Leucaena — Adaptation, Quality and Farming Systems

Proceedings of a workshop held in Hanoi, Vietnam 9–14 February 1998

Editors: H.M. Shelton, R.C. Gutteridge, B.F. Mullen and R.A. Bray

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Contents

Preface

Leucaena continues to be a valuable species for international agriculture. While *Leucaena leucocephala* (Lam.) de Wit is the most widely-used species, taxonomists now recognise 22 species with diversity in form, adaptation, feeding value and response to management practices. Worldwide, scientists, extension and rural community workers seek new opportunities to harness the value of this important genus. It is also recognised that there are environmental concerns associated with moving plants into new ecosystems. However, increasing knowledge of the biology of *Leucaena* will ensure that the many benefits of this multipurpose genus are maximised, and the negative impacts limited.

These Proceedings report the presentations at the international workshop on *Leucaena* held at the Vietnam National University in Hanoi, 9–14 February 1998.

These Proceedings comprise three major sections: Taxonomy and Agronomy, Forage Quality and Farming Systems. For each section, several speakers, eminent in their field, were invited to give keynote presentations overviewing their own work and that of other relevant international research. These papers were peer-reviewed by the editorial panel listed and thanks are extended to the panel for their efforts. Poster papers were edited by The University of Queensland editorial group.

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(editors)

Editorial Panel

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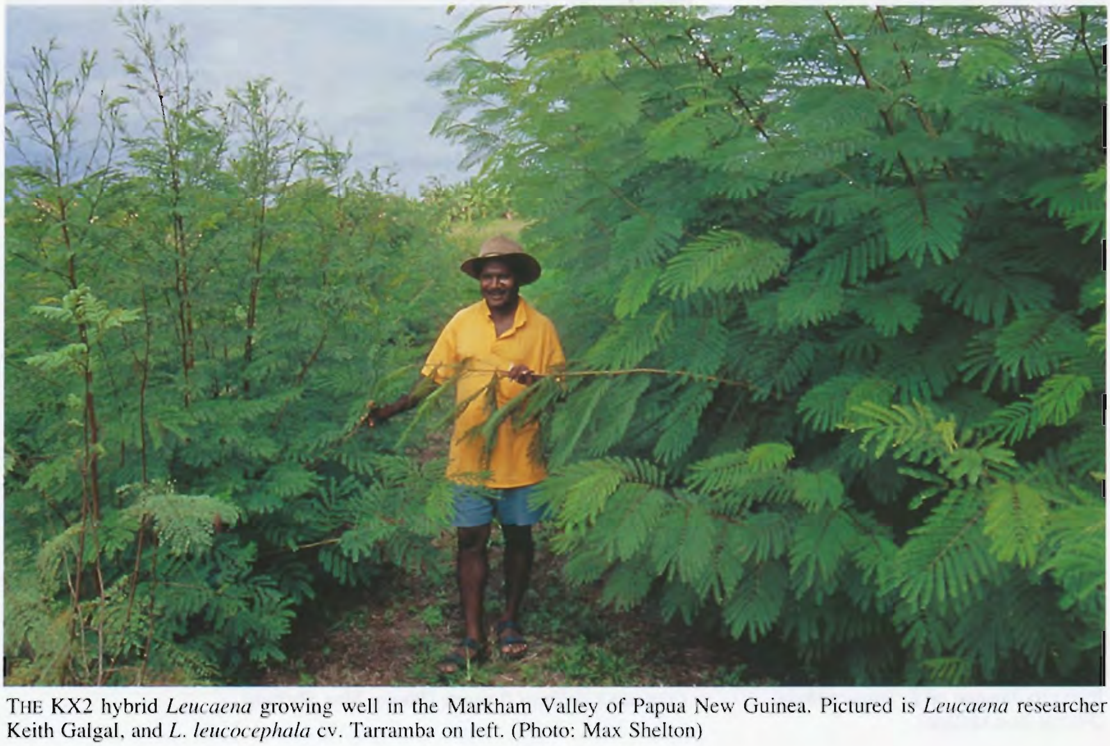
LEUCAENA seedling nursery in Papua New Guinea. (Photo: Max Shelton)



THE KX2 hybrid *Leucaena* growing well in the Markham Valley of Papua New Guinea. Pictured is *Leucaena* researcher Keith Galgal, and *L. leucocephala* cv. Tarramba on left. (Photo: Max Shelton)

THE KX2 hybrid *Leucaena* flourishing in Papua New Guinea. (Photo: Max Shelton)

PSYLLID damage on *L. leucocephala*. (Photo: Ben Mullen)

LEUCAENA collinsii flowers. (Photo: Max Shelton)

CUT and carry *Leucaena* in the Philippines. (Photo: Max Shelton)

LEUCAENA *leucocephala* collected for fuelwood in Mindanao, Philippines. (Photo: Max Shelton)

LEUCAENA researchers in Vietnam: Professor Le Van Khoa (left) and Dr Hoang Xuan Co (right) of Vietnam National University, and Dr Dinh Van Binh (centre) from the Vietnam National Institute of Animal Husbandry. (Photo: Max Shelton)

LEUCAENA researchers beside the KX2 hybrid *Leucaena* in the Philippines. Emily Victorio (left), Alex Castillo (centre) and Remy Acasio (right) are from the Bureau of Animal Husbandry. (Photo: Max Shelton)

Overview of Workshop Outcomes

The *Leucaena* Genus: New Opportunities for Agriculture (A Review of Workshop Outcomes)

H.M. Shelton[1]

Abstract

This paper reviews the main findings of the Workshop. Taxonomists now recognise 22 species of *Leucaena* including several new species and subspecies. *Leucaena* genetic resources databases can now be interrogated using the World *Leucaena* Catalogue. Highlights of regional agronomic trials were the high yielding ability of KX2 F1 hybrid accessions (*L. leucocephala* × *L. pallida*), cold tolerance of *L. trichandra* OFI 53/88 and variability of psyllid resistance among accessions of 'resistant species'. No accessions tolerant of severely acid soils were identified. Several species showed high forage quality with chemical parameters such as digestibility, protein content and fibre content similar to *L. leucocephala*. There was variation in both content and astringency of condensed tannin of species, with high tannin species giving poor N-retention in feeding trials. *L. collinsii* was of particular interest due to its low tannin content and psyllid resistance. Animal production trials demonstrated the superiority of *L. leucocephala and L. collinsii* and likely palatability problems with *L. pallida* and *L. trichandra*. Levels of adoption in the farming systems of Africa, Southeast Asia, Pacific and Australian regions are still low. Future research and development priorities and opportunities are identified and the success of Leucnet News is highlighted.

LEUCAENA leucocephala (Lam.) de Wit (leucaena) has been one of the most productive and versatile multi-purpose tree legumes available to tropical agriculture. It is the premier forage species in both extensive grazing systems and cut and carry systems for smallholders. It continues to make a major contribution to fuelwood supply in many developing countries and it is used to improve soil fertility and stabilise degraded lands.

However, both current and more widespread use has been limited by the narrow germplasm base of the commonly used *L. leucocephala* cultivars. They lack adaptation to acid soils and cool temperatures and they are susceptible to the psyllid insect (*Heteropsylla cubana*).

In 1994, an International Workshop entitled *Leucaena —Opportunities and Limitations* was held in Bogor, Indonesia and defined the current state of research and development in the *Leucaena* genus worldwide. Lack of knowledge and under-utilisation of the lesser-known species in the genus was recognised as a major shortcoming. Research and development priorities were identified and became the key objectives of the newly formed network, Leucnet (Leucaena Research and Development Network).

An ACIAR sponsored Project *9433 New Leucaenas for Southeast Asian, Pacific and Australian Agriculture* was implemented from 1995 to 1998. It involved collaboration of scientists from four Australian institutions (The University of Queensland, CSIRO, QDPI and WADA) and six developing countries partners (Papua New Guinea, the Philippines, Vietnam, Indonesia, Laos and Kenya).

It was therefore timely to once again review research and development in the *Leucaena* genus since the 1994 Workshop. Accordingly, a second ACIAR-sponsored workshop was organised by The University of Queensland and hosted by the Vietnam National University in Hanoi in February 1998. Other international institutions involved in the research and development programs presented at this workshop included the Oxford Forestry Institute (OFI), University of Hawaii, Hawaiian Agricultural Research Company, ICRAF, CIAT and CIRAD as well as many national groups. The workshop focussed on germplasm evaluation, forage quality assessment and the role of *Leucaena* in farming systems.

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This paper reviews the main outcomes of the Hanoi meeting and provides an overview of the *Leucaena* genus in relation to new opportunities for agriculture.

Taxonomy

An accurate naming of species and an understanding of species relationships underpins effective plant improvement. Colin Hughes from the Oxford Forestry Institute presented his revised taxonomy of *Leucaena* at the meeting (Hughes, these Proceedings). His work finally clarifies *Leucaena* taxonomy after an extended period of confusion. He has identified and named 22 species, 6 subspecies and varieties and 2 natural hybrids. Key changes are the diploid taxa of *L. diversifolia* subsp. *stenocarpa* now identified as *L. trichandra; L. esculenta* subsp. *paniculata* now *L. pallida*; *L. shannonii* subsp. *magnifica* now *L. magnifica*, *L. esculenta* subsp. *matudae* now *L. matudae*; a third variant of *L. leucocephala*, namely subsp, *ixtahuacana*; 2 new varieties of *L. confertiflora* — var. *confertiflora* and var. *adenotheloidea*; and a second variant *of L. macrophylla*, subsp. *istmensis*. A summary table of these new taxa is given in Hughes (these Proceedings). A brief description of the taxa can be found in the *Leucaena* Catalogue (Bray et al. 1997).

Publication of the World *Leucaena* Catalogue (Bray et al. 1997) has been an outstanding recent achievement. It contains cross-referenced lists of all accessions held by the five major *Leucaena* germplasm banks (CSIRO, UH, OFI, CIAT, ILRI). The Catalogue will be of great value to researchers interested in sourcing new material, or checking the origins and correctness of naming of existing accessions. It will also enable researchers to ensure that they have assembled a representative set of the available germplasm. Copies of the Catalogue are available in 3.5" floppy disk format from The University of Queensland.

Agronomy and Environmental Adaptation

The yield trials reported in these Proceedings are an outstanding example of the benefits of collaboration of scientists from differing countries/institutions and disciplinary backgrounds. The results of the trials have provided us with an excellent understanding of the agronomic potential of the *Leucaena* genus.

The first step in this program was to assemble a comprehensive collection of *Leucaena* germplasm representing the diversity in the genus. Seeds of *Leucaena,* collected from the native range in Central and South America by three separate organisations, were pooled in a cooperative effort to ensure that the best material was screened simultaneously. The inputs of Oxford Forestry Institute and University of Hawaii in particular were crucial both for the provision of the germplasm and for providing background knowledge used in selection of appropriate taxa for multi-site trials. Subsequently, the contributions of scientists from Australia, the Philippines, Papua New Guinea, Vietnam, Kenya, Indonesia, and Laos ensured the successful conduct of the trials. The use of the genotype × environment analysis techniques developed at the University of Queensland permitted a rational analysis of enormous data sets and permitted us to make conclusions as to the main findings of the trials.

The multi-environment trials comprised 25 accessions and were conducted at 17 experimental sites in seven countries (Mullen, Shelton et al., these Proceedings). Larger trials comprising the complete collection of 116 accessions (termed the foundation collection) were planted at sites in the Philippines and Australia (Mullen and Shelton, these Proceedings; Gabunada and Stür, these Proceedings). They demonstrated enormous variation in yield potential and showed that there was both broad adaptation (accessions with high yields across all environments), and specific adaptation (high yields in specific environments), with some accessions superior to existing commercial germplasm (Table 1).

Broad adaptation

The multi-site trials highlighted the outstanding broad adaptation and high yield ability of the KX2 F1 hybrid of *L. leucocephala* K636 × *L. pallida* K748. This line also had moderate psyllid resistance, excellent seedling vigour, and some cold tolerance. The accompanying foundation trials demonstrated that other KX2 combinations were similarly vigorous.

Other accessions that showed high yields, although not to the level of the KX2 F1 hybrids, are given in Table 1.

Regression techniques enabled analyses of the key 'drivers' of leucaena growth in the multi-environment trials (Mullen, Shelton et al., these Proceedings). Overall, low temperature, soil acidity and soil infertility had the greatest influence on yields. The effects of rainfall and psyllid pressure were also influential.

Specific adaptation

A detailed analysis of the multi-environment trials, foundation trials and glasshouse trials permitted us to identify accessions which showed specific tolerance of cold environments, severely acid soils and psyllid challenge. These are discussed now.

Table 1. Accessions showing broad and specific adaptation in multi-environment trials (Mullen, Shelton et al., these Proceedings), chemical composition (Dalzell et al., these Proceedings) and palatability (Faint et al., these Proceedings)

	Yield[1]	Chemical quality[2]	Palatability[2]
Species with Broad Adaptation			
• *L. leuc* × *L. pall.* KX2 F1 hybrid	*******	H	H
• *L. pallida* CQ3439	****	L	L
• *L. leuc.* × *L. pall.* KX2 F5 hybrid	****	H	H
• *L. pallida* OFI 79/93 and OFI 52/87	***	L	L
• *L. macrophylla* OFI 47/85	***	H	L
• *L. collinsii* OFI 52/88	*	H	H
Species with Specific Adaptation	Yield[1]	Chemical quality[1]	Palatability[2]
Cold/high psyllid environments			
• *L. trichandra* OFI 53/88	*****	M	M
• *L. diversifolia* OFI 83/92	*	M	M
• *L. esculenta* OFI 47/87	*	L	L
Hot/low psyllid environments			
• *L. leucocephala* K636	****	H	H
• *L. leucocephala* cv. Cunningham	***	H	H
• *L. salvadorensis* OFI 36/88	***	M	L

[1] No. of stars reflects relative ranking for this parameter
[2] H = high; M = medium; L = low

Cold tolerance

Data suggested no likelihood of finding leucaenas that will grow well at temperatures below 20 °C (Mullen, Castillo et al., these Proceedings). However, there was some differentiation of species at 28/23 °C indicating that there is potential to develop cultivars suitable for the highland tropics where temperatures are moderate, but too low for tropical species such as *L. leucocephala*. For such situations, the suitability of the *L. leucocephala* × *L. pallida* KX2 hybrids and *L. trichandra* OFI 53/88 was noted.

Experiments in Queensland and Botswana showed some frost tolerance, but no resistance. Accessions of *L. diversifolia, L. trichandra, L. pallida,* the KX2 and KX3 hybrids, and surprisingly *L. leucocephala*, showed some tolerance.

Acid soil tolerance

The identification of accessions tolerant of acid soils within a genus that has evolved in neutral to alkaline soils was a major challenge. In the multi-site trials, Mullen, Shelton et al. evaluated performance of accessions at acid soil sites in the Philippines, Indonesia, Laos and Vietnam. In their studies, no adaptation to severely acid infertile environments was found, and all accessions performed poorly in such environments. However, growth was not significantly limited at the mildly acid site in Indonesia (pH 5.4, Al saturation 2%).

It appeared that Al toxicity may be the principal determinant of poor growth on acid soils. Low pH *per se*, except at very low values, appeared not to be the key factor. There may be a need to define the critical Al saturation for *Leucaena* as this is the most commonly available soil measurement. It is concluded that if tree legumes are required for severely acid soils (pH < 5.0 and high Al saturation) they should be sought from genera such as *Gliricidia, Calliandra, Indigofera*, and *Erythrina,* which are known for their acid tolerance.

Psyllid resistance

Since the first devastating arrival of the psyllid in the mid-1980s when leucaena growth was severely limited and many plants died, psyllids in most leucaena growing areas have reached equilibrium with natural predators. Growth of once devastated areas has improved considerably although psyllids are still a limitation. Many natural predators of psyllids, both natural and exotic, have been identified around the world (approximately 30 species of insects, 3 species of spiders, and 6 species of fungi) (Mullen, Gabunada et al., these Proceedings). These authors related these damage scores to lost production of edible forage, and showed that even low damage scores reduced yield dramatically. Clearly psyllid damage continues to be a significant although less acute factor.

There is unlikely to be further effort to achieve biological control of the psyllid due to high cost, increasing difficulties in moving biological agents from country to country, and the high likelihood of achieving control through genetic resistance in the genus.

These studies have shown a complete range of psyllid response in *Leucaena* from highly resistant (*L. collinsii* subsp. *collinsii*, *L. confertiflora*, *L. esculenta* subsp. *esculenta* and *L. matudae*) to highly susceptible (*L. leucocephala* and *L. multicapitula*), with considerable variation both between and within species. Good resistance was also found in some, but not all, accessions of *L. collinsii, L. pallida and L. trichandra*. Unfortunately, there was no evidence of resistance in *L. leucocephala* although there was variation in degree of susceptibility. The mechanisms of psyllid resistance in *Leucaena* remain unresolved.

Increased use of psyllid resistance in the genus can now be achieved both by the direct use of agronomically useful psyllid resistant accessions, such as *L. collinsii* subsp. *collinsii, L. pallida* and *L. trichandra* and by the indirect use of resistance genes from such species in hybrid breeding programs involving *L. leucocephala*.

Rhizobium specificity

Twenty seven accessions representing 19 species of *Leucaena* were assessed by Lesueur et al. (these Proceedings) for effectiveness of N_2-fixation using 13 strains of *Rhizobium*. Fifteen accessions were effectively nodulated and can therefore be regarded as 'promiscuous nodulators'. The remaining 11 accessions formed partially effective associations with most *Rhizobium* strains and can be regarded as moderately specific. Fortunately, several strains of *Rhizobium* were effective including CB3060, the strain used in the multi-site evaluations. The less effectively nodulated accessions included taxa of agronomic interest *L. trichandra, L. diversifolia, L. macrophylla* and the *L. leucocephala* × *L. pallida* KX2 F1 hybrid. The apparent specificity of these taxa is of concern as new cultivars are likely to be developed and it is important to ensure that effective *Rhizobium* strains are available. Field trials are required to ensure that apparently effective strains are competitive in field environments (Mullen et al. 1998).

Propagation of *Leucaena*

Methodologies for the production of commercial quantities of seed of the outstanding hybrids *L. leucocephala* × *L. pallida* (KX2) have not been resolved. This remains a central issue limiting the commercial use of these outstanding plants in large-scale plantings. Developing the technology for production of hybrid seed is therefore of the highest possible priority. Successful hybrid seed production will be based on the principle of cloning the self-sterile female parents (e.g., *L. pallida, L. esculenta* or *L. trichandra*) and alternate planting of cloned trees with trees of *L. leucocephala* to provide a source of pollen. Solutions need to be found to ensure synchrony of flowering of parental lines, and that bees are able to successfully transfer pollen from male to female parents to ensure high degrees of cross-pollination.

