.

Many genera contain species that have high levels of tannins (>10%) e.g. *Acacia* (Woodward and Reed (1997), *Calliandra* (Shelton *et al*. 1996), *Prosopis* (Ibrahim 1992), *Leucaena* (Dalzell *et al*. 1998), and *Flemingia* (Kexian *et al*. 1998). However, there is great variation in CT levels both between and within species. This was shown in *Leucaena* where *L. collinsii, L. lanceolata, L. macrophylla, L. magnifica, L. shannonii, L. trichodes*, and *L. lempirana* had low CT content while *L. pallida*, *L. trichandra*, and *L. diversifolia* had high CT contents (Dalzell *et al*. 1998).

Some genera, such as *Acacia*, are unlikely to contain high quality species. They are clearly valuable for supplemental forage but most could not supply adequate minerals when used as sole feeds (Karachi *et al*. 1997). Volatile fatty acid (VFA) analysis showed that mixed rumen microbes, after 12 hours, produced only 15 æmol/ml from *A. angustissima* fermentation compared to 63.9 æmol/ml from *Sesbania sesban* (Osuji *et al*. 1997).

Similarly, *Prosopis*, *Flemingia*, *Calliandra*, *Erythrina*, whilst important, can be regarded as species of lower quality. In contrast, key species from *Leucaena*, *Gliricidia*, *Sesbania* and *Chamaecytisus* (Osuji *et al*. 1997) are generally of higher quality, but there can still be significant inter- and intra-specific variation, as was found in *Leucaena* (Dalzell *et al*. 1998).

There is also evidence that diets containing forage trees can influence rumen microbial composition. Extracts of *A. angustissima* inhibited the growth of pure cultures of rumen bacteria, while those from *Sesbania sesban* increased growth. *Acacia cyanophylla* decreased the numbers of protozoa in Ethiopian highland sheep (Osuji *et al*. 1997).

Palatability

Palatabilty is another complex issue with tree legumes. There are reports of low palatability in *Gliricidia*, *Sesbania*, and *Leucaena* whilst similar material at other locations was relished by livestock. It is now clear, that `palatability' of tree legumes is not constant and is influenced by prior learning, time to accustom to new feeds, smell, method of presentation and breed of animal (Faint *et al.* 1998).

Length of time of exposure to feeds is an especially crucial parameter in `palatability'. In 5-day trials at ILRI in Ethiopia, MPTs such as *Leucaena leucocephala* and *Sesbania sesban* and less well known species such as *Acacia venosa*, *Acacia persiciflora*, *Acacia melanoxylon*, *Acacia hockii*, *Acacia polyacantha*, *Tamarindus indica*, *Chamaecytisus palmensis*, *Tipuana tipu*, *Indigofera arrecta* and *Atriplex nummularia*, had high palatability. *Flemingia macrophylla*, *Erythrina abyssinica*, *Acacia salicina*, *Acacia coriacea*, *Albizia schimperana*, *Ceratonia siliqua*, *Casuarina glauca* and *Erythrina burana*, had poor palatability. *Gliricidia sepium* and *Calliandra calothyrsus*, had only a medium palatability ranking (Kaitho *et al*. 1996).

Educational programs are required to inform researchers, extension workers and farmers of the value of "apparently unpalatable" plants, including methods to overcome the initial reluctance of inexperienced animals to consume new materials.

Livestock species preferences

In semi-arid and arid Africa, cattle, sheep, equines, wildebeast, most antelopes and gazelles graze forage tree legumes in the dry season to balance their diets. During the wet season, they prefer grass. Species, such as goats, camels, eland, impala, kudu, elephant, giraffe, black rhino and a number of antelope, are primarilty browsers of forage tree legumes (Wickens *et al*. 1995). The Orma people in the Tana and Lamu Districts of Kenya, who keep cattle, goats, sheep, camels and donkeys (in descending order of importance) found that browse preferences varied with species (Anttila *et al*. 1994). The ability of herbivores to graze browse trees often depends on their ability to handle thorns, woody materials, or high tannin foliage. Goats have greater preference for high tannin species than sheep or cattle, because of their ability to secrete proline rich saliva to reduce the astringency of the tannins (Kaitho *et al*. 1997, Kexian *et al*. 1998).