Fortunately, it is possible to propagate hybrids vegetatively. A relatively simple technique has been developed at the University of Hawaii (Sun et al., these Proceedings) and confirmed at the University of Edinburgh (Dick, these Proceedings). The successful cloning technique involves a combination of appropriate cutting preparation (binodal cuttings), root promoting auxins (IBA and NAA), misting, shade, appropriate rooting medium and temperature. Quite high success rates (80%) have been obtained for some species but *L. pallida* and its KX2 hybrid with *L. leucocephala* are more difficult. These techniques provide excellent opportunities to extend the use of the most highly productive hybrids to smallholders in developing countries, and to eliminate the weed hazard as the cloned hybrids will either be sterile or self-infertile ensuring that little seed will be produced. A program of testing of both the cloning technique and the hybrids themselves in village situations is currently under way. Hybrid seedlings may also be attractive for moderate scale plantings (20–50 ha) for intensive livestock production e.g. dairy production.

Environmental hazard in *Leucaena*

L. leucocephala subsp. *leucocephala* continues to be a significant weed in many parts of the world and it now appears that subsp. *glabrata*, and perhaps other species of *Leucaena*, may have similar weed potential (Hughes and Jones, these Proceedings). This potential threat to our environment is a major issue to be addressed by those involved in the research and promotion of *Leucaena*. This wonderful plant, with many social and economic benefits, has already entered disturbed ecosystems where there are no ruminant livestock to provide control, and it has the potential to be a serious exotic weed.

Control measures are required to reduce or contain areas of weed leucaena and to educate leucaena growers in appropriate management procedures to minimise risk of escape of seed to outside ecosystems. Strategies were proposed by Hughes and

Jones (these Proceedings) to minimise the production of seed. Other approaches include release of seed eating bruchid beetles, development of seedless hybrids, or use of low seeding accessions

Soil acidification of nodulated leucaena plantations in poorly buffered light textured soils has been shown to be an environmental hazard, especially if material is cut and carried (Hughes and Jones, these Proceedings). However, on neutral to alkaline clay soils, of the kind on which leucaena thrives, acidification is unlikely to be a significant phenomenon. Other work has shown many benefits to the soil from long-term leucaena plantings. Lallijee et al. (these Proceedings), demonstrated significant increases in organic matter, total N, permeability, as well as increases in soil pH, under 11–21-year-old *L. leucocephala* plantations.

Wood Quality and Woodiness

Wood quality

The production of *Leucaena* for fuelwood remains a subsistence or semi-commercial activity, but is a vitally important role in many countries. For this reason, the wood quality and value of *Leucaena* species require investigation.

Pottinger et al. (these Proceedings) demonstrated that while *L. shanonni, L. collinsii* subsp. *zacapana* and *L. magnifica* had the highest wood densities (> 0.83 g/cm^3), there was no correlation of this parameter with wood yield. In their work, *L. salvadorensis, L. leucocephala, L. macrophylla* subsp. *istmensis* and *L. collinsii* subsp. *zacapana* produced the highest wood yields. The very high yielding KX2 hybrid was not included in this study.

Wood/leaf ratios

It is clear that the relative woodiness of species varies. While the biomass productivity of some accessions may be outstanding, they may provide disappointing wood yields or leaf yields for forage depending on their inherent wood/leaf ratios. Work at The University of Queensland (unpublished data) showed that even though all species became more woody with age they could be divided into leafy, woody and intermediate types. *Leucocephala leucocephala, L. collinsii* subsp. *zacapana* and *L. lanceolata* were identified as leafy species while *L. pallida, L. trichandra* and *L. magnifica* were woody species.

Forage quality

Chemical composition

Scientists now have extensive data on the chemical composition of *Leucaena* species. Several of the lesser-known species appear to be of high quality. The species *L. trichodes, L. shannonii, L. magnifica, L. macrophylla, L. lempirana, L. lanceolata*, and *L. collinsii* were highly digestible (DMD >65%), had high crude protein contents (CP >25%), very low extractable condensed tannin contents (CT <1.5%), and low NDF values (NDF <26%) (Dalzell et al., these Proceedings). Of special interest was the strong relationship of DMD with the CP/CT ratio indicating that in species with CT concentrations >5–6%, digestibilities will be reduced. Unfortunately, several of the agronomically interesting species (*L. pallida, L. trichandra, L. diversifolia*) had high CT values, though there was considerable intraspecific variation in CT and NDF, and therefore scope to select accessions with higher DMD.

The mean chemical status of the outstanding KX2 hybrid was IVDMD 61%, CP 31%, NDF 19%, and extractable CT 4.1% indicating the high quality of this agronomically important genotype.

Dalzell et al. (these Proceedings) noted that many of the chemical parameters measured were influenced by the environmental characteristics of the site where the material was grown. For instance, they showed that CT values appeared to be greatly reduced by stresses such as nutrient deficiencies (P), soil acidity, water stress and low temperature. Thus CT values from a single genotype will vary seasonally. Although there is scope to select low CT genotypes, more needs to be known about environmental effects on CT in tissues, in terms of both the absolute amount of CT present and their binding ability (astringency) with plant proteins

Finally, these chemical data should be viewed only as indicators of quality of *Leucaena* forages, and need to be verified by animal production data.

Palatability of *Leucaena* species

The acceptability of the lesser-known *Leucaena* species to livestock was a key question when it became evident that there were many accessions agronomically superior to *L. leucocephala*. The commercially used *L. leucocephala* cultivars are known for their high palatability and can be used as a benchmark for this character. Cafeteria and field selection trials have now confirmed the excellent palatability of all *L. leucocephala* accessions tested, and also showed that while all *Leucaena* species were palatable, some accessions of *L. collinsii* subsp. *zacapana, L. esculenta, L. macrophylla* subsp. *istmensis, L. pallida* and *L. salvadorensis* were less palatable than *L. leucocephala*. However, animals generally became accustomed to the new herbage over a 4-week period. It was also clear that all *Leucaena* species were more palatable than *Calliandra calothyrsus, Sesbania sesban* or *Gliricidia sepium* (Faint et al., these Proceedings) which required more accustomisation than *Leucaena* before they were readily accepted. However, longer-term grazing trials have shown that acceptability may vary with environment and with longer exposure. For instance, Jones et al. (these Proceedings) reported reduced palatability of *L. pallida, L. trichandra* and *L. diversifolia* during the dry season at Townsville and after longer periods of grazing in Papua New Guinea and the Philippines. This aspect needs to be further investigated.

Nutritional significance of condensed tannins

Of the chemical parameters measured, condensed tannins in *Leucaena* are particularly important as they have the potential to both increase, and dramatically reduce, the utilisation of protein in ruminants. The work of McNeill et al. (these Proceedings) showed that the moderate levels of CT in *L. leucocephala* cv Tarramba increased protein utilisation in cattle, while high CT containing leucaenas (*L. pallida* CQ3439 and *L. trichandra* OFI 51/88) reduced the digestibility and retention of nitrogen. They were also able to demonstrate much higher protein binding ability of CT in *L. pallida*, compared to CT in *L. leucocephala*. There was also evidence that *L. leucocephala* CT was able to release protein more readily in the low pH environment of the abomasum thus enhancing protein absorption post-rumen. The authors hypothesise that there may be losses of endogenous protein from the hind gut of ruminants fed diets high in astringent condensed tannin and that this phenomenon may contribute to reduced N-retention.

Animal production potential of lesser-known *Leucaena* species

Scientists now have preliminary data on animal production from lesser-known *Leucaena* species (Jones et al., these Proceedings). The trials at Townsville, Papua New Guinea and the Philippines compared liveweight gain of cattle grazing grass pastures containing hedgerows of various *Leucaena* species with those containing grass only pastures. There was little difference among cultivars of *L. leucocephala,* e.g., cv. Cunningham and K636 (cv. Tarramba) (gains ranged from 400–800 g/d) which both showed the expected excellent ability to promote liveweight gain. However, there was considerable variation among other species, although all improved liveweight gains compared to that achieved on grass alone. This demonstrated the value of all *Leucaena* species as a protein supplement for cattle grazing tropical grass pastures. *L. pallida* (250–450 g/d), *L. diversifolia* (665 g/d) and *L. trichandra* (310–355 g/d) were less productive than *L. leucocephala* in their respective trials; however *L. collinsii* subsp. *collinsii* appeared to be similar to *L. leucocephala* in promoting liveweight gain. This was an exciting finding in view of the psyllid resistance, high DMD, high palatability, and low condensed tannin status of this species.

There was insufficient data to determine the amount of *Leucaena* spp. on offer to optimise liveweight gains in cattle. The trials have so far been conducted for short periods only and even though trends are emerging, more time is needed to verify the long-term capability of the different species and their ability to sustain continued grazing. For instance, species such as *L. pallida*, and *L. collinsii* appeared to suffer greater branch damage than *L. leucocephala*.

Animal performance overall in the above trials was lower than achieved elsewhere but may improve as the trees become better established and are able to contribute a greater proportion of the dietary intake of animals.

Farming Systems — Challenges and Constraints

Africa

Leucaena has been the subject of much interest, evaluation and research for many years in Africa (Dzowela et al., these Proceedings). However, there has been very little adoption due to early concerns about mimosine toxicity, and subsequently to the advent of the psyllid in 1992–94. Since the arrival of the psyllid, more resistant species such as *L. pallida and L trichandra* have performed well in trials, although uptake of *Leucaena* in African farming systems remains minimal perhaps due to ineffective extension programs. There is concern about the high tannin content of some *Leucaena* species and conjecture that the use of tannin binding agents such as polyetheleneglycol (PEG) may be valuable to aid the utilisation of such species. High quality is important to African farmers as *Leucaena* has the potential to substitute for concentrate rations in smallholder dairy production. Dzowela et al. reported the crucial need for additional protein sources for ruminant feeding systems, and they reported many examples of *Leucaena* being evaluated as a feed with positive results. However, there has been little uptake by the rural communities. Surprisingly, there is little reported use of *Leucaena* as a fuelwood in a continent where energy resources are scarce. The authors call for increased efforts to promote the value of the genus for rural and peri-urban use. To support this promotion, Dsowela et al. noted the need for improved seed availability of high quality germplasm.

Southeast Asia and Pacific regions

The largest areas and the greatest use of leucaena (*L. leucocephala*) can be found in Southeast Asia. While there are large areas of naturalised leucaena in the South Pacific region, use of this resource is limited. The reasons for the greater use of leucaena in Southeast Asia are associated with the region's high populations and intensive agricultural systems comprising small mixed farms which have a high requirement for multi-purpose trees, particularly in the Philippines. Moog et al. (these Proceedings) outline the many uses of leucaena in the region (fodder for ruminants and pigs, poles, fuelwood, trellises, fence lines, leaf meal, shade and soil protection, alley cropping) in production systems ranging from home gardens to upland sloping land, communal areas, plantation crops, and fuelwood lots.

Moog et al. noted that the invasion of the leucaena psyllid in the mid-1980s has greatly reduced leucaena productivity. Although productivity is now recovering, adoption remains low due primarily to poor understanding of the farmers' needs and exaggerated expectations from the plant. Other factors are lack of access to credit, land tenure problems, scarcity of land and lack of time for new plantings by over-pressed farmers. In the South Pacific region, a lack of promotion and therefore poor understanding of the benefits of leucaena, as well as insufficient information on the planting, management and use of leucaena has retarded its more widespread adoption. Moog et al. pointed out that improved adoption will be achieved by working more closely with farming communities to identify economic, social and institutional constraints leading to the preparation of more relevant development programs.

Latin America

Since this region is the 'home' of *Leucaena*, it comes as little surprise that indigenous Indian peoples of the region continue to cultivate several species for food (unripe pods), shade, fuelwood, fence posts and construction, and fodder for goats, cattle, pigs and rabbits (Argel et al., these Proceedings). However, these are long-standing traditional uses and despite 10 to 15 years of research showing the potential advantages of leucaena for commercial livestock production and as fuelwood, there is little adoption outside the abovementioned traditional uses. This is despite there being large areas of suitable soils (medium to good fertility) in Central and South America which carry high populations of beef and dual purpose cattle

Argel et al. blame poor awareness by farmers of the potential benefits, lack of technical information on establishment, management and profitability of commercial development, and poorly supported extension programs, for the lack of adoption.

Australia

Larsen at al. (these Proceedings) discussed the great potential for increased plantings of leucaena in Australia. GIS analysis suggests 10 M ha of land suitable for leucaena (H.M. Shelton, unpublished data). There is currently around 50 000 ha planted in northern Australia for commercial beef production. The main areas are in Queensland on fertile clay soils in the 600 to 800 mm rainfall zone, and these highly productive pastures are used to target high value domestic and export markets to Southeast Asia (Larsen et al.).

Leucaena has a high and positive awareness profile in Australia, and adoption is proceeding at a modest pace. The authors note that the high cost of establishment and the high number of establishment failures, due to inadequate weed control, remain important issues.

They suggest a number of technical and social restrictions that impede more rapid adoption. Participatory research and extension approaches have been successful and they suggest the formation of a *Leucaena Growers Association* to educate, promote and assure high quality of their product.

Communication of *Leucaena* R&D

The formation of the Leucaena Research and Development Network (LEUCNET) at the 1994 Bogor *Leucaena* Workshop proved to be a successful and innovative approach to the problem of communication among research and development workers. LEUCNET is a network of scientists and institutions who share common interest in improving the productivity and utility of the *Leucaena* genus. Five issues of the newsletter have been published since July 1995 and there are now over 500 LEUCNET participants. The newsletter is a forum to highlight findings concerning leucaena research and development. It is an important means of linking those with an interest in leucaena worldwide and to some extent has been successful in influencing the direction of research and development in the genus.

Future Opportunities

Participants at the Workshop came from many countries, all with their own knowledge and experiences with *Leucaena*. This provided a unique opportunity to conduct a survey to prioritise future R&D activities. A questionnaire was prepared, circulated and completed by 55 participants (see Table 2). Five key areas were identified for further work (listed below). Groups were formed to discuss key issues in each of

Table 2. Survey questionnaire showing priority scores for future R&D work with *Leucaena* spp. (number of completed questionnaires was 55).

Priorities for Future R&D in the *Leucaena* Genus
(participants allocated 50 points according to their future priorities for R&D work on *Leucaena*)

Priority topics	Priority points for Individual topics	Overall priority for section
TAXONOMY and GENETIC RESOURCES		
Systematics	0.1	
Genetic resource property rights	0.4	
New seed collection of specific taxa eg. *L. collinsii*	0.9	
Study of cytogenetics and origins of tetraploid species	0.0	
Study of breeding systems	0.8	
Study of occurrence of spontaneous hybrids	0.4	
Development of genetic conservation methods	1.0*	
Colchicine doubling to produce new 4n's	0.1	3.8
AGRONOMY		
Plant evaluation of specific taxa e.g. *L. collinsii*	1.2*	
Develop new hybrids of *L. leucocephala*	0.9	
Study mechanisms of psyllid resistance	0.7	
More work on biological control of psyllids	0.8	
Study environmental reasons for build-up of psyllids	0.5	
Continue search for cold tolerance cultivars	0.8	
Continue search for acid soil tolerance cultivars	0.9	
Field studies of *Rhizobium* effectiveness	0.8	
Develop methods for vegetative propagation of hybrids	2.5**	
Develop methods for seed production of KX2 hybrids	2.6**	
Develop seedless triploids	0.9	
Methods for control of weed *Leucaena*	0.9	
Study problem of acidification	1.1*	
Control of pests other than psyllids	0.1	
Work on control of weeds in young *Leucaena*	0.6	
Evaluation of gum production	0.1	
Distribution/production of *Rhizobium* inoculum	0.2	15.5
WOOD QUALITY		
More study of wood quality	0.8	
More work on wood production of *Leucaena*	0.4	
Management for hardwood production	0.1	1.3
FORAGE QUALITY		
Study of environmental effects on tannins in plants	1.4*	
Study of *Leucaena* for monogastrics	0.9	
New analytical procedures for proximate analysis	0.3	
More long-term palatability studies	0.6	
Studies on protein binding ability of tannins	1.9*	
Study methods to manage trees to maximise intake	2.1**	
Study capacity of trees to survive direct grazing	0.9	
Evaluate *Leucaena* for dairy production	2.5**	
Study grazing value of KX2	1.8*	
Study of effects of feeding *Leucaena* on breeding cows	1.5*	
Metabolic effects of secondary metabolites	0.1	
Tannin on endogenous protein loss	0.1	
Grazing studies with different leucaenas	0.3	14.2
FARMING SYSTEMS and ON-FARM ACTIVITIES		
Seed multiplication best accessions	3.6***	
On-farm testing of KX2 hybrids and triploids	2.0**	
On-farm evaluation of other taxa eg. *L. collinsii*	2.2**	
Education programs on management and use of *Leucaena*	2.9**	
Economics of establishment of *Leucaena*	2.1**	
Compare *L. collinsii* with indigenous MPTs	1.1*	
Providing inoculum to farmers	0.0	13.9
Total scores	49	49

* Priority rating 1–2 ** Priority rating 2–3 *** Priority rating >3

these priority areas and the outcomes are presented below.

Taxonomy and genetic resources

There was recognition that all are dependent on genetic resources and that seed needs to be available when required. It was agreed that new methods of conservation were not necessary (in situ, ex situ, circa situm methods were available) but that there is a need for more resources for conservation including recognition of the role of farmers, communities and countries in the conservation process.

The group reported an acute need to diversify genetic material in commercial use. However, present holdings of *Leucaena* germplasm were regarded as adequate for important species such as *L. leucocephala, L. collinsii, L. pallida* and *L. trichandra.* Until it has been established that available variation is inadequate there is no need for further collections or high-tech solutions.

In view of the importance of the KX2 hybrid, further investigation of other hybrid combinations may be useful and, in particular, production of sterile triploids to reduce weed risk will be important. Development of weed eradication and management strategies for weed leucaena is necessary.

Propagation methods for best accessions

Participants reported that production of high quality seeds of the best accessions, and vegetation propagation methods for the outstanding KX2 hybrid, were very high priority. There was a recommendation that the production of foundation seeds might occur with LEUCNET oversight to ensure genetic purity. This could be further aided by a *Seed Production Protocol Manual.* It was suggested that there were advantages in focussing international funding to an institute (e.g., ICRAF).

The group recommended that research priorities should centre on methodologies for propagation of the hybrid varieties both vegetatively and by seed. This latter objective would be expedited if a self-incompatible form of *L. leucocephala* or male sterility in any of the species, could be found. There may even be scope to breed for clonability.

To date, there appears to be little variation in the wood quality within species in the genus. A search for high value, high quality wood *Leucaena* may be fruitful.

Forage quality and animal production

Condensed tannins

This group noted that tannins could waste protein! The overall aim of tannin management should be to maximise protein retention by the animal. Key priorities are to determine maximum tolerable level. This needs to be done using in vivo metabolic studies involving forages with different (known) tannin levels, and with goats and cattle.

Work presented at the workshop showed that tannin concentrations in *Leucaena* will be affected by season, management, post-harvest processing (leaf meal, wilting), nutrient supply, and herbivory and that these effects were poorly understood. The group noted that tannin binding ability varied with species and that there were a number of amelioration methods available including the use of PEG, mineral complexation, and mixtures of high tannin forages with tannin-free forages (high-protein).

Animal production

Evaluation of the feeding value of KX2s in feeding and grazing trials are clearly of highest priority. The agronomic value of this material is outstanding yet relatively little is known about its feeding value except that it is likely to be intermediate between both parents (*L. leucocephala* and *L. pallida*). There is a need to ensure that the long-term palatability of the KX2 is satisfactory in view of problems occurring with *L. pallida.*

Other priorities identified were improved understanding of plant and animal management factors giving the most desirable intake of *Leucaena* to maximise animal productivity. It was noted that there is still uncertainty as to whether some countries have the DHP degrading rumen 'bug' *Synergistes jonesii.*

On-farm evaluation

This group recommended the need for on-farm testing of the outstanding germplasm including the KX2, KX3 hybrids and *L. collinsii* in diverse farming systems. They emphasised the need for readily available planting material of the new KX2 hybrids and they preferred seed to clonal cuttings because of ease of dissemination. Possible priority systems include the upland farming systems in Southeast Asia and Africa for both fodder and fuelwood, and extensive systems in PNG and Australia. This would be greatly assisted by preparation of planting and management manuals

The group emphasised the need to establish seed multiplication orchards of new elite germplasm and to initiate pilot 'on farm' evaluations of the new accessions using participatory approaches. Another group suggested various extension approaches including small groups of farmers making farm visits to demonstrations sites, with adequate one-on-one contact to achieve trust and confidence.

Education and economics

The survey identified the need for education programs on the use of *Leucaena* including information on the economics of establishment and management of *Leucaena*. The group recommended cost/benefit analysis of *Leucaena* systems separating short term, intermediate and longer term issues. They recommended a more commercial and professional sales approach to extension and education using farmer testimonies emphasising the profitability of *Leucaena* systems. They suggested that scientists may not have the appropriate skills for this task.

In another discussion, it was agreed that continuation of *Leucnet News* to promote *Leucaena* R&D was a priority.

Reference

Bray, R.A., Hughes, C.E., Brewbaker, J.L., Hanson, J., Thomas, B.D. and Ortiz, A. 1997. The World Leucaena Catalogue, Department of Agriculture, The University of Queensland, Brisbane, Australia, 48 p + diskette.

Taxonomy and Agronomy

Presented Papers

Taxonomy of *Leucaena*

C.E. Hughes[1]

Abstract

The scope and fundamental importance of systematic studies are outlined and a recent systematic investigation of *Leucaena* is reviewed. Recent taxonomic research shows that *Leucaena* comprises 22 species, six infraspecific taxa (subspecies and varieties) and two named hybrids. The background to and basis for delimitation of 22 species is explained and justified. Specific implications for name changes to well-known species are clarified in detail. Three hypotheses of species relationships and evidence pertaining to the origins of the four known tetraploid species are presented and discussed. Finally, pointers are provided to three major taxonomic outputs, a new taxonomic monograph of *Leucaena*, a Genetic Resources Handbook and a botanical database — the BRAHMS Monograph Series: *Leucaena*.

THE terms *systematics* and *taxonomy* are often used interchangeably to refer to the science of discovery, description, comparative biology and classification of species. Any systematic study comprises several components. Firstly, it involves the delimitation and description of species in answer to the basic question — **what species are there in the study group?** Species description precedes comparative study of morphological and molecular variation to **analyse species relationships**. A scheme of relationships, presented as a hierarchical branching diagram is used to construct a **classification**.

Most analyses of relationships among taxa rely on cladistic methods, sometimes referred to as phylogenetic systematics. Cladistics is an objective and maximally informative systematic discovery procedure that reveals hierarchical order in character data. This allows natural (or monophyletic) groups supported by the maximum number of shared characters (synapomorphies) to be identified and recognised in classifications.

The product of a systematic study is a classification presented in an efficiently retrievable form, such as **a taxonomic account, monograph or biodiversity database**. Taxonomic accounts cover the organisation and history of diversity, providing data on what species there are, where these species occur, what characteristics and properties they have and how are they related.

For economically important plant groups, such as *Leucaena*, clear knowledge and documentation of species diversity directs both the search for close relatives of widely planted species that are the source of new genetic diversity, and the setting of priorities for conservation.

On a more prosaic level, classifications provide the scientific names that are the universal language for communication among agronomists, foresters, agroforesters, crop and tree breeders, natural resource managers, conservation biologists and ecologists, as well as the basis for developing identification tools and a reliable backbone upon which to locate and synthesise applied data on species characteristics. Systematics thus provides important foundations for all efforts to conserve, utilise and improve plant genetic resources.

In an ideal world, taxonomic research to discover, delimit and describe species, understand their relationships and map their distributions should precede efforts to assemble seed collections. In practice, this is never the case. The two proceed hand-in-hand. Field exploration and seed collection expeditions provide insights into taxonomy and material for taxonomic research, which subsequently suggests how collection strategies might be refined, or what new collections of previously unknown or poorly known species are needed. This has been very much the case for *Leucaena*.

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Systematic field exploration and collection of *Leucaena* started in 1961. By the early 1980s, the University of Hawaii and CSIRO in Australia had already assembled two large seed collections of *Leucaena*, and new seed collections were contemplated. At the same time, a substantial program of applied research was underway to investigate the agronomy, silviculture, artificial crossability, *Rhizobium* affinities, cytology, fodder quality and site adaptability of species of *Leucaena*. In spite of this intense applied research activity and ever expanding promotion of *Leucaena* planting, basic taxonomic knowledge remained lacking. There was no up-to-date taxonomic revision of the genus; new species were being discovered, old neglected species rediscovered, and the origin of the most widely cultivated species, *L. leucocephala*, remained unknown. In short, it was clear that the utilisation, breeding and conservation of *Leucaena* genetic resources were resting on shaky foundations.

The past decade has seen a period of intense research activity to investigate diversity in *Leucaena*. Intensive field exploration, collection of seed and botanical specimens, and ethnobotanical survey (Casas and Caballero 1996; Zárate 1997; Hughes 1998a) have been carried out in the natural populations of *Leucaena* throughout its range in 11 countries in Latin America. Molecular techniques have been applied for the first time to examine species relationships, the origins of tetraploid species and hybrids (Harris et al. 1994a; Hughes and Harris 1994) and patterns of genetic diversity within species (e.g., Harris et al. 1994b; Chamberlain et al. 1996).

A botanical database of *Leucaena* containing data on 2800 herbarium specimens has been built. Taxonomic research to delimit species, analyse their relationships (Harris et al. 1994a; Hughes 1998b) and resolve synonymy has been completed and compiled as a new taxonomic monograph of the genus (Hughes 1998b). Spontaneous hybrids have been analysed and identified (Hughes and Harris 1994; 1998) and new species and subspecies discovered, described and named (Brewbaker 1987a; Zárate 1984a, 1987a, 1987b, 1994; Hughes 1986, 1988, 1991, 1997a; Hughes and Harris 1994; 1998). Generic relationships have been analysed to establish whether *Leucaena* forms a natural group (Luckow 1997; Hughes 1998b). The conservation status of *Leucaena* species has been assessed systematically for the first time (Hughes 1998a). In short, knowledge of the genus, its systematics and genetic diversity has been transformed; shaky foundations have been reinforced.

Results of all this research, along with applied data on species characteristics, seed collections and domestication have been assembled, synthesised and presented in a single, readily accessible Genetic Resources Handbook (Hughes 1998a) for all those concerned with the cultivation, utilisation, improvement and conservation of the genetic resources of *Leucaena*.

This paper is based on, but much modified from Chapter 2 of that Handbook. The aim of this paper is to provide pointers to the published outputs of recent taxonomic research rather than duplicate their contents and repeat the results in detail.

Species Delimitation

Perhaps the most surprising and significant outcome of recent taxonomic research for *Leucaena* growers and applied researchers is that the number of species in the genus has increased from 17 (as recognised by Hughes and Harris (1995) in the Proceedings of the *Leucaena* Workshop held in Bogor, Indonesia in 1994) to 22.

In the recent taxonomic monograph (Hughes 1998b) *Leucaena* is shown to comprise 22 species, six named infraspecific taxa (subspecies and varieties) and two named hybrids. New species and name combinations to account for these taxa (apart from the hybrid species) were published in advance (Hughes, 1997a) of the new taxonomic monograph to facilitate their use in the Genetic Resources Handbook (Hughes 1998a) and the World Leucaena Catalogue (Bray et al. 1997).

Accepted names for the 22 species and six infraspecific taxa with their synonyms, following Hughes (1998b), are listed in Table 1. Given the turbulent taxonomic history of *Leucaena* in terms of numbers of species (ranging from 10 to 39 over the last century), it would be reasonable to ask — why does the number of species vary? — why do some well-known species change their names and status? — what expectation is there that these latest changes will result in greater stability in years to come? The background to, and justification and basis for, delimitation of 22 species, are explained below.

The genus *Leucaena* was established by Bentham (1842) with four species: *L. glauca*, *L. pulverulenta*, *L. diversifolia* and *L. trichodes*, all previously placed in *Acacia*. Following Bentham's later recognition of six (Bentham 1846), then nine species (Bentham 1875), four botanists, each with a different approach to species delimitation, Nathaniel Britton and Joseph Rose, James Brewbaker and Sergio Zárate, have figured prominently in the classification of *Leucaena*. The number of species recognised has varied from ten to 39.

After Bentham's (1875) revision, field exploration over the next 50 years led to the description of many supposed new species and culminated in the

Table 1. *Leucaena* species, infraspecific taxa, and their synonyms recognised by Hughes (1998b). A complete checklist of all accepted names, synonyms, their place of publication and type specimens is presented by Hughes (1998a)

Recognised species and authorities	Recognised infraspecific taxa	Synonyms (excluding basionyms)
L. collinsii Britton & Rose	subsp. *collinsii*	*L. esculenta* (Sessé & Moc. ex DC.) Benth. subsp. *collinsii* (Britton & Rose) S. Zárate
	subsp. *zacapana* C.E. Hughes	—
L. confertiflora S. Zárate	var. *confertiflora*	—
	var. *adenotheloidea* (S. Zárate) C.E. Hughes	*L. confertiflora* S. Zárate subsp. *adenotheloidea* S. Zárate
L. cuspidata Standley	—	*L. cuspidata* Standley subsp. *jacalensis* S. Zárate
L. diversifolia (Schltdl.) Benth.	—	*L. diversifolia* (Schltdl.) Benth. subsp. *diversifolia sensu* Pan (1988) *L. brachycarpa* Urban *L. laxifolia* Urban
L. esculenta (Sessé & Moc. ex DC.) Benth.	—	*L. confusa* Britton & Rose *L. doylei* Britton & Rose
L. greggii S. Watson	—	—
L. involucrata S. Zárate	—	—
L. lanceolata S. Watson	var. *lanceolata*	*L. microcarpa* Rose *L. brandegeei* Britton & Rose *L. cruziana* Britton & Rose *L. palmeri* Britton & Rose *L. pubescens* Britton & Rose *L. purpusii* Britton & Rose *L. sinaloensis* Britton & Rose *L. sonorensis* Britton & Rose *L. nitens* M.E. Jones
	var. *sousae* (S. Zárate) C.E. Hughes	*L. lanceolata* S. Watson subsp. *sousae* S. Zárate
L. lempirana C.E. Hughes	—	—
L. leucocephala (Lam.) de Wit	subsp. *leucocephala*	*L. glauca* (Willd.) Benth. *L. latisiliqua sensu* Gillis & Stearn
	subsp. *glabrata* (Rose) S. Zárate	
	subsp. *ixtahuacana* C.E. Hughes	
L. macrophylla Benth.	subsp. *macrophylla*	*L. macrocarpa* Rose *L. houghii* Britton & Rose *L. nelsonii* Britton & Rose *L. macrophylla* Benth. subsp. *nelsonii* (Britton & Rose) S. Zárate
	subsp. *istmensis* C.E. Hughes	—
L. magnifica (C.E. Hughes) C.E. Hughes	—	*L. shannonii* J.D. Smith subsp. *magnifica* C.E. Hughes
L. matudae (S. Zárate) C.E. Hughes	—	*L. esculenta* (Sessé & Moc. ex DC.) Benth. subsp. *matudae* S. Zárate
L. multicapitula Schery	—	—
L. pallida Britton & Rose	—	*L. dugesiana* Britton & Rose *L. oaxacana* Britton & Rose *L. paniculata* Britton & Rose *L. esculenta* (Sessé & Moc. ex DC.) Benth. subsp. *paniculata* (Britton & Rose) S. Zárate

Table 1. *Leucaena* species, infraspecific taxa, and their synonyms recognised by Hughes (1998b). A complete checklist of all accepted names, synonyms, their place of publication and type specimens is presented by Hughes (1998a) continued

Recognised species and authorities	Recognised infraspecific taxa	Synonyms (excluding basionyms)
L. pueblana Britton & Rose	—	—
L. pulverulenta (Schltdl.) Benth.	—	—
L. retusa Benth.	—	*Acacia sabeana* Buckley
L. salvadorensis Standley ex Britton & Rose	—	—
L. shannonii J.D. Smith	—	—
L. trichandra (Zucc.) Urban	—	*L. stenocarpa* Urban *L. diversifolia* (Schltdl.) Benth. subsp. *stenocarpa* (Urban) S. Zárate *L. guatemalensis* Britton & Rose *L. revoluta* Britton & Rose *L. standleyi* Britton & Rose *Acacia albanensis* Britton & Rose
L. trichodes (Jacq.) Benth.	—	*L. canescens* Benth. *L. pseudotrichodes* (DC.) Britton & Rose *L. colombiana* Britton & Killip *L. bolivarensis* Britton & Killip *L. trichodes* (Jacq.) Benth. var. *acutifolia* Macbride

revisions of Standley (1922), who recognised 15 species and Britton and Rose (1928), who alone added 24 species, bringing the total to 39. Britton and Rose (1928) based their delimitation of species on characters that are now viewed as unreliable, either because they present continuous patterns of variation across species (e.g., leaf, leaflet and pod dimensions) and are therefore not amenable to anything but arbitrary division, or because they vary within populations that are otherwise constant (e.g., leaf and pod pubescence). In the absence of rangewide sampling, they failed to detect the continuities and population variation that are now obvious. The result was a proliferation of supposed new species.

James Brewbaker and colleagues at the University of Hawaii made the first attempt to rationalise this proliferation of species. Their knowledge of *Leucaena* was gained from several seed collection expeditions and their work on genetic improvement of *Leucaena* species through hybridisation from the 1960s onwards. They adopted an approach to species delimitation, based on observation of material in cultivation in Hawaii and on crossability, and reduced the number of species recognised initially to 10 (Brewbaker and Ito 1980), with gradual reacceptance of additional species to 16 as they were added to the Hawaii collection (Brewbaker 1987a, 1987b; Brewbaker and Sorensson 1994). The criteria used by Brewbaker and colleagues to delimit species (Brewbaker et al. 1972; Brewbaker and Ito 1980; Brewbaker 1987a; Brewbaker and Sorensson 1994) were never explicitly stated and no formal taxonomic account was produced. What is clear, however, is that Brewbaker maintained a sceptical view of the validity of any species until he had collected material of it himself and observed its progeny in cultivation in the Waimanalo arboretum in Hawaii. Additional species were acknowledged only with some reluctance during the 20 years after his initial acceptance of 10.

Sergio Zárate of the National University of Mexico, worked on *Leucaena* initially for the Flora of Oaxaca, later collecting more widely with the Australian forage germplasm collector Bob Reid. From the 1970s onwards, he has continued to investigate the taxonomy, ethnobotany and indigenous domestication of the Mexican species of *Leucaena* as minor food plants (Zárate 1982, 1984a, 1984b, 1987a, 1997), work which culminated in publication of a taxonomic revision of the Mexican species (Zárate 1994). This revision included two new species, four new subspecies and five new combinations, four of them based on species recognised by Britton and Rose.

Zárate's approach to species delimitation relied on extensive use of subspecies. Zárate (1994) justified this by the frequent occurrence of interspecific hybridisation in *Leucaena*, and the unusual '*abundance of incipient allopatric speciation*' (Zárate

1994: 88), which he attributed to the complex biogeographical history of the region. Subspecies were viewed as a solution to these perceived difficulties. Zárate also apparently saw subspecies as a mechanism to indicate relationships reflected in his belief that '*a classification exclusively of distinct species is of no benefit either to the interested scientist, or for communication of this knowledge to the user community*' (Zárate 1994: 88, translated from Spanish). Zárate further mentioned ease of identification (to species) with certainty, as more than compensating for the inconvenience caused by a system composed mainly of subspecies.

Although this marked variation in numbers of recognised species and in the importance given to subspecific ranks by different authors is partly attributable to the history of collection and species discovery, it is mainly a function of differing views about what constitutes good character evidence for species or infraspecific taxa. The aim in delimiting species (Hughes 1997a; 1998b) has been to name, as species, all the diagnosable entities based on all available qualitative, or discrete, character states which appear to be fixed within and among populations. Such an approach emphasises distinctions rather than similarities as pursued by Zárate (1994) so that well-formed and incipient species are circumscribed, thus allowing finer distinction of useful variants, important units for conservation and identification of biogeographic patterns. This author has used an explicit pattern-based species concept — the so-called phylogenetic species concept (Rosen 1979; Eldredge and Cracraft 1980; Nelson and Platnick 1981; Cracraft 1983; Nixon and Wheeler 1990), which recognises species that possess constant and unique character states or unique combinations of character states.

Much new morphological data have been gathered (Hughes 1998b) providing additional field, macromorphological and microscopic characters. Many of these characters have proved useful in species delimitation. For example, investigation of pollen and another morphology using Scanning Electron Microscopy revealed a suite of discrete character states which unequivocally separate *L. multicapitula*, previously considered as doubtfully distinct from *L. trichodes* (Hughes 1997b).

Process-based (hybridisation, crossability, domestication, physiology), as opposed to pattern-based (morphological) evidence, has not been used directly in species delimitation. Quantitative characters, because they vary continuously within and among species and show overlapping variation when viewed across the genus as a whole, do not provide an objective basis for species delimitation and have only been used at infraspecific level. Subspecies were used for entities which are distinguished by several quantitative traits and which are clearly correlated with geography (e.g., *L. collinsii*). Varieties were used for entities which differ in several quantitative traits but which are not correlated with geography (e.g., *L. lanceolata*) or for which the geographic limits of the variants are poorly known. Although there is ample evidence for hybridisation within *Leucaena* (Zárate 1994; Sorensson and Brewbaker 1994; Hughes and Harris 1994; 1998), infraspecific taxa provide no solution to the problem of naming hybrids.

Zárate's second contention that subspecies are an effective way to indicate groups of closely related taxa, is again little substitute for an informed analysis of species relationships and presentation of an explicit hypothesis of relationships in the form of a hierarchical branching diagram (see Figure 2).