There is opportunity for mixing both livestock and plant species to take advantage of the varying preferences of livestock species.

Monograstric animals consume very little forage from tree legumes although there are many examples of MPTs being used for supplementing diets of monogastric livestock. However, the general consensus is that they have a limited role to play in monograstric feeding, and only as leaf protein concentrate. In general, they are not a suitable feed due to (a) their high content of anti-nutritive compounds, which non-ruminants have greater difficulty utilizing, (b) their high fibre content (Dutton 1992) and (c) their low energy content. Seeds are sometimes fed to monogastrics but may need detoxification procedures before being fed (D'Mello 1992).

Diseases and insects

Diseases and insects of forage tree legumes limit productivity worldwide. As the use of tree legumes is expanding rapidly, pest problems are likely to increase in occurrence and severity, yet the extent of knowledge of diseases and insects of tree legumes is generally poor.

There are data providing lists of pathogens but little information on their significance or on pathogenic variability (Lenné 1992). Disease and insect pests are reviewed for specific species and genera including *Gliridicia* (Boa and Lenné 1996), *Leucaena* (Boa and Lenné 1995), *Erythrina* (Westley and Powell 1993) and *Sesbania* (Murphy 1990). There are some important tree legume species with little information available (Lenné and Boa 1994).

There are also summary tables of insects pests on tree legumes (Walter and Parry 1994) but little is known about insect and host plant relationships and other aspects of their ecology. For this reason, there is often ignorance concerning acceptable control measures. Chemical control may be the easiest approach as a range of broad spectrum insecticides are available. However, in many cases, chemical control may not be an acceptable approach as (a) chemicals are sometimes not accessible to farmers, (b) chemicals are expensive, (c) broad spectrum chemicals have other harmful effects, and (d) animals may consume the sprayed leaf material with detrimental results. The leucaena psyllid (*Heteropsylla cubana*) is the most studied insect pest. While chemical control measures are effective and biological control using predatory insects is partially effective, the most practical, the most cost-effective, and the most ecologically sound approach is the use of resistant varieties. We still do not understand the mechanisms of resistance in *Leucaena* necessary to develop effective screening programs (Mullen *et al*. 1998a).

It is vital that more detailed information is assembled on the diseases and pests affecting the cultivation and productivity of tree legumes. Country and region surveys are needed to describe the location and extent of problems. The existing networks are an appropriate way to gain information on disease and insect problems currently experienced (Lenné and Boa 1994). Catalogues and manuals illustrating the key insect and disease species are required to assist field workers, not only with identification but also with formulation of control measures. Preparation of quarantine guidelines to ensure the safe movement of seed to limit the spread of pests is another priority.

Unfortunately, there is often a lack of specialist expertise to address these problems.

Conservation issues

The development and improvement of tree legumes for farm use is contingent on the availability of germplasm from the Centres of Origin of species to underpin improvement programs. It is therefore imperative that the native ranges of tree legumes are protected from exploitation and over use. Some examples of the current status for selected species are given below.

According to Wickens *et al*. (1995), the former *Acacia* communities in the Sahel i North Africa and the Near East have deteriorated almost beyond recovery. This has been due principally to excessive demand for fuelwood, but also to overgrazing, and demand for more agricultural land, all driven by increasing population pressures. The result is almost irreversible. Rehabilitation of these areas will be very slow where desertification and soil movement has occurred as there is little soil seed reserve. They stress the need for low cost participatory approaches, emphasising preventative rather than remedial measures.

Stands of *Faidherbia albida* in Wadi Aribo in western Sudan are endangered due to indiscriminate lopping for browse by nomads for their camels (Wickens *et al*. 1995).