The result of applying a rigorous, pattern-based morphological species concept across the genus as a whole, using the full spectrum of available morphological characters, and critically re-evaluating quantitative characters is that many of the species described by Britton and Rose are not now recognised as distinct and their names are treated as synonyms (Table 1; Hughes, 1997a; 1998b). In contrast, some of the subspecies recognised by Zárate (1994) qualify as distinct species. Important changes which are potential sources of taxonomic confusion are clarified in detail as follows:

L. diversifolia

The known tetraploid and diploid taxa, treated in the past as subspecies of *L. diversifolia* (Brewbaker 1987a; Pan and Brewbaker 1988; Zárate 1994), are now recognised as distinct species, *L. diversifolia* (tetraploid) and *L. trichandra* (diploid) (Hughes and Harris 1995; Hughes 1998a; 1998b). The name *L. diversifolia* subsp. *diversifolia*, previously used by Brewbaker (1987a), Pan and Brewbaker (1988), Zárate (1994), and Harris et al. (1994a) and in the early distribution of OFI seedlots (notably ident Nos. 45/87 and 46/87) (Hughes 1993), is now replaced simply by *L. diversifolia*. Previously the diploid taxon was recognised as *L. diversifolia* subsp. *stenocarpa* (Zárate 1984a; 1994). This name was used by Hughes (1993), Harris et al. (1994a) and applied to the OFI *Leucaena* seed (notably ident Nos. 35/88 and 53/88) distributed up to 1996. However, Pan (1985, 1988), Pan and Brewbaker (1988) and Brewbaker and Sorensson (1994) used the name *L. diversifolia* subsp. *trichandra*. The correct name for the diploid taxon, which is now recognised as a distinct species, is *L. trichandra* (Hughes 1998a; 1998b).

L. pallida

Although Brewbaker (1985, 1987a), Zárate (1994) and Hughes (1993) all agreed that the four species described by Britton and Rose (1928), *L. dugesiana, L. oaxacana, L. pallida* and *L. paniculata* are the same thing, there has been disagreement about the accepted name and whether it should be treated as a separate species, or a subspecies of *L. esculenta*. It was originally designated as *L. paniculata* in the CSIRO *Leucaena* seed collection (Bray[1], pers. comm), as *L. esculenta* subsp. *paniculata* by Zárate (1984a, 1994) and as *L. pallida* by Brewbaker and colleagues in Hawaii. Hughes (1993) originally followed Zárate (1984a) and used the name *L. esculenta* subsp. *paniculata* in the OFI seed distribution. The correct name for this taxon has now been clarified and justified as *L. pallida* by Hughes (1998b), in line with the majority of recent agronomic literature (Brewbaker 1987b; Brewbaker and Sorensson 1994).

L. magnifica* and *L. matudae

Both these species were originally described as subspecies (*L. shannonii* subsp. *magnifica* and *L. esculenta* subsp. *matudae* respectively) and OFI seed was distributed under these names up to 1996. Adoption of a uniform, pattern-based species concept has meant that these two subspecies now qualify as distinct species based on unique morphological characters, or combinations of characters (Hughes 1997a; 1998b).

L. leucocephala

Variation within *L. leucocephala* was first noted by agronomists evaluating different accessions for fodder production (e.g., Brewbaker et al. 1972). Two main variants, based primarily on habit, branchiness and vigour were recognised: firstly, a shrubby, low growing, highly branched, seedy, and often weedy, variant designated the '*Common* type'; secondly, an erect, arborescent, lightly branched, less seedy variant designated the '*Giant*' or '*Salvador* type' (Brewbaker et al. 1972; Brewbaker 1980; Brewbaker 1987b). These variants were formally recognised as distinct subspecies by Zárate (1987a). The two subspecies recognised by Zárate (1987a) correspond directly to the agronomic types viz: subsp. *leucocephala* = '*Common* type'; subsp. *glabrata* = '*Giant*' or '*Salvador*' type. A third agronomic variant, the so-called '*Peru* type' also belongs with subsp. *glabrata*. During a recent exploration by Hughes and collaborators in northern Guatemala, an additional variant, which differed from both subsp. *leucocephala* and *glabrata*, was encountered and described as a third subspecies named *ixtahuacana* by Hughes (1997a).

L. collinsii* subsp. *zacapana

Pre-1991, this taxon, native to the Motagua Valley system in southeast Guatemala, was confused with *L. diversifolia*. Seed of *L. collinsii* subsp. *zacapana* distributed from OFI (Ident Nos 15/83 and 18/84) during the 1980s was misidentified as *L. diversifolia*. This name was also wrongly used by the regional, CATIE-based MADELENA project in all its research activities with this taxon in Central America.

Species Relationships

Understanding of species relationships, based on analysis of comparative morphological and molecular data, provides the basis for classification. There are three published analyses of species relationships within *Leucaena* — Zárate's (1984a, 1994) division of the genus into two sections, an analysis of chloroplast DNA variation by Harris et al. (1994a) and a cladistic analysis of 29 morphological characters by Hughes (1998b).

Zárate (1984a) suggested dividing the genus into two sections based on three conspicuous leaf characters — leaflet size, number of pinnae, and shape of petiole gland. This informal division was claimed by Zárate (1984a: 27) to be *'somewhat natural'* although the problematic position of *L. shannonii* with its polymorphic leaflets which are intermediate between the two sections was recognised. The two sections were formally designated by Zárate (1994) as section Macrophylla, typified by *L. macrophylla*, comprising *L. macrophylla, L. lanceolata, L. shannonii, L. retusa* and *L. trichodes*, and section Leucaena, typified by *L. leucocephala*, comprising the remaining species.

Harris et al. (1994a) produced the first explicit hypothesis of relationships within *Leucaena* based on chloroplast DNA variation. This scheme of relationships shows three major groups (Figure 1) and does not support the sectional classification of Zárate (1994). Cytoplasmic DNA phylogenies may differ from species phylogenies particularly where there has been hybridisation and introgression (Doyle 1992). Given that there is considerable evidence that hybridisation has been important in *Leucaena*, the cpDNA tree (Figure 1) should be treated as a 'gene tree' and not a 'species tree'. This also means that it is difficult to compare directly the morphological tree (Figure 2) with the cpDNA tree, or to combine the two as an integrated scheme of relationships.

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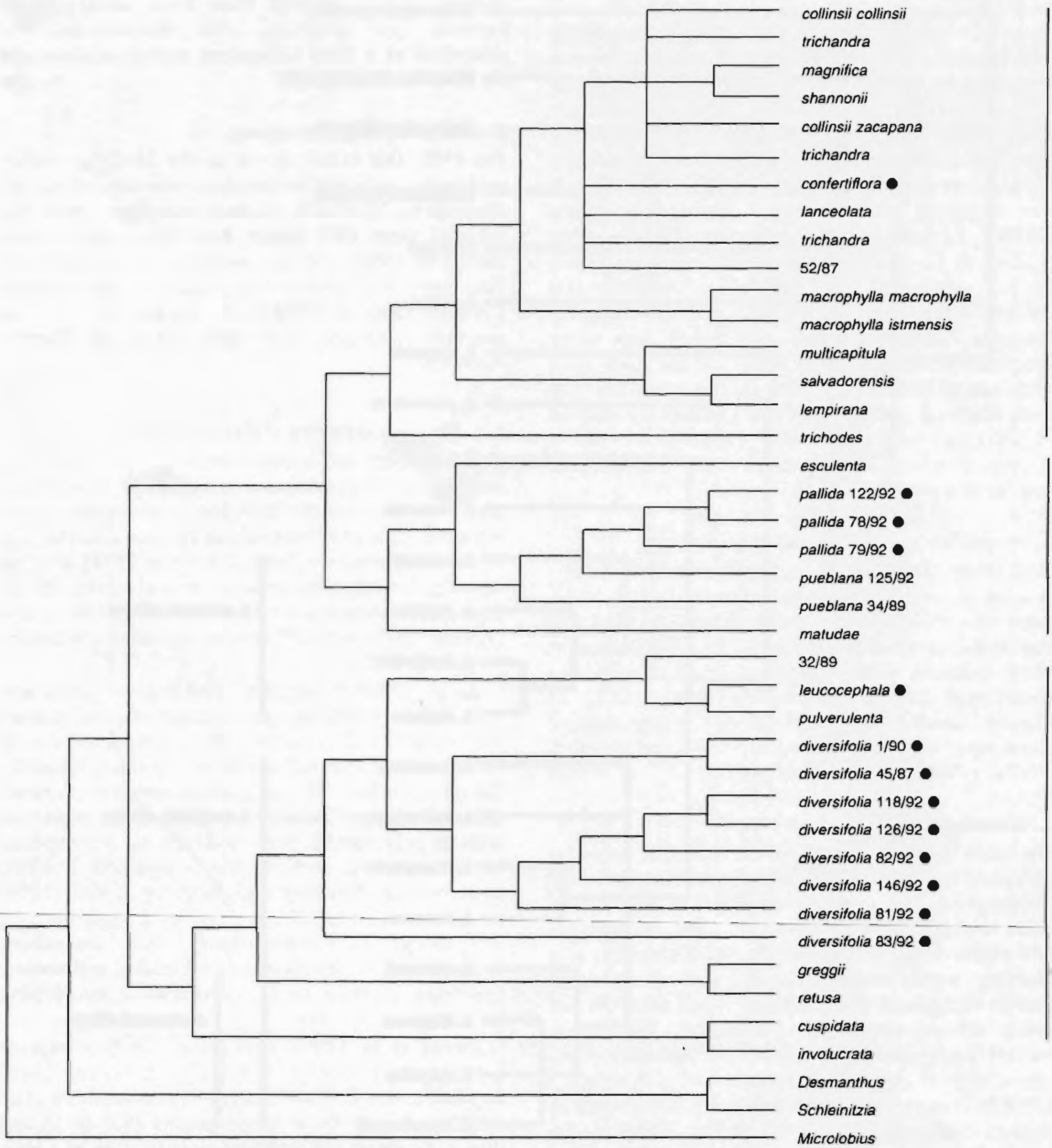

Figure 1. Analysis of chloroplast DNA and origins of tetraploid species. Scheme of relationships derived from analysis of chloroplast DNA variation. Tetraploid accessions are marked ●. Numbers refer to OFI seed accession numbers — see Hughes (1998a) for details (modified from Harris et al. 1994a).

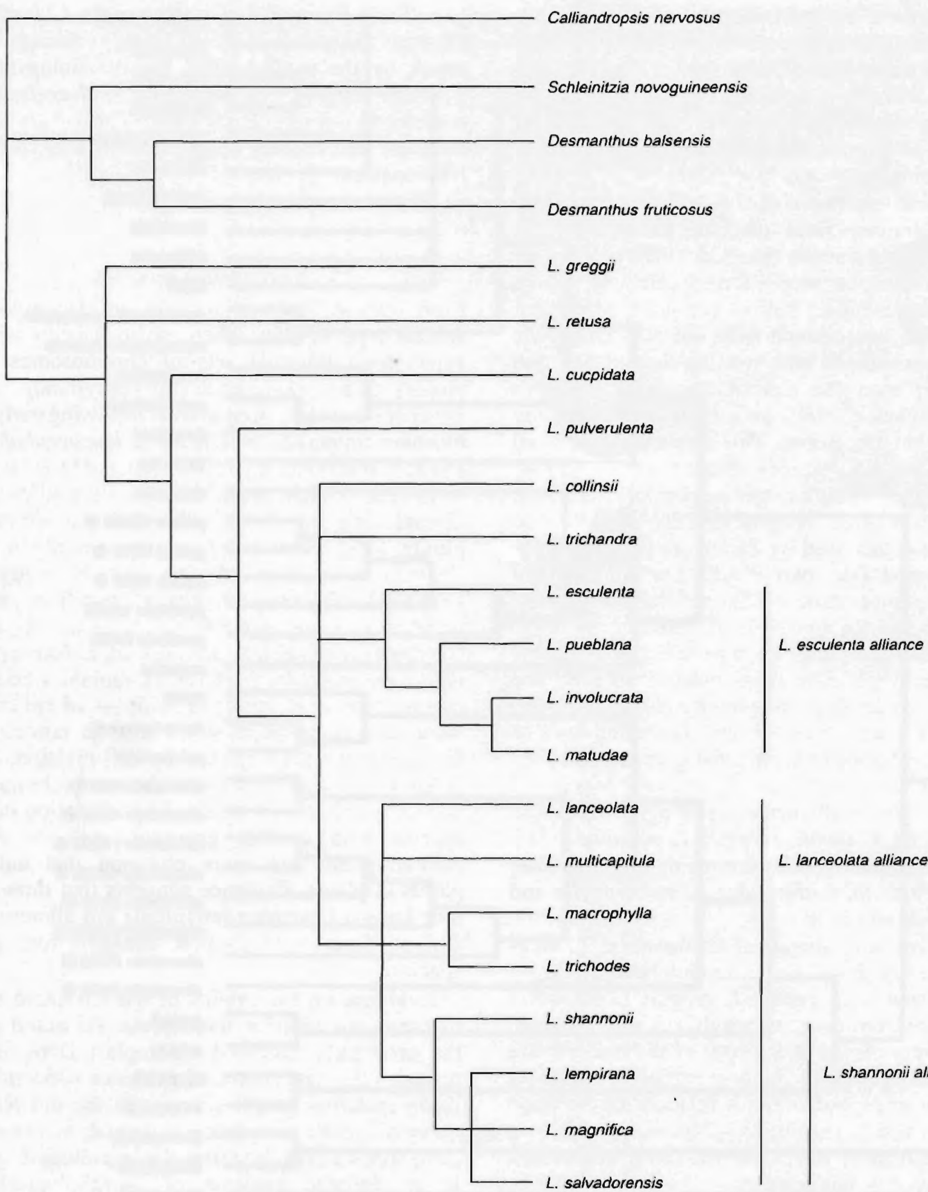

Figure 2. Species relationships in *Leucaena*. Scheme of relationships of diploid species hypothesised by cladistic analysis of 29 morphological characters showing three species groups within *Leucaena* (modified from Hughes 1998b).

However, known maternal inheritance (Harris et al. 1993), while limiting the usefulness of cpDNA in estimating species relationships, makes it particularly useful for detecting cases of hybridisation and for determining the maternal parent of tetraploid species originating as hybrids between two diploid species (allotetraploids).

The third scheme of species relationships (Figure 2) derived from cladistic analysis of 29 morphological characters (Hughes 1998b) shows no support for the two sections designated by Zárate (1994). It shows broad, but not complete, agreement with the gene tree derived from cpDNA. Given the difficulties associated with treating the cpDNA tree as a species tree, the morphological analysis was used by Hughes (1998b) as a basis for classifying species within the genus. This scheme is favoured over the sectional classification of Zárate (1994) because it is based on a larger number of characters: 29 rather than three. Hughes (1998b) also showed that the characters used by Zárate are not satisfactorily partitioned into two states. Leaflet size and number of pinnae show continuous variation across species and are not amenable to anything but arbitrary division. Also variation in petiole gland shape is divided into three basic types rather than two. The scheme of relationships adopted by Hughes (1998b) identifies a number of groups or 'alliances' of closely related species within the genus (Figure 2). These include:

- the *L. esculenta* alliance comprising *L. esculenta, L. pueblana, L. involucrata* and *L. matudae*.
- the *L. lanceolata* group comprising *L. lanceolata, L. multicapitula, L. trichodes, L. macrophylla* and a subgroup within it:
- the *L. shannonii* alliance of *L. shannonii, L. magnifica, L. lempirana* and *L. salvadorensis*.
- the four species, *L. retusa, L. greggii, L. cuspidata* and *L. pulverulenta*, although not a group, are consistently placed at the base of the tree and are hypothesised to be closely related. There is evidence to support a close relationship between *L. retusa* and *L. greggii*.

The relationships of *L. collinsii* and *L. trichandra* are unresolved in this analysis.

It remains to be seen what the predictive value of this classification (Figure 2) will be in terms of either new character data or species characteristics more widely. Two observations are of note at this stage. Firstly, it is known that condensed tannin content of leaves, an important determinant of nutritive value of livestock fodder, varies significantly across species (Stewart and Dunsdon 1998). It is notable that very low (sometimes zero) condensed tannin levels are found for all the species of the *L. lanceolata* alliance and for no other species except the unresolved *L. collinsii*. Secondly, all species of the *L. lanceolata* alliance are moderately or highly susceptible to attack by the psyllid while the remaining species, with the notable exception of *L. pulverulenta*, are moderately or highly resistant. These two applied traits are thus broadly congruent with this scheme of relationships.

Tetraploid species

Chromosome number (ploidy level) provides a special type of data where some species within a genus have multiple sets of chromosomes (polyploids). The occurrence of polyploidy within *Leucaena* has long been known following early chromosome counts (2n = 104) for *L. leucocephala* (Tjio 1948; Frahm-Leliveld 1957; Shibata 1962; González et al. 1967). Subsequent studies showed that both diploids and tetraploids occur and that within each ploidy level there are two chromosome numbers (2n = 2x = 52; 2n = 2x = 56; 2n = 4x = 104; 2n = 4x = 112). While the majority of species are diploid, there are four known tetraploids in *Leucaena*, *L. confertiflora* (2n = 112), *L. diversifolia*, *L. leucocephala*, and *L. pallida* (all 2n = 104). Tetraploid species may originate either as autotetraploids — where chromosome doubling occurs when mitotic chromosomal division is not accompanied by cell division, AA → AAAA — or as allotetraploids where chromosome doubling occurs as a result of hybridisation between species with distinct genomes, AB → AABB. Allotetraploids are more common that autotetraploids in plants. Evidence suggests that three of the four known *Leucaena* tetraploids are allotetraploids derived from hybridisation between two diploid species.

Evidence on the origins of the tetraploid species of *Leucaena* remains incomplete. As noted earlier, the maternally inherited chloroplast DNA analysis provides the best source of evidence concerning the likely maternal parent species. In the cpDNA tree, tetraploid species are likely to appear as sister (adjacent) species to their maternal progenitors (Figure 1). In a cladistic analysis of morphological data, hybrids, with their reticulating evolutionary histories, violate the fundamental assumption that Nature's hierarchy can be effectively represented by a dichotomous branching diagram. For this reason, the four tetraploid species of *Leucaena* were omitted from the initial analysis of morphological data which was carried out including only the diploid species (Figure 2) (Hughes 1998b). However, morphological analysis may still provide some additional data on hybrid (tetraploid) origins by including the tetraploid species one by one in the analysis (Hughes 1998b).

The currently available evidence on the origin of the known tetraploid species of *Leucaena* is summarised below. Further molecular research that may cast light on these origins is in progress (Harris, unpubl.; Hartman and Cocking 1996).

L. leucocephala

The cpDNA data suggest that *L. leucocephala* had *L. pulverulenta*, or a species with the cpDNA type of *L. pulverulenta*, as the maternal parent. The morphological analysis suggested that *L. leucocephala* is a hybrid between two distantly related species, one with large and one (*L. pulverulenta*) with small leaflets. Given the distribution of *L. pulverulenta* in NE and E Mexico, one of the two large leaflet species from that area, *L. lanceolata* or *L. macrophylla*, is the most likely male parent species. Low crossability of *L. macrophylla*, suggests *L. lanceolata* as the most likely second parent species. The possibility that *L. leucocephala* arose in cultivation was suggested and discussed by Hughes and Harris (1995) and Harris *et al.* (1996). Such an origin is compatible with ethnobotanical evidence (Hughes, 1998a). Given the existence of three recognised subspecies of *L. leucocephala* multiple origins with slightly differing parentage are likely.

L. diversifolia

Although Pan (1985) and Pan and Brewbaker (1988) hypothesised *L. diversifolia* to be an autotetraploid derived from *L. trichandra*, the cpDNA data of Harris *et al.* (1994a) showed that this is not the case. *L. trichandra* and *L. diversifolia* have highly distinctive chloroplast genomes and were placed as distantly related on the cpDNA tree (Figure 1). The cpDNA data instead suggest that *L. diversifolia* also had *L. pulverulenta* as its maternal parent (Harris et al. 1994a). *L. pulverulenta, L. leucocephala* and *L. diversifolia* have very similar chloroplast genomes (Hughes and Harris 1998). Morphological analysis placed *L. diversifolia* as sister species to *L. trichandra* indicating that species as a possible paternal parent.

L. pallida

Pan (1985) hypothesised *L. pallida* to be an allotetraploid derived from hybridisation between *L. esculenta* and *L. trichandra* based on morphological intermediacy and geography. The analysis of cpDNA (Harris et al. 1994a) was compatible with that hypothesis until *L. pueblana* was resurrected as a species distinct from *L. pallida* by Hughes (1998b). When *L. pueblana* is recognised, this species becomes the likely maternal progenitor (Figure 1). This is compatible with the morphological analysis which placed these two species as sister species.

L. confertiflora

The origin of *L. confertiflora* remains unknown.

Outputs

Recent taxonomic research has resulted in three major outputs: (i) a new taxonomic monograph of *Leucaena* (Hughes 1998b); (ii) A *Genetic Resources Handbook* (Hughes, 1998a); (iii) a botanical database — the BRAHMS Monograph Series: *Leucaena.*

Taxonomic Monograph

A new taxonomic monograph of *Leucaena* has been completed and published in *Systematic Botany Monographs* (Hughes 1998b). The monograph combines alpha taxonomic descriptive botany with systematic analysis of morphological data and includes discussion of taxonomic history, a full presentation of morphological variation, cladistic analyses of generic and species relationships and a complete taxonomic account. The taxonomic account comprises a key for identification of species, complete synonymy, full descriptions, notes on phenology, distribution and vernacular names, specimen citation lists, botanical drawings and distribution maps.

Genetic Resources Handbook

Formal taxonomic publications, such as the revision of Mexican species (Zárate, 1994) or the recent taxonomic monograph of the genus (Hughes 1998b) are of limited use to foresters, agronomists, breeders, other *Leucaena* growers, ecologists and ethnobotanists, not necessarily botanically trained, who are interested in identifying trees in the field or understanding diversity in terms of useful characteristics of species. Such publications are not widely distributed and available to all. They tend to use a lot of technical jargon and they usually rely on details of flowers and fruits which are generally present on herbarium specimens — and even microscopic characters, such as pollen morphology — but which are not always observable in the field. Finally they usually adopt a strictly taxonomic focus and do not include data on wider aspects of genetic resources, ethnobotany, conservation and domestication.

Recognising the need for more 'user-friendly' products that address the needs of non-botanists and include discussion of the wider issues, a Genetic Resources *Handbook* (Hughes, 1998a) has recently been published. One of the principal aims of that *Handbook* is to clarify the taxonomy of *Leucaena* and facilitate identification of species by non-botanists. To achieve this it includes Chapters on recent taxonomic research, how to identify *Leucaena* species and hybrids (including keys, spot characters and illustrations), and individual species accounts which include descriptions, botanical drawings and distribution maps of all taxa and further notes on taxonomy, as well as updated identifications of all the OFI *Leucaena* seedlots. The *Handbook* also incorporates information on species characteristics (ecogeography, phenology, wood and leaf quality and weediness), ethnobotany and indigenous domestication, hybrids, germplasm collections, seed storage and processing, conservation and domestication.

BRAHMS Monograph Series — Leucaena Version 1. October 1997

One of the products of this new monographic revision is a herbarium specimen database for *Leucaena* assembled using the Botanical Research and Herbarium Management System, BRAHMS (Filer 1996). It is being distributed as the first of a new *BRAHMS Monograph Series*. It includes data on more than 2800 botanical specimens lodged in 26 Latin American, North American and European herbaria. Detailed field notes, common names, phenology and wild/cultivated codes, and duplicate records are included and the majority of specimens (2393) have accurate geographical data (Lat/Long). Full nomenclatural data including name status (accepted, basionym, heterotypic synonym, excluded *etc.*), synonymy and protologues are included in the database. TYPE collections are linked to names. Associated research material (nodules, wood, photos, bruchids, seed, dried leaves *etc.*) is cited.

Data from botanical specimens of *Leucaena* assembled as a user-friendly database provide an invaluable tool for herbarium curation as well as the most detailed and complete source of information to guide future field exploration and collection. Detailed locality data can be retrieved and sorted by species, collector, geographic area (Country, State, Department, Municipality or individual locality), or year of collection, making this a powerful tool for planning collecting expeditions. Such data are particularly useful for day-to-day planning of routes and printouts of all localities by species or region are an essential tool to take to the field. Copies of this database are being distributed to key herbaria and are available from the author. Customised printouts, sorted to user's specification can also be prepared on request.

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Agronomic Adaptation to Environmental Challenges in the Genus *Leucaena*

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Abstract

Growth of 25 accessions of *Leucaena* was assessed in 61 'environments' at 19 sites over a 2.5-year period to identify agronomic adaptation to environmental challenges. From analysis of variance, accessions, 'environments' and accession × environment interaction accounted for 14%, 48% and 26% of the variation respectively. The large environment component of variance reflected the diversity of test environments, from non-limiting to severely limiting. Genotype × environment analysis techniques were used to identify broad and specific adaptation to environmental limitations. The F1 hybrid accession *L. pallida* K748 × *L. leucocephala* K636 was comparatively very high yielding in all environments, and displayed excellent broad adaptation. Other accessions which displayed broad adaptation but at lower yield levels included *L. pallida* CQ3439 and *L. pallida* K376 × *L. leucocephala* K8 F5 hybrid. *L. trichandra* OFI 53/88 displayed specific adaptation to low temperatures in highland tropical environments. No accessions were specifically adapted to strongly acid-infertile soils or to low rainfall. Correlations between dry matter production and six environmental variables attempted to identify the major factors limiting growth of the *Leucaena* genus. Highly significant correlations were found for soil acidity, minimum temperature and psyllid pressure, and of these soil acidity most affected growth.

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COMPREHENSIVE evaluation of the agronomic diversity and adaptation within the *Leucaena* genus became essential following the arrival of the psyllid insect (*Heteropsylla cubana*) in the early 1980s. The psyllid devastated stands of *L. leucocephala*, and highlighted the narrow genetic base of this self-fertilised polyploid (Harris et al. 1994; Sorensson and Brewbaker 1987). New cultivars with broader genetic base were required to overcome the specific limitations of psyllids, low temperatures and acid soils, and to limit possible devastation from future unknown biotic challenges (Harris et al. 1994; Brewbaker and Sorensson 1990).

As part of the ACIAR project PN9433, 'New Leucaenas for Southeast Asian, Pacific and Australian Agriculture', a multi-environment trial (MET) was established to assess the potential within the genus to overcome these edaphoclimatic and biotic limitations. A collection of 120 *Leucaena* accessions, covering the diversity within the genus, was assembled from collections held by the Oxford Forestry Institute (OFI), the University of Hawaii and the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in Australia. This foundation collection was planted at Los Baños in the Philippines and at Brisbane in Australia and results from these experiments are reported separately (Gabunada and Stür; Mullen and Shelton, these Proceedings). A subset of accessions, representative of most taxa in the genus, were selected from the foundation collection for inclusion in the METs at experimental sites throughout Southeast Asia, New Guinea, Australia and Kenya.

The objectives of this study were:

1. To identify accessions of *Leucaena* with broad adaptation to diverse target environments;
2. To identify accessions of *Leucaena* with specific adaptation to environments characterised by low temperatures, acid-infertile soils and high psyllid pressure; and/or
3. To develop an understanding of environmental limitations to growth of *Leucaena*.

For the purpose of this evaluation 'adaptation' refers to the ability of an accession to produce biomass under a regular coppicing regime, in a growth limiting environment, rather than the evolutionary definition which concerns species survival mechanisms. The ability to survive regular coppicing is an essential feature of productive forage trees.

Materials and Methods

Sites and accessions

Twenty-five core accessions, representing 14 species of *Leucaena* and two interspecific hybrid taxa, were selected for evaluation in METs (Table 1) and were planted at 19 sites. Sites were selected to include current *L. leucocephala* production regions, and environments with high and low psyllid pressure, fertile and acid-infertile soils, high and low temperatures and wet and dry environments (Table 2). The inclusion of accessions in the MET was based on the detailed knowledge of the OFI collection of C.E. Hughes and of other collections of H.M. Shelton. For each taxon, the accessions perceived to be high yielding were selected, based on growth in the native range and/or agronomic trials.

The data set was largely balanced, with 23 accessions planted in at least of 16 sites. Seed shortages prevented 9 accessions from being planted at all sites. A standardised protocol was used to maximise genotypic and environmental effects and to minimise management effects on growth.

Planting, management and experimental design

Accessions of *Leucaena* were raised in polybags and subsequently planted into the field between March 1995 and June 1996. *Rhizobium* strain CB3060, an effective strain for diverse species of *Leucaena* (Mullen et al. 1998), was applied to seedlings in the nursery. Field planting dates were selected to correspond with the onset of wet season rains.

Row plots, 5 m long, were planted with seedlings at 50 cm spacings. Plots were maintained in a weed free condition and irrigated, if required, during establishment. After establishment, no further irrigation was applied. With the exception of the strongly acid-infertile sites, no fertiliser was applied. At Nam Suang, plots received 40 kg/ha P and 30 kg/ha N and at Bac Thai, plots received 5 t/ha lime, 100 kg/ha potassium sulphate, 20 kg/ha magnesium sulphate and 200 kg/ha superphosphate. The Tanay and Ha Tay sites included lime/fertiliser treatments in a split plot design as follows: Tanay–2 t/ha lime, and Ha Tay–5 t/ha lime, 100 kg/ha potassium sulphate, 20 kg/ha magnesium sulphate and 200 kg/ha superphosphate.

A randomised complete block design with three replicates was used, except at Tanay, Ha Tay and Bac Thai, where plus and minus liming treatments were incorporated into a split-plot design with two replicates.

Measurements

Dry matter (DM) productivity was assessed over a 2–2.5-year period from planting. Following a 6–10-month establishment period, trees were cut to 50 cm above ground level. Subsequent harvests were scheduled to provide a measure of cumulative growth within a season or 'environment' (e.g., hot or cool, wet or dry), so that DM yield could be related to specific climatic and edaphic conditions (Table 3). Each environment generally spanned 5–7 months and consisted of 1–3 harvests. Harvesting continued until October 1997. In most cases, establishment periods unavoidably spanned more than one season. At each site, growth was measured in a minimum of two, and a maximum of five environments. Total DM yields rather than edible fractions were used for data analysis. This avoided errors in assessing edible yields and bias caused by the scheduling of harvest intervals. Long harvest intervals may preferentially favour the wood component, whereas short intervals favour the edible component (B.F. Mullen, unpublished data).

Table 1. Accession identification, mean DM yields in 61 'environments', accession group membership from cluster analysis, and psyllid resistance for 25 accessions of *Leucaena* evaluated in METs.

Species/subspecies	Accession	DM yield (g/m row/ month)[1]	Accession group[2]	Psyllid resistance[3]
L. pallida K748 × *L. leucocephala* K636	KX2 F1	358	n.a.[4]	2.8
L. pallida	CQ3439	164	1	2.4
L. leucocephala subsp. *glabrata*	K636	161	2	5.1
L. pallida K376 × *L. leucocephala* K8	KX2 F5	156	2	3.2
L. trichandra	OFI 53/88	135	3	1.4
L. pallida	OFI 79/92	134	4	3.1
L. pallida (unknown hybrid)	OFI 52/87	137	4	4.6
L. macrophylla subsp. *istmensis*	OFI 47/85	148	5	3.7
L. salvadorensis	OFI 36/88	133	5	4.5
L. diversifolia K156 × *L. leucocephala* K8	KX3 F2	125	6	5.1
L. lanceolata var. *lanceolata*	OFI 43/85	111	6	5.2
L. leucocephala subsp. *glabrata*	Cunningham	116	6	5.6
L. collinsii subsp. *collinsii*	OFI 52/88	132	7	2.1
L. diversifolia	OFI 83/92	97	7	3.2
L. esculenta	OFI 47/87	109	7	1.9
L. collinsii subsp. *zacapana*	OFI 56/88	79	8	5.0
L. diversifolia	K156	71	8	5.4
L. magnifica	OFI 19/84	66	8	4.4
L. diversifolia	OFI 82/92	47	9	5.1
L. involucrata	OFI 87/92	27	9	4.9
L. lempirana	OFI 6/91	53	9	5.2
L. pulverulenta	OFI 83/87	40	9	4.8
L. trichandra	CPI46568	74	9	1.7
L. trichandra	OFI 4/91	49	9	4.7
L. trichodes	OFI 61/88	53	9	4.4

[1] Refers to group membership from second cluster analysis.
[2] For comparison among accession yield means, LSD ($P<0.05$) = 23.
[3] Rating 1–2 = highly resistant, 2.1-4 = moderately resistant, 4.1–5 = moderately susceptible and 5.1-9 = highly susceptible. (source: B.F. Mullen unpublished data).
[4] Included in initial cluster analysis only.

Table 2. Location soil characteristics and climate for multi-environment trial sites

Site	Country	Latitude	Altitude (m)	Soil pH (1:5 H_2O)	P[1] (mg/kg)	Al sat'n (%)	CEC (meq/ 100g)	Seasons
Brisbane	Australia	27°37'S	10	5.8	200	5	7	Hot/cool
Gayndah	Australia	25°39'S	131	6.7	70	0	29	Hot-wet/cool-dry
Theodore	Australia	24°51'S	150	8.6	13	0	32	Hot-wet/cool-dry
Townsville	Australia	19°38'S	61	6.3	13	0	3	Wet/dry
Kununurra	Australia	15°39'S	43	8.1	19	0	29	Wet/dry
Lae	New Guinea	6°35'S	30	6.4	57	0	23	NDS[2]
Erap	New Guinea	6°45'S	100	6.7	9	0	31	Wet/dry
Aiyura	New Guinea	6°15'S	1700	5.6	8	0	8	NDS
Sungei Putih	Indonesia	3°24'N	50	5.4	3	2	3	NDS
Buon Ma Tuot	Vietnam	12°36'N	150	4.7	93	20	3	Wet/dry
Ha Tay (limed)	Vietnam	21°20'N	20	4.8	17	68	3	Hot-wet/cool-dry
Ha Tay (unlimed)	Vietnam	21°20'N	20	4.8	17	68	3	Hot-wet/cool-dry
Bac Thai	Vietnam	21°36'N	25	4.9	6	39	2	Hot-wet/cool-dry
Los Baños	Philippines	14°13'N	23	6.5	130	0	210	Wet/dry
Lipa City	Philippines	13°09'N	312	5.9	88	0	16	Wet/dry
Palayan City	Philippines	15°29'N	32	6.4	15	0	38	Wet/dry
Tanay (limed)	Philippines	14°36'N	550	4.9	10	55	8	Wet/dry
Nam Suang	Laos	18°12'N	175	4.6	3	71	1	Wet/dry
Machakos	Kenya	1°58'S	1600	6.4	24	0	7	Warm-wet/cool-dry

[1] Colwell P method, [2] NDS = no distinct season

Daily weather data were collected at all sites and converted to mean monthly data for each environment (Table 3). Psyllid damage ratings were collected monthly using the scale of Wheeler (1988). Ratings for the six most susceptible accessions were used to calculate a psyllid pressure index for each environment (Table 3). Acidity and infertility indices were developed for each site from soil analyses data (Table 2). The acidity index (scale 0–6) was based on pH and Al saturation in the 0 to 15 cm soil layer (rating 0 = pH >5.5 and Al saturation ≤25%, 6 = pH ≤4.7 and Al saturation >75%). The infertility index was based on critical concentrations of P, K, S, Ca, Mg, Zn, Fe and Mn and cation exchange capacity (scale 0–18, 0 = no nutrient limitations, 18 = severe limitations of all nutrients).

By this method, growth of 25 accessions of *Leucaena* was assessed in 61 'environments', for which specific weather, soil and psyllid pressure data were available (Table 3).

Data analysis

Analysis of variance

Analysis of variance was performed on DM yield to establish the relative significance of accessions, environments and accession × environment (A×E) interactions.

Adaptation analysis

Since identification of superior accessions in METs is often confounded by A×E interactions (Cooper and Byth 1996), cluster analysis and principal component analysis (PCA) (Williams 1976) of standardised data were used to simplify comparisons and enable identification of both broad and specific adaptation (Basford et al. 1991). Clustering was performed using an hierarchical, agglomerative process using incremental sums of squares as a fusion strategy and squared Euclidean distance as a dissimilarity measure (Williams 1976). Data were environment standardised to remove the effect of environment means (Fox and Rosielle 1982). This facilitated comparison of the genotypes across environments and assisted in the identification of specific adaptation. Dendrograms were used to display hierarchical relationships among accessions, while biplots of the principal components were used to visualise the results of the ordination.

Biplot interpretation

Accession scores are presented on the biplot as points and environments are represented as vectors. The relative performance of accessions in an environment can be compared by dropping a perpendicular line from the accession points to the environment vector. Accessions that intersect the environment vector in the most positive position have higher relative performance in that environment. Alignment of environment vectors is determined by the response of accessions to characteristics of the environments. Closely aligned vectors are positively correlated whereas horizontally opposed vectors (180°) are negatively correlated, and vectors at right angles (90°) are uncorrelated in terms of accession responses to environments (Kroonenberg 1995).

To aid in interpetation of the biplot and particularly in finding specific adaptation to environmental limitations, correlation analysis was used to identify the major factors influencing principal components 1, 2 and 3. Accession scores were regressed against mean accession yield and mean accession psyllid damage ratings, and environment scores were regressed against the six environmental variables.

Environmental limitations to growth

Environmental limitations to growth of the *Leucaena* genus were investigated using regression analysis based on the mean accession yield responses to six environmental variables. For this purpose, the establishment data were omitted from the analyses as they spanned seasons and produced lower yields due to their juvenility. In addition, 'environments' with strongly acid soil, highly infertile, high psyllid pressure, very low rainfall and/or very low temperatures were removed from the appropriate correlations to minimise confounding effects on the variable being analysed. A maximum of 28 and a minimum of 14 'environments' were used to derive these correlations.