Due to its colonising nature, *G. sepium* is not under threat at the species level, but certain important provenances such as Retalhuleu in Guatemala are under serious threat from human encroachment and river erosion (Stewart *et al*. 1996).

The majority of *Albizia* species is severely depleted in their native range in Mexico and Central America. Most species remain abundant in only a few areas. Promotion of greater use of the species would assist with their *in situ* conservation (Hughes and Pottinger 1997).

In *Leucaena*, the majority of species are of no conservation concern. However, three species, *L. matudae*, *L. magnifica* and *L. involucrata* are rare and threatened. There are less than 400 known individual plants of *L. magnifica* (Hughes 1998a).

Prosopis africana is seriously threatened in the semi-arid lowlands of West Africa in Burkina Faso, Niger, Mali and Senegal. ICRAF has organized seed collections of this species to capture the genetic diversity before invaluable genetic resources are lost (Tchoundjeu *et al*. 1998). Patterns of genetic diversity in populations of *Calliandra calothyrsus* were examined using isozyme analysis and their conservation status was reported by Chamberlain (1998).

There are various methods used to conserve genetic resources. Hughes (1998) discusses the merits of *in situ* (maintenance of natural population), *ex situ* (e.g. germlasm banks and botanic gardens) and *circa situm* (maintenance while in agricultural use e.g. as hedge row) conservation. *In vitro* techniques for conservation and multiplication of germplasm, and elimination of disease, have been applied to the conservation of *Leucaena leucocephala*, *Erythrina brucei* and *Sesbania sesban* by Ruredzo and Hanson (1988). Perhaps a combination of all approaches may be necessary. As with taxonomic studies, it is now exceedingly difficult to obtain financial support for conservation of undomesticated genetic resources in their native range.

The debate over exotic versus native species

"Too often in extension work, a few exotic species have been strongly promoted without any attention being given to the rich indigenous flora and local knowledge of it" (Bekele-Tesemma *et al.* 1993).

Over recent years there has been increasing interest in indigenous species as an alternative to introducing exotic species, and debate concerning the appropriateness of introducing exotic species into indigenous ecosystems. There are many reasons for this trend:

(a) Farming communities have very detailed knowledge of the use and value of indigenous species, and often this has not been documented, assessed or verified (B. Calub, personal communication, Schrempp *et al.* 1992).

(b) There are ecological advantages in using a diversity of indigenous species, compared to a monoculture of exotics.

(c) There is concern about preserving and conserving indigenous germplasm.

(d) A reduced emphasis on promotion of exotic species and greater *in situ* use of local tree diversity, may reduce risk of unwanted weed invasion and genetic pollution through hybridisation (Hughes 1994).

There is no simple answer to this debate and decisions have to be made on merit based on the important issues. Combined use of native and exotic species may be an option in some instances.

Indigenous forage tree species have generally been used for subsistence feeding rather than in commercial systems. Wickens *et al.* (1995) describe how fuelwood and grazing were the principal uses of the former *Acacia* communities in the Sahel, North Africa and the Near East. However, due to overuse, some have now deteriorated, almost beyond recovery.

Often exotic species are more vigorous and produce higher yields than indigenous species. This was the case in Malawi where *L. leucocephala*, *Cassia spectabilis* and *Gliricidia sepium* have been promoted over the indigenous *Faidherbia albida* which is slow growing (Cromwell *et al.* 1996). There are many regions where exotic species have made invaluable contributions. It has been estimated that 150 to 200 M people use gliricidia world-wide, the majority of whom live outside its native range (Simons 1996). *Leucaena* is now naturalised in the Philippines where it is the principal source of tree fodder and of fuelwood. This species underpins a sustainable, highly productive beef cattle production system in northern Australia (Middleton *et al.* 1995).

In India, fast growing, multipurpose exotic tree species introduced with the relatively slow growing *Acacia nilotica* (an indigenous tree) enhance biomass production. However, competition reduces growth of the indigenous tree. Careful planning and thoughtful species selection was recommended before implementation of exotic large-scale afforestation programmes (Neelam-Bhatnagar *et al.* 1993).