Results

Yield comparisons

Highly significant differences (P<0.01) were identified among accessions and environments and there were significant A×E interactions. The environments and A×E interaction variance components accounted for 48% and 26% of the total variation respectively, while accessions, pooled error and blocks within sources accounted for 14%, 11% and 1% of variation respectively.

Mean environment yields ranged from 2 g/m row/month, during the hot season at Bac Thai in Vietnam, up to 568 g/m row/month, during the hot/wet season at Lae in PNG (Table 3). High environment mean yields were achieved from second year growth at Los Baños, Lae and Sungei Putih, all fertile, high rainfall, humid tropical sites. Poor mean yields (<50 g/m row/month) were recorded in 26 of the 61 environments. These included all strongly acid soil environments' (pH<5.0 1:5 H_2O), most

Table 3. Climatic characteristics, psyllid pressure, environment group membership from second cluster analysis and mean accession yields for MET environments

Site	Environments	Rainfall (mm/month)	Max temp. (°C)[1]	Min temp. (°C)[1]	Psyllid pressure[2]	Environment group membership	DM yield (g/m row/month)[3]
Brisbane	Estab	91	24.5	14.3	3.5	10	69
	Hot 1	141	25.9	16.7	3.8	9	119
	Cool 1	40	22.0	10.5	1.9	1	69
	Hot 2	88	26.9	18.0	5.1	10	171
	Cool 2	53	21.7	10.7	3.7	5	47
Gayndah	Estab	91	29.9	16.7	2.3	9	90
	Cool/dry 1	39	26.7	12.6	1.3	2	21
	Hot/wet 1	69	31.6	19.4	1.9	2	116
Theodore	Estab	98	31.7	17.5	1.0	2	9
	Cool/dry 1	40	26.9	11.4	1.1	2	10
	Hot/wet 1	146	33.2	19.4	1.0	2	75
	Cool/dry 2	78	28.1	13.6	1.0	2	25
Townsville	Estab	91	31.3	19.8	1.0	4	94
	Hot/wet 1	33	31.2	19.6	1.5	4	152
	Cool/dry 1	28	28.8	14.1	4.0	9	62
	Hot/wet 2	141	31.4	20.4	1.0	2	162
	Cool/dry 2	14	27.2	12.7	4.9	9	35
Kununurra	Estab	200	37.1	23.1	1.0	2	20
	Cool 1	200	33.2	15.5	1.0	2	11
	Hot 1	200	36.4	21.9	1.0	1	173
Lae	Estab	314	28.9	24.9	2.3	3	266
	NDS[3] 1	555	30.0	25.0	1.0	3	246
	NDS 2	450	29.8	24.8	1.3	3	568
	NDS 3	167	29.5	24.9	1.8	3	466
Erap	Estab	100	32.8	22.5	1.5	3	275
	Dry 1	21	31.5	21.2	2.0	9	135
	Wet 1	100	32.8	22.5	1.5	3	289
Aiyura	Estab	194	23.4	13.1	1.5	11	49
	NDS 1	137	23.6	13.5	1.6	11	68
	NDS 2	145	23.2	12.9	2.8	11	9
Sungei Putih	Estab	112	29.4	23.4	1.9	9	46
	NDS 1	130	29.0	23.0	2.1	3	265
	NDS 2	113	29.3	23.3	1.8	7	376
	NDS 3	130	29.3	23.3	1.1	7	261
Buon Ma Thuot	Estab	150	28.0	20.0	3.8	10	100
	Wet 1	151	27.4	19.4	2.8	4	87
Ha Tay (limed)	Estab	289	30.3	23.6	2.1	4	6
	Hot 1	240	30.7	23.6	3.3	10	47
Ha Tay (unlimed)	Estab	289	30.3	23.6	1.9	4	6
	Hot 1	240	30.7	23.6	3.1	10	27
Bac Thai	Estab	110	26.8	19.7	1.0	4	15
	Hot 1	275	31.5	23.9	1.0	4	2
Los Baños	Estab	154	30.6	23.4	3.1	1	98
	Wet 1	237	31.7	23.9	1.9	1	266
	Dry 1	23.6	31.3	22.3	3.4	1	214
	Wet 2	200	33.8	24.0	1.9	1	492
Lipa City	Estab	171	33.0	23.7	3.2	6	112
	Wet 1	235	32.8	22.4	1.8	6	71
	Dry 1	49	33.8	19.1	3.2	6	77
	Wet 2	206	32.9	24.1	1.6	6	156
Palayan City	Estab	313	33.1	23.1	1.0	1	30
	Wet 1	246	32.8	24.1	1.0	4	87
	Dry 1	105	33.1	22.1	1.0	1	24
	Wet 2	352	32.0	23.2	1.0	4	131
Tanay (limed)	Estab	283	27.7	20.4	1.0	2	5
	Dry 1	105	27.3	19.7	1.0	2	3
Nam Suang	Estab	150	31.3	22.5	1.3	4	4
	Wet 1	333	31.0	24.5	1.1	4	3
Machakos	Estab	22	24.5	11.9	5.3	9	4
	Warm/wet 1	70	26.5	13.9	3.8	10	73
	Cool/dry 1	5	23.6	10.8	5.9	9	33

[1] mean seasonal maximum and minimum temperature, [2] mean monthly psyllid damage rating over the season, [3] For comparison among environment mean yields, LSD ($P<0.05$) = 26.

highland tropical 'environments' and most cool/dry season 'environments' at seasonally cool/dry sites. Mean environment yields of <5 g/m row/month were recorded at the strongly acid soil sites of Nam Suang, Tanay and Ha Tay, and during establishment at Machakos (a highland tropical site).

The *L. pallida* K748 × *L. leucocephala* K636 F1 hybrid (KX2 F1) was the highest yielding accession (mean of 358 g/m row/month) and outyielded the next best accessions by more than twofold (Table 1). Other high yielding accessions were *L. pallida* CQ3439, *L. leucocephala* K636, *L. pallida* K376 × *L. leucocephala* K8 F5 hybrid (KX2 F5) and *L. macrophylla* OFI 47/85, with mean yields of 148–164 g/m row/month. The lowest yielding accession was *L. involucrata* (27 g/m row/month). Other low yielding accessions were *L. pulverulenta* OFI 83/87, *L. diversifolia* OFI 82/92, *L. trichandra* OFI 4/91, *L. lempirana* OFI 6/91 and *L. trichodes* OFI 61/88, with mean yields of 40–53 g/m row/month (Table 1).

Cluster and principal component analysis

The cluster analysis was truncated at six accession groups (AG) and 11 environment groups (EG) and these levels retained 34% of the GxE interaction variation. EGs tended to form around specific locations, with seven of the 11 EGs being dominated by a single site. Three single member AGs (KX2 F1, CQ3439 and OFI 53/88) and three multiple member AGs were identified, with KX2 F1 (AG1) being most dissimilar to other accessions. The outstanding broad adaptation of accession KX2 F1 is obvious from the PCA biplot (Figure 1). However, discrimination among other accessions was difficult as the excellent broad adaptation of KX2 F1 masked variation between other accessions in cluster and principal components analyses. Consequently, a second analysis was performed with the KX2 F1 accession omitted to provide better separation of remaining accessions and the results concentrate on this analysis. (See Materials and Methods for information on biplot interpretation).

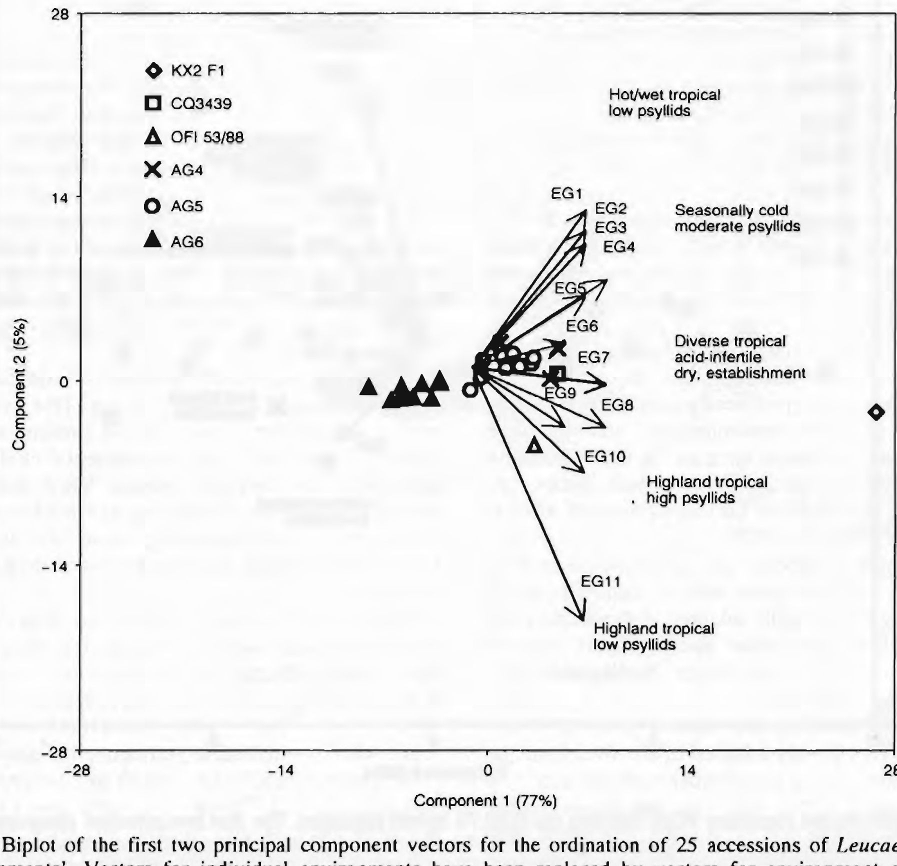

Figure 1. Biplot of the first two principal component vectors for the ordination of 25 accessions of *Leucaena* grown in 61 'environments'. Vectors for individual environments have been replaced by vectors for environment groups (EGs) identified by cluster analysis.

Secondary PCA and cluster analysis

The second cluster analysis was truncated at nine AGs (Table 1) and 11 EGs (Table 3), and retained 33% of the GxE interaction variation. EG membership was similar to the first analysis, and again tended to form around specific locations, with seven of the 11 EGs being dominated by 'environments' from a single site. EG 2 contained 11 'environments' from predominantly fertile, seasonally cool/dry sub-tropical sites. EG 4 contained 11 seasonally dry, humid-tropical environments, and included both fertile and acid-infertile soils. Highland tropical 'environments' were contained in EGs 11 and 9. No exclusive acid-infertile EGs were identified, with acid-infertile 'environments' contained in EGs 2, 4 and 10.

The principal component analysis explained 70% of the variation on the first two components (Figure 2). Most of this variation was in component 1 (63%), with components 2 and 3 explaining only a small additional amount of variation (7% and 6% respectively). The accession scores on principal component 1 were highly correlated with accession mean yields (r^2=0.98). Accession scores on principal components 2 and 3 were not correlated with yield, but accession scores on principal component 2 were correlated with accession psyllid damage rating (r^2=0.39). Accession points on the PCA biplot (Figure 2) were therefore reasonably interpreted in terms of increasing DM yield potential on principal component 1 and psyllid resistance and other unknown factors on principal component 2.

Environment scores on principal components 1 and 3 were poorly correlated with environment indices (Table 4). Environment scores on principal component 2 were correlated with maximum

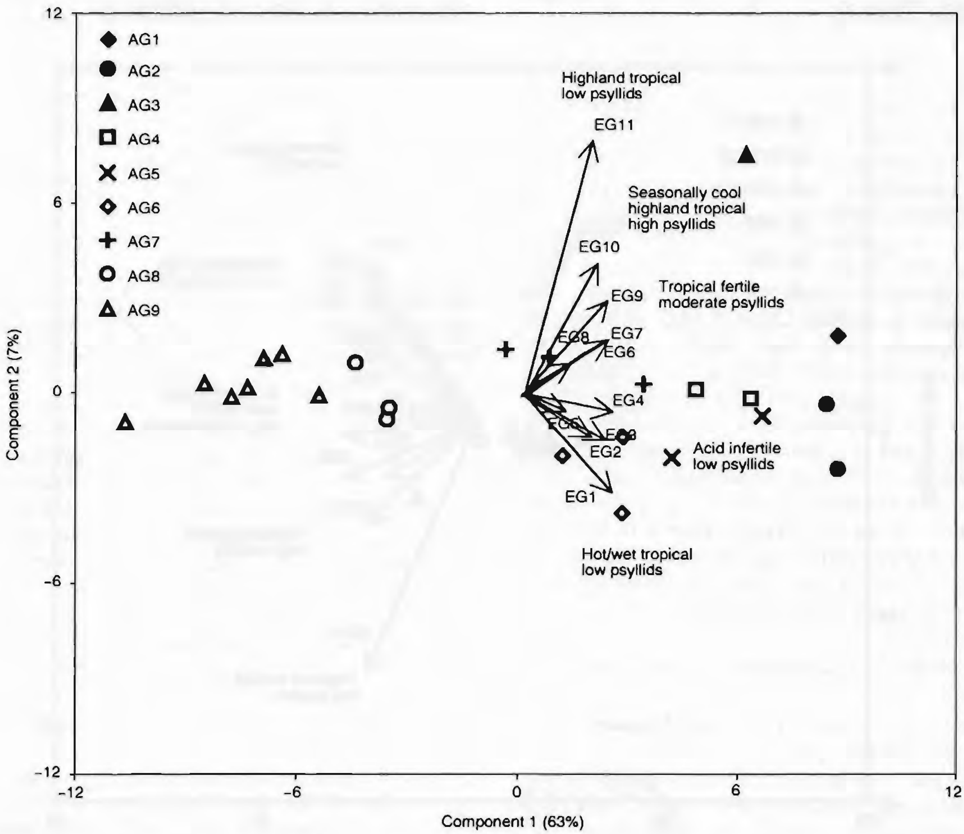

Figure 2. Biplot for the secondary PCA, omitting the KX2 F1 hybrid accession. The first two principal component vectors for the ordination of 24 accessions of *Leucaena* grown in 61 'environments'. Vectors for individual environments have been replaced by vectors for environment groups (EGs) identified by cluster analysis. Accessions with the same symbols belong to the same accession group (AG).

Table 4. Coefficient of determination values for correlations between edaphoclimatic variables and psyllid pressure in 61 "environments" and environmental loadings from second principal components analysis. Significant correlations are denoted by * (P<0.05) and ** (P<0.01).

PCA 2	Rainfall	Max Temp.	Min Temp.	Psyllid[1]	Acidity[2]	Fertility[3]	Yield
Principal component 1	0.06	0.11*	006	0.02	0.11*	0.02	0.04
Principal component 2	0.03	0.40**	0.21**	0.27**	0.00	0.04	0.08
Principal component 3	0.15	0.03	0.19	0.00	0.07	0.01	0.09

[1] Mean monthly psyllid pressure during environment period
[2] acidity index
[3] infertility index

(r^2=0.40) and minimum (r^2=0.21) temperatures and psyllid damage ratings (r^2=0.27), but were not correlated with acidity (r^2=0.01) and infertility (r^2=0.04) indices and rainfall (r^2=0.03). Biplot environment scores on principal component 2 were therefore interpreted in terms of accession response to temperature and psyllids (Figure 2). These correlations reflect the degree of adaptation to environmental variables present in the test accessions.

The second PCA elucidated considerable variation in the adaptation among accessions (Figure 2). *L. trichandra* OFI 53/88 (AG 3) was identified as being specifically adapted to highland tropical and high psyllid pressure environments. In comparison, *L. leucocephala* K636 and the KX2 F5 hybrid (AG 2) were more productive in humid tropical, low psyllid pressure environments, but were less productive in highland tropical and high psyllid pressure environments. *L. pallida* CQ3439 (AG 1) displayed broad adaptation at a high yield level, whereas *L. pallida* accessions OFI 79/92 and OFI 52/87 (AG 4) and *L. macrophylla* OFI 47/85 displayed broad adaptation with moderate yields. *L. leucocephala* cv. Cunningham and to a lesser extent *L. salvadorensis* OFI 36/88, KX3 F2 and *L. lanceolata* OFI 43/85 were productive in humid tropical, low psyllid 'environments' but were very poorly adapted to highland tropical and high psyllid 'environments' (Figure 2). AG 8 and AG 9 comprised 10 accessions which were very low yielding in all environments.

Identification of environmental growth limitations

Significant correlations were found between mean DM yields and 5 environmental variables (Figure 3), with strongest correlations being developed for the acidity index and minimum temperature. However, inconsistent variation across the data range prevented a relationship being developed with the infertility index and limited strong conclusions being drawn for correlations with rainfall and maximum temperature, although trends were obvious.

Yield was highly variable at acidity index ratings of 0, but was strongly negatively correlated with acidity index at ratings above 0 (Figure 3c). A strong positive relationship was apparent between minimum temperature and yield (Figure 3b). Yields increased linearly as minimum temperatures increased up to 22 °C, but at higher temperatures large variation about the regression line indicated that other factors were also affecting yield. Similarly for maximum temperature, yield increase was linear up to 28 °C, but the correlation was weak at higher temperatures.

Yield decline as psyllid damage rating increased from 2 to 6 was close to linear (Figure 3e). There was a general trend of linear yield increase with increasing rainfall.

Discussion

The MET design and genotype × environment analysis methodology enabled clear identification of broad and specific adaptation in the *Leucaena* genus. Results indicated that specific adaptation to temperature and psyllids existed but not to acid or infertile soils or to low rainfall. Variable resistance of *Leucaena* species to the psyllid insect (Wheeler and Brewbaker 1990; Mullen et al., these Proceedings) and to low temperature (Sorensson and Brewbaker 1987) is well reported. However, adaptation to acid soil environments has also been reported (Hutton 1990). In this study, best performing accessions in acid infertile soils were broadly adapted accessions which produced comparatively high yields in all environments. However, even the highest yields in the strongly acid infertile 'environments' of the MET were insufficient to confidently recommend any accessions to farmers. More encouraging yields were achieved at the mildly acid-infertile, Sungei Putih site in North Sumatra (Table 3), confirming that *Leucaena* can produce high yields at pH less than 5.5, as long as aluminium saturation is low (Blamey and Hutton 1995).

Most *Leucaena* species are known to survive long periods of drought in their native range. However, this survival adaptation did not confer biomass production adaptation in the seasonally dry environments of this study. Accession rankings at seasonally dry sites did not change significantly between wet and dry seasons.

Broadly adapted accessions

The outstanding broad adaptation of the *L. pallida* K748 × *L. leucocephala* K636 F1 hybrid is an important outcome of the study. This accession was among the highest yielding accessions in the foundation collection evaluations, together with other similarly high yielding *L. pallida* × *L. leucocephala* (KX2) F1 hybrid accessions and a *L. diversifolia* × *L. leucocephala* (KX3) F4 hybrid accession (Mullen and Shelton; Gabunada and Stür, these Proceedings). These hybrids were developed by Charles Sorensson at the University of Hawaii and seed scarcity has prevented their widespread evaluation. Methodologies for commercial seed or vegetative production should be a priority in order to evaluate ruminant production from the KX2 F1. The KX2 F5 accession (*L. pallida* K376 × *L. leucocephala* K8) was broadly adapted at a lower level of productivity than the KX2 F1. Commercial quantities of seed of the KX3 F4 and KX2 F5 hybrids are currently available and these accessions should be evaluated on-farm.

Several other accessions were broadly adapted, but less productive than the KX2 F1. Accessions of *L. pallida* were also broadly adapted and, from an agronomic perspective, their inclusion in previous hybrid breeding programs is well justified. The composite accession *L. pallida* CQ3439 (and its second generation OFI 137/94), was consistently the highest yielding *L. pallida* accession. *L. leucocephala* K636 was generally well adapted but did not perform well in highland tropical environments. In comparison, cv. Cunningham was specifically adapted to hot, wet, low psyllid pressure 'environments' and was less tolerant of environmental stresses. In the foundation collection evaluations, *L. leucocephala* accessions K584, K584 × K636 and OFI32/88 were of similar yield and adaptation to K636.

Lesser known species *L. macrophylla* subsp. *istmensis, L. salvadorensis* and *L. collinsii* subsp. *collinsii* were also broadly adapted at moderate yield levels. Of these, the latter species is of interest because of its very high forage quality (McNeill et al. these Proceedings).

Two accessions of *L. diversifolia* (OFI 82/92 and K156) were very poorly adapted to all environments, displaying none of the low temperature and acid soil adaptation reported for this species. Better accessions (K778 and K784) than those evaluated here were identified in the foundation collection evaluations. Other accessions displaying very low yields in all 'environments' were *L. trichodes* OFI 61/88, *L. involucrata* OFI 87/92, *L. trichandra* OFI 4/91 and CPI 46568, *L. lempirana* OFI 6/91, *L. pulverulenta* OFI 83/87, *L. magnifica* and *L. collinsii* subsp. *zacapana* OFI 56/88. All accessions of these species were low yielding in the foundation collection evaluations.

Specific adaptation

In this study, specific adaptation to low temperature, highland tropical 'environments' was identified in *L. trichandra* OFI 53/88, and to a lesser extent in *L. diversifolia* OFI 83/92 and *L. esculenta* 47/87 but not in other accessions. In addition, *L. diversifolia* accessions K778 and K784 were identified in the foundation collection evaluations as possessing considerable low temperature adaptation. High yielding, broadly adapted accessions KX2 F1 and *L. pallida* CQ3439 also produced worthwhile yields in low temperature 'environments' (approx. 250 and 125 g/m row/month respectively). The low temperature adaptation reported for *L. diversifolia* K156 (Brewbaker and Sorensson 1987) was not evident in the METs.

No specific adaptation to acid/infertile soil environments was identified. Furthermore, mean accession yields in acid-infertile 'environments' were very low, and even the highest yielding accessions did not produce worthwhile yields.

L. leucocephala cv. Cunningham was very productive in fertile, low psyllid pressure, tropical sites, but yielded poorly in low temperature, acid soil and high psyllid pressure sites. *L. leucocephala* K636 displayed a similar adaptation trend but was considerably less affected by these limitations to growth.

Edaphic and environmental limitations to growth

The correlations between mean DM yield and environmental variables revealed preliminary information of the effects of environmental challenges to growth of the *Leucaena* genus. Yield decline was most dramatic with increasing soil acidity and, to a lesser extent, with decreasing minimum temperature. Critical levels were apparent for most environmental variables.

Sharp reductions in growth occurred as the acidity index increased above 1 (Figure 3c), indicating the deleterious effects on growth of soil acidity decreasing below a pH of 5.0 and aluminium saturation increasing above 50%. These levels are in agreement with controlled experiments investigating the effects of soil acidity on growth of *Leucaena* (Ruaysoongnern 1987). The acidity index was a very poor predictor of DM yield below an index of 1, indicating that factors other than pH and aluminium saturation dominated growth.

The relationship between minimum temperature and growth was close to linear from 10 to 22 °C, with higher growth rates occurring as temperature increased (Figure 3b). However, as minimum temperature increased above 22 °C the relationship became weak, indicating that other factors had more affect on growth. The weaker correlation of maximum temperature with growth may reflect the importance of minimum temperatures to growth in environments with wide diurnal temperature fluctuations. However, while growth rates varied greatly across the maximum temperature range, highest growth rates were achieved only when maximum temperature exceeded 28 °C (Figure 3d). In a controlled temperature glasshouse experiment (Mullen Castillo et al., these Proceedings), mean growth of 17 *Leucaena* accessions increased linearly as maximum and minimum temperatures increased from 18 to 33 °C and 13 to 28 °C respectively.

Psyllid pressure was a moderately effective indicator of growth of psyllid susceptible *Leucaena* accessions (Figure 3e). The highest yielding

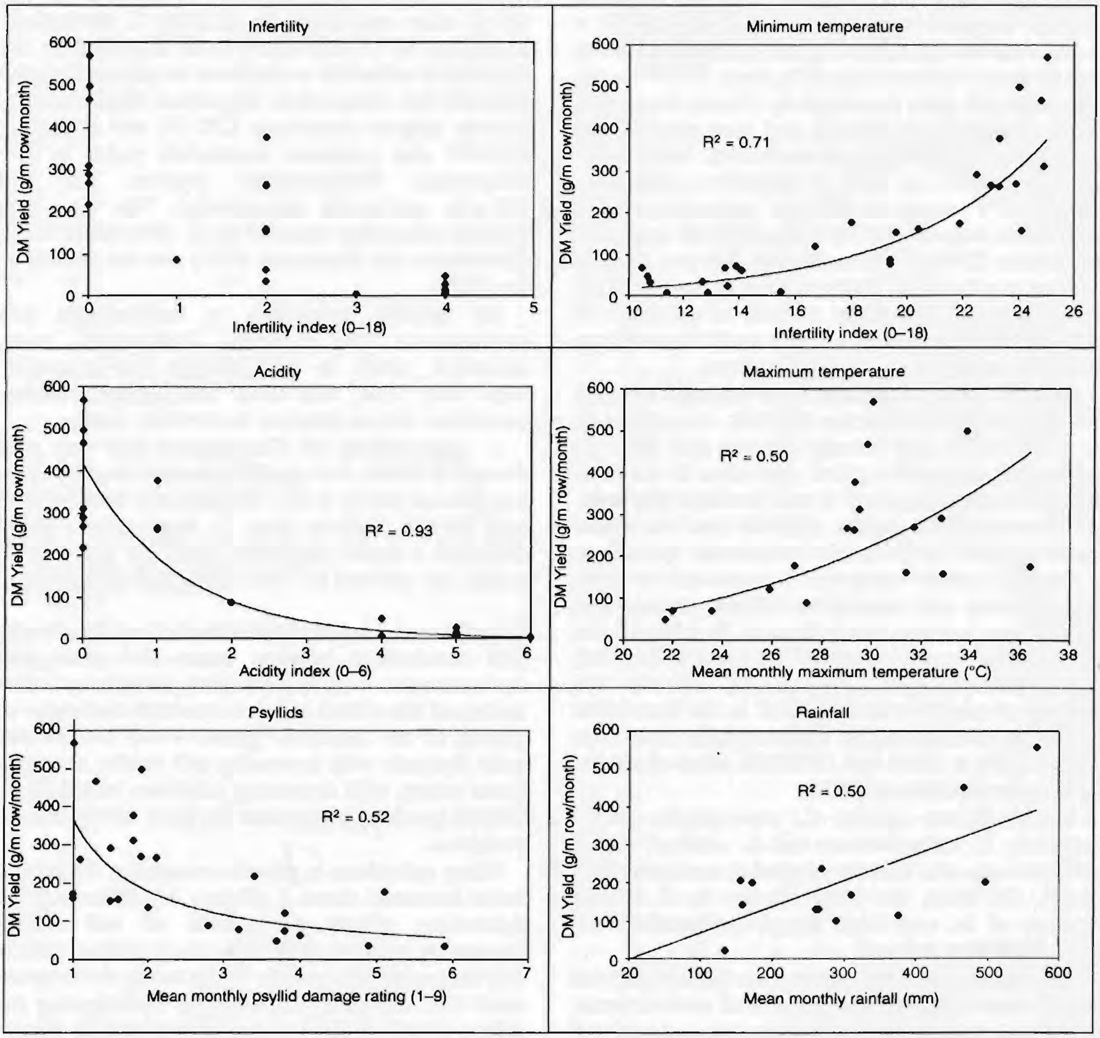

Figure 3. Scatter plots of mean DM yield of accessions of *Leucaena* in 14 to 28 'environments' against infertility index (a), minimum temperature (b), acidity index (c), maximum temperature (d), psyllid pressure (e) and rainfall (f). Psyllid pressure correlation was based on yields and psyllid damage ratings for 6 pyllid susceptible accessions. For other correlations mean yields of 25 accessions were used. Coefficients of determination are given for the line.

'environments' were low psyllid pressure 'environments' (mean PDR<2), indicating that optimum growth rates will not be achieved in the presence of moderate–high psyllid pressure. Within an environment, psyllid pressure can significantly impact upon the utilisation of susceptible accessions such as *L. leucocephala* (Mullen, Gabunada et al. these Proceedings). However, the effects of psyllids in the MET were comparatively minor in comparison to edaphoclimatic limitations.

A weak positive correlation was evident between rainfall and rate of growth (Figure 3f). This result is not unexpected, however, as mean monthly rainfall is likely to be a poor indicator of plant available soil water (not measured in these experiments) in the diverse soil types of the MET sites, and particularly in the subhumid environments where temporal distribution of rainfall is uneven.

Conclusions

Soil acidity and infertility and minimum temperature, and to a lesser extent psyllid pressure and rainfall most affected the yield of *Leucaena* accessions in the test 'environments' in this study. However, specific agronomic adaptation existed only to low temperature and high psyllid challenges. No specific adaptation to strongly acid-infertile soil 'environments' or to seasonally very dry 'environments' was identified within the *Leucaena* genus. There existed a number of broadly adapted accessions which were comparatively high yielding in all test environments. Of these accessions, the *L. pallida* K748 × *L. leucocephala* K636 F1 hybrid was very high yielding in all 'environments' except the strongly acid-infertile soil 'environments' and seasonally very dry environments. The authors conclude that it would be more constructive to look outside the *Leucaena* genus for adaptation to the strongly acid-infertile soil environments.

The multi-environment trial design and genotype × environment analytical methods used in the study enabled reduction of the large data set without significant loss of information. Further, the truncation of growth of *Leucaena* accessions at experimental sites into seasonal 'environments' allowed growth to be matched to relatively specific environmental factors. These methodologies enabled identification of broad and specific adaptation within the *Leucaena* genus and would be useful for evaluation of other multipurpose tree genera.

Ultimately, utilisation of *Leucaena* accessions will depend not only on DM productivity, but on edible fraction, nutritive value, ability to tolerate grazing and coppicing, wood quality, seed availability, ease of vegetative propagation and other factors not included in this analysis. Many of these important issues are investigated in subsequent papers in these Proceedings.

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Psyllid Resistance in *Leucaena*

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Abstract

The leucaena psyllid (*Heteropsylla cubana* Crawford) has severely reduced the productivity of *Leucaena leucocephala* pantropically since spreading from its native range in the early 1980s. Quantification of a commonly used psyllid damage rating scale in terms of loss of yield showed that, at even moderate damage ratings, yield loss of susceptible accessions can be greater than 50%. Psyllid populations have responded differentially to a number of climatic variables; psyllid damage was low when temperatures were above 33 °C or below 10 °C. The two main approaches to psyllid damage management are biological control and genetic resistance. Biological control agents, including the coccinellids *Curinus coeruleus* and *Olla v–nigrum* and the parasitoid *Psyllaephagus yaseeni*, have reduced the severity of yield reduction due to psyllids but damage can still be significant. Genetic resistance in *Leucaena* spp. is therefore an important goal and, when comprehensively evaluated in Australia and the Philippines, ranged from highly resistant to highly susceptible. There was considerable intraspecific variation in psyllid resistance within species such as *L. collinsii*, *L. diversifolia*, *L. trichandra* and *L. pallida*. *L. leucocephala* was the most susceptible species. Chemical and physical plant factors conferring psyllid resistance were reviewed. No single factor was identified and data were inconsistent across studies.

DURING the 10–year period from the early 1980s, the leucaena psyllid, *Heteropsylla cubana* Crawford (Homoptera: Psyllidae), a sucking insect which damages the young leaves of *Leucaena leucocephala*, has spread westward from tropical America to Asia and Australia and finally to Africa in the early 1990s (Geiger et al. 1995). The initial impact of the leucaena psyllid was particularly serious throughout the Asia–Pacific region where *L. leucocephala* has been extensively adopted as a multi–purpose tree (MPT) legume (Napompeth 1994). The psyllid caused defoliation levels of 95%–100% in older trees in the Philippines (Napompeth 1994) and considerable tree death in Indonesia (Geiger et al. 1995). The initial devastation has been alleviated to some extent as populations of natural control agents have increased (Geiger et al. 1995), but damage can still be severe. In Australia, yield reductions in *L. leucocephala* due to psyllids were reported at an average 36% across seven sites and up to 75% at a highly productive site (Room et al. 1993). Economic losses to the Australasian–Southeast Asian region were estimated to be US$525 million in the year following invasion (Room et al. 1993) with losses of US$316 million occurring in Indonesia alone during 1986 (Oka 1990).

Aside from economic losses, the psyllid problem has negatively affected the adoption and use of leucaena (Shelton and Jones 1995). In Indonesia, many farmers found that their animals did not eat psyllid–infested leucaena and this has reduced the number of new plantings (M. Tuhulele, pers. comm.). Psyllids have not only affected the use of leucaena for feed but also its use for charcoal (Sampet et al. 1995).

The two principal means of controlling psyllids are: (1) biological control using natural insect predators and parasitoids (Napompeth 1994); and (2) genetic control using psyllid resistance within the genus (Mullen et al. 1997). Chemical control cannot be seriously considered because of the high cost and environmental concerns.

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In developing an understanding of the psyllid and management strategies for its control, research programs have studied the biology of the psyllid (Napompeth and Maneeratana 1990), climatic variables responsible for the rapid fluctuations in psyllid populations (Mangoendihardjo et al. 1990), variation in resistance between and within species of leucaena (Sorensson and Brewbaker 1987) and plant factors that may be responsible for genetic resistance to psyllids (Sorensson and Brewbaker 1987). This paper presents recent research findings relevant to management of the leucaena psyllid.

Psyllid Biology

Life cycle

The biology of the leucaena psyllid, *H. cubana*, was described by Napompeth and Maneeratana (1990). It is a sap–sucking insect of approximately 2.0 mm in length. The psyllid undergoes 5 nymphal stages to reach adulthood. Eggs are laid singly but in dense clusters, lodged between the folds of developing leaflets of young leucaena shoot tips. After hatching, the early instar nymphs feed gregariously.

In later instars, they begin to feed in a solitary manner as the leaflets unfold. Eggs, nymphs and adults are often found together on the shoot terminals. On average, the total life cycle from egg to adult takes 10–20 days, depending on environmental conditions.

In Thailand, it was reported that populations doubled every 2.5 days and this explains the population explosions and rapid subsequent damage to host plants that are frequently observed (Napompeth and Maneeratana 1990).

Climatic influences on psyllid populations

Psyllid population pressure is often highly seasonal, and dramatic patterns of abundance and decline throughout the year have been reported in its native range and in other countries (Napompeth 1994). Many studies have attempted to correlate climatic variables with psyllid pressure but there appears to be little agreement between studies as to which factors most affect psyllid populations.

At a humid–tropical site in Indonesia (1800 mm annual rainfall), Mangoendihardjo et al. (1990) found psyllid pressure to be negatively correlated with rainfall, and positively correlated with solar radiation and wind velocity (r^2=0.51, 0.52 and 0.68 respectively). Wet season rainfall suppressed psyllid populations whereas higher wind velocities during the dry season helped to disseminate and increase the number of psyllids.

In the sub–humid, seasonally dry tropics of Thailand, psyllid numbers peak at the end of the dry season and the beginning of the wet season (Napompeth 1989), whereas in cooler climates such as Southeast Queensland and upland regions in Hawaii, psyllid numbers can be high throughout the year (Castillo et al. 1997; Austin et al. 1996). In the drier sub–humid environments of Central Queensland (650 mm annual rainfall), psyllids are not seen during dry or windy weather, but populations build up quickly during rainy periods associated with high relative humidity.

A 3-year evaluation of a large collection of *Leucaena* accessions at Los Baños, Philippines (humid tropical site with 2100 mm annual rainfall) and at Brisbane, Australia (sub–tropical with summer dominant rainfall of 1500 mm annually) provided some insights into the effects of climatic parameters on psyllid damage. Psyllid pressure was assessed by psyllid damage to susceptible *Leucaena* accessions. Plant responses to changes in climatic variables may also affect the severity of psyllid damage, thereby confounding studies based solely on psyllid damage. However, psyllid damage scores (Wheeler 1988) are highly correlated with psyllid populations (Bray and Woodroffe 1988) and in this study, minimum scores only occurred in the absence of psyllids.

At subtropical Brisbane, psyllid pressure was high throughout summer, autumn and winter but was consistently low during the spring, a season associated with low rainfall and relative humidity, cool nights and warm days (Figure 1). At this site significant, positive correlations were obtained between psyllid damage and mean minimum temperature (r^2=0.30), mean maximum temperature (r^2=0.17) and mean daily temperature (r^2=0.22), indicating that psyllids may favour warmer temperatures. The study also showed that there was little or no psyllid damage when mean minimum temperatures were less than 10 °C (Figure 2). These findings confirmed those of Austin et al. (1996) in Florida where low mean daily temperatures below 12 °C were associated with low psyllid populations.

At tropical Los Baños, significant but negative relationships were obtained between psyllid damage and mean daily maximum temperature (r^2=0.62), mean daily radiation (r^2=0.46) and mean daily temperature (r^2=0.42). The results showed that psyllid damage was low at maximum temperatures above 33 °C (Figure 3) and confirmed the findings of Patil et al. (1992) who identified an upper developmental temperature range for psyllids of 30–35 °C under laboratory conditions. A similar effect was observed at Townsville, Australia (R.J. Jones, pers. comm.) and at sites in the Philippines (A.C. Castillo, pers. comm.).