Significantly, most commercial use of forage from tree legumes has been with exotic species. Indigenous species appear to have been confined to subsistence feeding systems perhaps due to their lower productivity and lower quality. The communal management regimes employed in traditional systems place few limits on use, and this has led to over exploitation (Wickens *et al*. 1995).

Sometimes indigenous species are better adapted to difficult soils. In Costa Rica, native leguminous species had more potential for reforestation and agroforestry on acid soils high in aluminum and manganese than exotic species (Tilki and Fisher 1998). In contrast, in the mountainous area of Minas Gerais, Brazil, where acid infertile soils predominate, the exotic species *Acacia mangium* and *A. auriculiformis* achieved faster growth than indigenous species when introduced into an existing *B. decumbens* pasture (Carvalho 1997).

Exotic species can have significant effects on associated ecosystem species. In Hawaii, 4 species of native birds rarely feed on the fruits of the exotic nitrogen-fixing tree *Myrica faya* which is invading Hawai'i Volcanoes National Park. However, five species of exotic birds were seen ingesting the fruit (Woodward *et al*. 1990). In South Africa, invasive exotic plants such as *Acacia longifolia* and *A. mearnsii*, were detrimental to native, ground-living, invertebrate fauna. There was no significant effect on species richness and diversity, but there was a different assemblage of species associated with exotic compared to indigenous vegetation. Management should therefore be sensitive to the needs of the ecosystem to ensure conservation of desirable species when native vegetation is replaced by exotics (Samways *et al.*1996).

Over the last three decades, there has been movement of plant material around the world on an unprecedented scale, with few restrictions covering movement. Hughes (1994) advocated a more cautious approach to species introduction and a more thorough assessment of the advantages and limitations of native and exotic species to lessen the risks of introduction of a weed.

Many native plants are incompletely studied. Some species are only now undergoing preliminary domestication and are still harvested by the traditional gathering activities associated with wild species. A case in point is *Acacia albida* (*Faidherbia albida*) which is now the focus of international collaborative efforts to extend its versatility of utilization (Nouaille 1992). There is large variability in performance of individual trees as little plant improvement has occurred, and little is known of the silviculture of the species (Cromwell *et al.* 1996).

It is likely that the most appropriate path through this minefield is judicious use of both native and exotic species. For instance, in tropical humid Africa, research may continue on species such as *Leucaena*, *Gliricidia* and *Sesbania*, but emphasis may gradually shift to local species as adoption may be more rapid and widespread. Schrempp *et al.* (1989) (cited in Schrempp *et al.* 1992) noted from their work in the eastern highlands of Ethiopia that preferred species in fields were indigenous species such as *A. albida*, while preferred species off-field were fast growing exotics such as *A. mearnsii*, *A. saligna*, *Eucalyptus* spp. and *P. procera*.

Weediness

A number of introduced tree legumes have become serious weed pests. Given the large number of introductions to many new environments, this is not surprising. Weediness of introduced exotic trees has generally occurred when:

- The purpose for the introduction has failed, or has resulted in only partial use of trees,
- Seedlings and trees are protected from grazing by thorns, or by low palatability,
- Trees have abundant, precocious seed production,
- Seeds are only partially digested by ruminant grazers, and viable seeds are spread in faeces,
- Seed is spread on the hoofs of animals, or transported by flood waters,
- Seeds are long-lived in the soil,
- Young plants grow and colonise rapidly, and tolerate drought, grazing and fire,
- Trees are long-lived,
- There are disturbed areas nearby suitable for invasion,
- There is unpredictable growth as trees perform beyond expectations away from natural predators, or in new climatic, edaphic or management environments.

These conditions have been partially met by a number of introduction events e.g. *Acacia nilotica* was introduced to provide shade and fodder for sheep in western Queensland but now infests 6 M ha of *Astrebla* grasslands (Carter 1994).

Over the past 80-100 years, mesquite (*Prosopis* spp.) has become an aggressive invader of desert grasslands in the southwest United States (Ibrahim 1992) due to interference in the natural ecological balance by man and his activities. Strategies for control and management of this problem are still not available. Grazing livestock and reduced occurrence of fire were key factors in the increase in density of mesquite. The original movement of *Leucaena leucocephala* subspecies *leucocaphala* around the world has lead to this inferior but seedy variety becoming a weed in many tropical environments (Hughes 1994).

pecies may also become a weed in their own environment. *Albizia tomentosa* is a weed in disturbed areas in Mexico (Hughes and Pottinger 1997) and *Acacia aneura* is often weedy in southwest Queensland when poorly managed (Beale 1994).

The question of weed risk raises many difficult questions with few easy answers. Some suggest that only indigenous species should be considered in agroforestry programs. But this is an unrealistic constraint on the development of competitive farming systems and indeed on the environment. Forage tree legumes are already major contributors to the sustainability of our farming systems. They have the potential to become even more important in our livestock industries, thus enhancing the quality of life of rural communities. However, it will be imperative to pursue our objectives with environmental responsibility. The key is to carefully evaluate the level of risk, reject high risk introductions, and carefully manage introductions to minimise the chances of weed outbreak.

When introducing new species to an environment it may be necessary to first:

- Review susceptibility of seedlings and trees to grazing (thorns, toxins, anti-palatability will reduce animal access)
- Assess seed production and longevity,
- Assess seed dispersal mechanisms,
- Study climatic and soil characteristics to predict potential areas susceptible to invasion,
- Study insect predators and pathogens in the native range of species,
- Evaluate methods of control e.g. pests, fire, chemical and mechanical methods,
- After introduction, install long-term monitoring and rapid action systems, and
- Ensure that farmers have support to make full use of MPT introductions

Other approaches should also be used. For example, to minimise the weed risk status of *Leucaena*, it will be necessary to (a) educate farmers to achieve good grazing management to minimise seed production and to prevent seedling growth; (b) spray or slash isolated seedlings; (c) introduce less seedy varieties, e.g. the KX2 hybrid; (d) develop sterile hybrids which will eliminate risk; and (e) utilise biological control methods such as the leucaena bruchid beetle (*Acanthosceloides macrophthalmus*) which greatly reduces the amount of viable seed produced. A number of these strategies can be combined to reduce the weed risk of this species.

Perhaps the most important step is to ensure that the rural community adopting the new species have the tools to make full use of the MPT. There are many examples of apparent weediness occurring because villagers may be unaware of the many uses of new plants.

Nevertheless, tree legumes should not be introduced where risk is high, or where nearby disturbed vegetation might be ecologically threatened.

Integrating forage tree legumes into farming systems and farmer uptake

Examples of successful adoption of exotic and indigenous tree legumes, for multi-purpose uses including forage are numerous. Outstanding examples are *Leucaena leucocephala* in Australia (Middleton *et al*. 1995) and Asia (Moog *et al*. 1998), *Gliricidia sepium* in southeast Asia (Stewart 1996), *Sesbania grandiflora* in Indonesia (Gutteridge 1994b), *Calliandra calothyrsus* in Indonesia (Palmer *et al*. 1994), and *Acacia* spp. in Africa (Wickens *et al*. 1995).

Nevertheless, despite high levels of promotion, farmer uptake has been lower than anticipated. Recent attempts to achieve adoption of complex agroforestry packages, such as alley cropping, have been only partially successful due to unrecognised failings in approach (Gutteridge 1998). Difficulties in achieving high levels of adoption for *Leucaena* are reported for Africa (Dzowela *et al*. 1998), South America (Argel *et al*. 1998) and Asia (Moog *et al*. 1998).

Although the forage bank concept has been shown to be feasible in tropical Africa, rate of adoption has been low due to socio-economic constraints such as land tenure insecurity and lack of infrastructure support (Cromwell *et al*. 1996).

The value of alley cropping, is hotly debated in Africa (Cromwell *et al*. 1996). Research groups have become cautious about the sustainable benefits of the system and in particular the value of the mulch in terms of increased crop yields on farm. Part of the problem has been identified by Grist *et al*. (1999). They found that while alley cropping of *Gliricidia* in *Imperata* grasslands can increase soil fertility, farmers were likely to incur a loss in the first year of development, and that it would take c. 4 years to begin making a profit. Humphreys (1994) concluded that alley cropping systems were more successful when prunings were used for livestock feeding rather than for fertility improvement alone. Gutteridge (1998) argued that alley cropping was less successful in subhumid environmetns where competition for moisture reduced inter-planted crop yields.

There have been many reasons advanced to explain success or lower than anticipated levels of adoption (Smith 1992, Cromwell *et al.* 1996, Larsen *et al.* 1998) . Simple innovations e.g. a new variety overcoming a key problem, may be adopted with relatively little intervention. However, complex innovation, involving a new farming system, generally require sustained, high profile intervention. From case studies reviewed, several factors were common to successful adoption including:

Technical.

- Technical constraints must be resolved promptly to avoid farmers and extension workers becoming discouraged and losing interest.

- Technical information needs to flow frequently, accurately and in a variety of appropriate formats (field visits, manuals, videos, newsletters, discussion groups) to farmers.

- A range of MPT species may need to be available to meet the diverse needs of farmers, their environments and farming systems. New germplasm needs to be markedly superior than existing material, as is the case with the KX2 Leucaena hybrid being introduced into the Philippines.

- The best planting material should be available to farmers. This will require education of both extension agents and farmers to ensure adequate farmer knowledge concerning suppliers and their varieties available.

Socio-economic.

- Farmers, local leaders and groups, and government all need to be closely involved in the process and there needs to be frequent contact among all players. All need to feel some ownership and all need to be respected for their contribution to the innovation. The importance of communication / training / extension and research networks needs to be stressed (Dutton 1992).

- Innovation needs to have positive commercial outcomes for individual farmers as well as environmental outcomes. Cook *et al*. (1989) stressed the importance of understanding the economics of agroforestry systems from the farmer's point of view as well as from the broader perspective of benefits to society. Project implementation should take into account local markets and opportunities for off-farm employment offered by tree products, as well as the opportunity costs perceived by farmers in making adoption decisions. A full cost-benefit analysis of new agroforestry systems is essential. It is unlikely that farmers will adopt new MPT systems on the basis of environmental benefit only.

Other

- Interestingly, successful tree legume-based interventions have commonly involved long-term, top-down extension methodologies. The need for institutional direction and long-term commitment may be necessary due to the complexity of many of the tree legume systems being promoted. However, successful adoption of tree legume interventions through a process of on-farm and participatory research has also been a consistent theme.

- Perhaps the most important elements of successful adoption are the time, enthusiasm and long-term commitment, of farmers, researchers, and extension agents involved. Successful innovation needs champions to ensure continuity of interest and support over an extended time period (often > 10 years and sometimes up to 30 years).

One thing is certain – without improved levels of adoption, and more explicit demonstration of the relevance and benefits of forage tree legumes, the good will and support of funding and donor agencies will be limited.

Conclusions

The principal commercial use and future potential of multi-purpose tree legumes is forage for livestock production. There is great potential to expand their use for both smallholder and large-scale ranch production systems. Key R & D conclusions and recommendations are:

- While there are significant examples of adoption and use of MPT species world-wide, there remains excellent opportunity to increase the use of this valuable group of plants using participatory research and extension approaches.

- There is only a small number of MPT species currently in commercial use by farmers c. 20, but they cover a wide range of ecological environments. Many existing MPT plantings worldwide are from a narrow germplasm base, and access to the highest quality varieties needs to be improved. Apart from improved distribution networks, further study of taxonomy and nomenclature of important genera is required. There is opportunity for mixed use of both native and exotic MPTs to suit both environmental and production objectives.

- The range of MPTs that will be valuable as forage is restricted by low palatability and low nutritive value of many species. This is primarily due to their high content or anti-nutritive compounds such as tannins.

- The conservation status of some MPTs is threatened due to over exploitation in their native range, and there is potential for weediness of both new and existing introductions that needs to be carefully assessed.

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Table 1 - Most used tree legume species for forage purposes (key references in parenthesis)

Higher quality species	Lower quality species
▪ Albizia lebbeck (Lowry 1989)	▪ Acacia aneura (Beale 1994) *
▪ Chamaecytisus palmensis (Snook 1982)	▪ Acacia nilotica (Carter 1994)
▪ Cratylia argentea (Argel and Lascano 1998)	▪ Acacia tortilis (Wickens et al. 1995) *
▪ Desmodium rensonii (Djojo et al. 1995)	▪ Albizia chinensis (Zabala 1997)
▪ Desmanthus virgatus (Gutteridge 1994a)	▪ Albizia saman (Roshetko 1995)
▪ Gliricidia sepium (Stewart et al. 1996)	▪ Calliandra calothyrsus (Evans 1996)
▪ Leucaena leucocephala (Shelton et al. 1998)	▪ Erythrina spp. (Westley and Powell 1993)
▪ Leucaena diversifolia (Shelton et al. 1998	▪ Faidherbia albida (Wickens et al. 1995) *
▪ Sesbania grandiflora (Gutteridge and Rekib 1995)	▪ Flemingia macrophylla (Gutteridge 1994a)
▪ Sesbania sesban (Gutteridge and Rekib 1995)	▪ Prosopis juliflora (Dutton 1992)

* Principal application is in indigenous semi-subsistence systems

Table 2 - Tolerance of some fodder tree legumes to various environments

Species	Acid soils (pH<5.5)	Cool temp. (15-25oC)	Rainfall (mm)			Poor drainage	High salinity
			Low (<500)	Medium (500-1000)	High (>1000)		
Acacia aneura	T	T	T	NT	NT	NT	NT
Acacia angustissima	T	NT	NT	NT	T	NT	NT
Acacia nilotica	NT	NT	NT	NT	NT	T	T
Acacia tortilis	NT	NT	T	NT	NT	NT	NT
Albizia chinensis	T	T	NT	T	T	NT	NT
Albizia lebbeck	T	T	T	T	T	NT	T
Albizia saman	T	NT	NT	NT	T	T	NT
Calliandra calothrysus	T	NT	NT	NT	T	NT	NT
Chamaecytisus palmensis	NT	T	NT	T	NT	NT	NT
Cratylia agentea	T	NT	NT	NT	T	NT	NT
Desmodium rensonii	T	NT	NT	NT	T	NT	NT
Desmodium virgatus	NT	NT	NT	T	T	NT	NT
Erthrina spp.	T	NT	NT	NT	T	NT	NT
Faidherbia albida	NT	NT	T	NT	NT	T	NT
Flemingia macrophylla	T	NT	NT	NT	T	T	NT
Gliricidia sepium	T	NT	NT	NT	T	NT	NT
Leucaena diversifolia	NT	T	NT	T	T	NT	NT
Leucaena KX2 hybrid	NT	T	NT	T	T	NT	NT
Leucaena leucocephala	NT	NT	NT	T	T	NT	NT
Leucaena pallida	NT	T	NT	T	T	NT	NT
Leucaena trichandra	NT	T	NT	T	T	NT	NT
Prosopis juliflora	NT	NT	T	NT	NT	NT	NT
Sesbania grandiflora	NT	NT	NT	NT	T	T	T
Sesbania sesban	NT	T	NT	NT	T	T	T

T = tolerant; NT = not tolerant
Source: Roshetko *et al*. (1996), Shelton (1994a)