In tropical countries such as Mexico, Thailand, Papua New Guinea and northern Australia, the

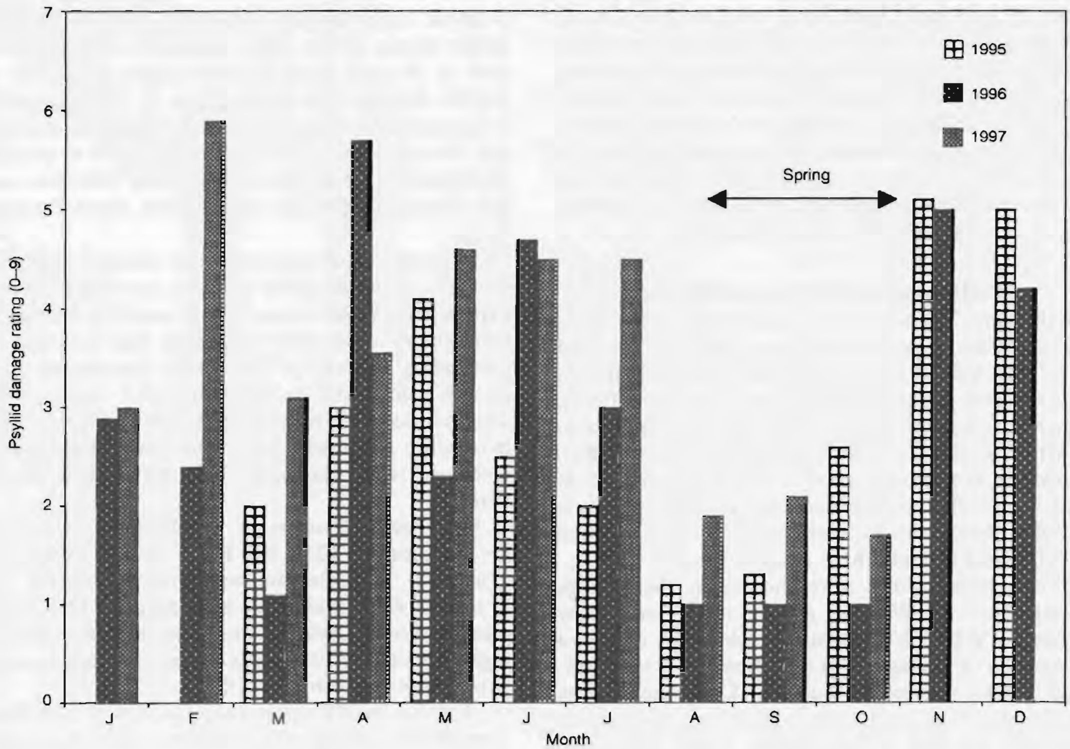

Figure 1. Mean monthly psyllid damage ratings over a 3 year period at Brisbane, Australia, showing the consistently low psyllid pressure over the cool, dry spring period (psyllid damage ratings: 1 = no damage to 9 = blakened stems and total leaf loss (Wheeler 1988)).

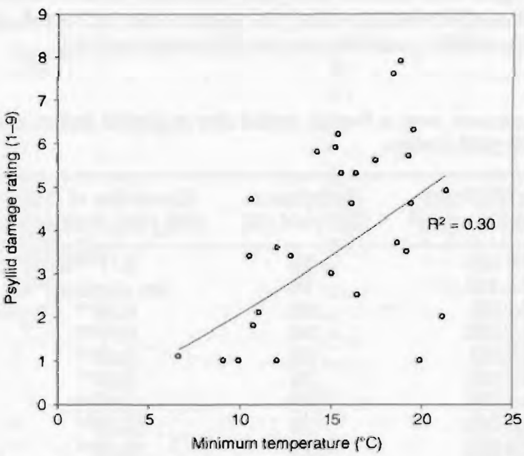

Figure 2. Correlation between mean minimum tempterature and psyllid damage at Brisbane, Australia. Monthly psyllid damage ratings (Wheeler 1988) for 6 susceptible accessions of *Leucaena* were used as an index of psyllid pressure.

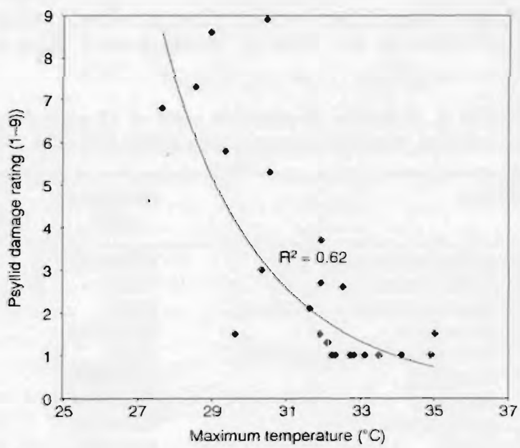

Figure 3. Correlation between mean maximum temperature and psyllid pressure at Los Baños, Philippines. Monthly psyllid damage ratings (Wheeler 1988) for 6 susceptible accessions of *Leucaena* were used as an index of psyllid pressure.

psyllid is most active during the cooler months (Napompeth 1994). Napompeth (1994) hypothesised that psyllid populations required a narrow optimum temperature range for persistence and development.

The relatively low coefficients of determination obtained in these studies imply no strong relationship between psyllid damage and climatic variables. It is likely that psyllid damage is a result of interaction between several different climatic factors.

Production Losses due to Psyllids

Production losses of *L. leucocephala* cv. Cunningham due to psyllids were estimated at 52% and 79% for leaf and stem respectively in Southeast Queensland, Australia (Bray and Woodroffe 1991), whereas in eastern Indonesia, yield reductions due to psyllids were 20% and 38% (Palmer et al. 1989). However, both studies used checks in which psyllids were controlled with dimethoate (Rogor) which is mildly phytotoxic to many species of *Leucaena* (Mullen and Dalzell, these Proceedings).

Since these studies were undertaken, the damage rating scale of Wheeler (1988) has been widely adopted. While it provides a relatively objective indication of damage, it is not known how these ratings relate to lost production. Consequently, an experiment was conducted at Brisbane, Australia to quantify the loss in dry matter (DM) production associated with the psyllid damage ratings (PDR) of Wheeler (1988) and to confirm the effects of psyllids on production using non–phytotoxic insecticides.

Quantifying psyllid damage

Twelve accessions of *Leucaena* (Table 1), covering a range of species and psyllid resistance levels, were established in the field at Brisbane and, after a 5-month establishment period, were cut back to single stems, 50 cm high. Regrowth was measured over a 9–week period from plants subjected to psyllid damage and from plants in which psyllids were controlled by spraying with chlorpyrifos (1 mg ai/L water), a chemical which was shown to be least phytotoxic to *Leucaena* while giving effective control of psyllids (Mullen and Dalzell, these Proceedings).

The experiment was conducted during a period of moderate-to-high psyllid pressure and all accessions experienced yield losses due to psyllids (Table 1). Quantification of yield reductions was achieved by calculating 2–weekly DM yield increments from growth curves for psyllid-controlled and psyllid-affected plants of the same size, and then calculating percentage yield reductions. These were then associated with corresponding PDRs for each 2-weekly period.

Yield reductions were significantly correlated with associated PDR for 10 of the 12 accessions (Table 1). Correlations were not significant for *L. pallida* K953 and for *L. salvadorensis* OFI 36/88. Visual damage ratings for these accessions were highly inconsistent across sites in the previous experiment (Mullen et al. 1997).

Data for the 10 accessions for which significant correlations existed were combined and a linear relationship between PDR and percentage yield reduction was developed (Figure 4). While only 43% of variation was explained by the model, it gave a highly significant relationship for predicting yield loss due to psyllid pressure. From this analysis, a PDR of 2 resulted in a yield reduction of 53% while a psyllid damage rating of greater than 6.5 resulted in >100% yield loss due to substantial leaf fall.

Table 1. Reduction in total DM yield of 12 accessions of *Leucaena* over a 9-week period due to psyllid insects and correlations of psyllid damage ratings (PDR) (Wheeler 1988) with yield decline.

Species	Accession code	Mean PDR[1] and resistance category[2]	Reduction in DM yield (%)	Correlation of PDR with yield decline (r^2)
L. collinsii subsp. *zacapana*	OFI56/88	5.0 HS	76	0.71**
L. pallida (unknown hybrid)	K953	3.8 MS	74	not correlated
L. leucocephala subsp. *glabrata*	K636	5.1 HS	69	0.52**
L. diversifolia	OFI83/92	3.2 MR	64	0.59**
L. leucocephala subsp. *glabrata*	K500	5.6 HS	62	0.60**
L. lanceolata	OFI44/85	4.7 MS	55	0.51**
L. magnifica	OFI19/84	4.4 MS	43	0.50**
L. macrophylla	OFI47/85	3.7 MR	38	0.32**
L. pallida	CQ3439	2.4 MR	33	0.44**
L. salvadorensis	OFI36/88	4.5 MR	37	not correlated
L. collinsii subsp. *collinsii*	OFI52/88	2.1 MR	27	0.31**
L. stenocarpa	OFI53/88	1.4 HR	10	0.68**

[1] Source: Mullen and Shelton, these Proceedings

[2] Resistance categories: HR=highly resistant; MR=moderately resistant; MS=moderately susceptible; HS=highly susceptible

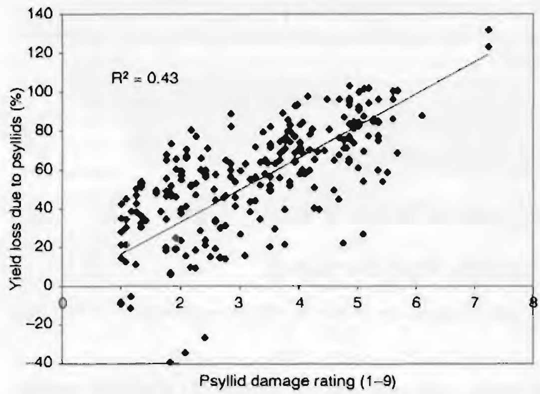

Figure 4. Correlation between psyllid damage ratings (Wheeler 1988) and yield loss (% of control DM) for 9 accessions of *Leucaena*.

This does not imply that a negative yield is possible over an extended regrowth period, as psyllid pressure fluctuates and is often low during early regrowth. However, yield loss will occur during the regrowth period when damage ratings exceed 6.5. Even a PDR of 1, indicating no visible damage, resulted in a yield loss of 17%. This result was not totally surprising, as subclinical insect damage is likely to reduce yield. It may give justification to extending the ratings scale to include a '0' rating, indicating that no psyllids are present.

Biological Control

Soon after its detection in Hawaii, work began to identify natural enemies of the leucaena psyllid. Two important predatory coccinellids, *Curinuus coeruleus* Mulsant and *Olla v–nigrum* Mulsant (Coleoptera: Coccinellidae) had been imported into Hawaii from Mexico in the early part of the century but their numbers had declined dramatically. With the invasion of the psyllid, both of these coccinellids increased in numbers and significantly depressed populations of the psyllid.

A third natural enemy, an encyrtid nymphal parasitoid, *Psyllaephagus yaseeni* Noyes (Hymenoptera: Encyrtidae), was introduced into Hawaii from Trinidad in 1987 and has become widely established.

An eupelmid nymphal parasitoid, *Tamarixia leucaena* Boucek (Hymenoptera: Eupelmidae), introduced to China, Malaysia, Nepal and Thailand in 1993 failed to become established (unpublished data, B. Napompeth). The exotic natural enemies introduced as biological control agents of the psyllid, their sources and destinations in the Asia–Pacific region are given in Table 2.

Both coccinellids and parasitoids were introduced into Thailand and the Philippines in 1987 and later into Réunion, India, Nepal, Vietnam, Indonesia and the Pacific Islands (Napompeth 1994). Of these, *C. coeruleus* and *P. yaseeni* established well and have become significant biological control agents limiting the devastation achieved by initial psyllid outbreaks. They form associations with the psyllid all-year-round at elevations above 300 m in the northern and central highland regions of Thailand.

Since these initial introductions of natural enemies, an increasing number of endemic enemies have been identified. A number of entomopathogens of the psyllid have been reported in Asia. The more dominant of these are *Conidiobolus coronatus* (Constantin) Butko, *Entomophthora* sp., *Hirsutella thompsonii* Fischer, *Fusarium* spp., *Beauvaria bassiana*, *Metarhizum anisoplae* var. *anisoplae* and *Paecilomyces javanicus*. Under suitable climatic conditions, many of these entomogenous fungi were found infecting the leucaena psyllid resulting in heavy mortality. Unfortunately, none have been cultured and developed under laboratory conditions and cannot be transferred for use as microbial control agents (Napompeth 1994).

In Thailand, 30 species of insects, 3 species of spiders and 6 species of fungi have been identified as natural enemies of the leucaena psyllid (Winotai 1989). Napompeth (1994) concluded that natural and exotic enemies were at least partially responsible for the decline in psyllid populations throughout the Asia–Pacific region. Nevertheless, psyllids remain a significant seasonal problem to farmers dependent on *L. leucocephala* for forage and fuelwood.

Psyllid Resistance in *Leucaena*

Early work

Study of early psyllid infestations in *Leucaena* germplasm evaluation experiments in Florida, USA identified resistance in *L. shannonii* and *L. pulverulenta* but moderate susceptibility in 10 accessions of *L. diversifolia*, 572 of *L. leucocephala* and 12 of *L. esculenta* (Othman and Prine 1984). A later evaluation in Hawaii and an international psyllid trial network coordinated from Hawaii, reported results which conflicted with the Florida study. *L. shannonii* and *L. pulverulenta* accessions were found to be highly susceptible, whereas *L. collinsii*, *L. esculenta* and *L. pallida* were highly resistant, and *L. diversifolia*, *L. greggii* and *L. retusa* were noted as having variable resistance depending on accession (Sorensson and Brewbaker 1987; Wheeler and Brewbaker 1990). Unfortunately, no resistance has been found in *L. leucocephala*. These findings were

Table 2. Exotic and natural enemies introduced as biological control agents of the psyllid in the Asia–Pacific region.

Species	Sources and destinations
Curinus coeruleus Mulsant (Coleoptera: Coccinellidae)	Mexico via Hawaii to Indonesia, Palau Islands, Philippines, Thailand, and via Thailand to Réunion, India, Nepal and Vietnam
Olla v–nigrum Mulsant (Coleoptera: Coccinellidae)	Mexico via Hawaii to Samoa, Tahiti and Thailand
Psyllaephagus yaseeni Noyes (Hymenoptera: Encyrtidae)	Tabago via Hawaii to Thailand and via Thailand to Réunion, Indonesia, New Caledonia
Tamarixia leucaena Boucek (Hymenoptera: Eupelmidae)	Trinidad to China, Hawaii, Malaysia, Nepal and Thailand

supported by an evaluation of 20 accessions in Australia (Bray and Woodroffe 1988). Sorensson and Brewbaker (1987) evaluated 531 accessions of *L. leucocephala* and, while all were found to be susceptible, considerable variation in degree of susceptibility was evident. Later studies elsewhere examined the susceptibility of *L. pallida* × *L. leucocephala* hybrids to psyllids (Castillo et al. 1997; Austin et al. 1996) and reported that several hybrid lines were intermediate in resistance between the two parents.

Resistance and Susceptibility among Species

A more detailed evaluation of psyllid resistance in the genus *Leucaena* was recently coordinated by The University of Queensland. A comprehensive collection of accessions was acquired from the Oxford Forestry Institute (OFI), augmented by hybrid and elite accessions from the University of Hawaii and CSIRO, Australia. The collection comprised 116 accessions of *Leucaena* from 22 species and hybrids and was grown at Brisbane, Australia and at Los Baños in the Philippines (Mullen et al. 1997)

Psyllid damage ratings (PDRs) were taken monthly throughout the experimental period (May 1995 to June 1996 at Brisbane; November 1995 to June 1996 at Los Baños) using the damage scale developed by Wheeler (1988) (ratings of 1–9, rating 1 = no damage observed, rating 9 = blackened stems with total leaf loss). Damage by psyllids, rather than psyllid numbers was used as an index of resistance or susceptibility (Austin et al. 1996). For simplicity, the psyllid data were averaged for each species and mean and range are shown for all accessions in each species for Brisbane and Los Baños in Table 3. Data were omitted for periods of very low psyllid challenge (mean PDR<2.0) as useful data on resistance and susceptibility could not be collected during such periods.

A complete range of psyllid damage responses, from highly resistant to highly susceptible, was measured. There was broad agreement in the findings between the two sites. *L. collinsii* subsp. *collinsii*, *L. confertiflora*, *L. esculenta*, *L. pueblana*, *L. retusa*, *L. greggii* and *L. matudae* were highly resistant at both sites, while species such as *L. leucocephala*, *L. lempirana*, *L. leucocephala* × *L. leucocephala* and *L. multicapitula* were highly susceptible at both sites. Other species were intermediate and fell into either resistant or susceptible categories as shown in Table 3.

There was considerable variation in psyllid resistance within some species. *L. collinsii* subsp. *collinsii* was highly resistant to psyllids at both sites, whereas *L. collinsii* subsp. *zacapana* was moderately susceptible at Brisbane and moderately resistant at Los Baños. Variation within *L. pallida*, *L. trichandra* and *L. diversifolia* indicated that the mean PDR for each species in Table 3 was an oversimplification as there are both resistant and susceptible accessions in these species.

At the Brisbane site, damage ratings for individual accessions of *L. pallida* varied from highly resistant (K376 and OFI 44/87) to moderately susceptible (OFI 92/94), except for high susceptibility in K953 perhaps due to its hybrid origin (Hughes 1993). *L. trichandra* damage ratings also varied from highly resistant (OFI 53/88) to moderately susceptible (OFI 4/91). For *L. diversifolia*, damage ratings varied from highly resistant (K778) to highly susceptible (OFI82/92). The ranges were less at Los Baños although the general trends were similar. It is therefore clear that great diversity exists, not only between species and subspecies, but also within some species. Other taxa to show high variability in damage ratings were the interspecific hybrids. This was expected due to the polarity of parental psyllid resistance. Lack of variability in other species may be due to the limited availability of accessions tested in those species.

There was little variation in psyllid resistance in either subspecies of *L. leucocephala* reflecting the narrow genetic diversity within this species reported by Hughes (1993).

Table 3. Psyllid damage of *Leucaena* species at Brisbane, Australia and at Los Baños, Philippines.

Species	Brisbane			Los Baños		
	Psyllid damage[1]		Resistance category[2]	Psyllid damage		Resistance category
	Mean	Range		Mean	Range	
L. greggii	1.4 (1)[3]	–[4]	HR	1.0 (1)	–	HR
L. esculenta	1.7 (2)	1.4–1.9	HR	1.3 (2)	1.3–1.4	HR
L. matudae	1.7 (1)	–	HR	1.5 (1)	–	HR
L. pueblana	1.7 (2)	1.4–2.0	HR	1.1 (1)	–	HR
L. retusa	1.7 (1)	–	HR	2.3 (1)	–	MR
L. collinsii subsp. *collinsii*	1.9 (2)	1.8–2.1	HR	1.0 (2)	1.0–1.0	HR
L. confertiflora	1.9 (2)	1.5–2.3	HR	1.4 (1)	–	HR
L. cuspidata	2.1 (1)	–	MR	1.1 (1)	–	HR
L. pallida	2.8 (9)	1.7–4.6	MR	1.8 (6)	1.0–3.0	HR
L. pallida x leucocephala	3.0 (6)	2.6–3.8	MR	1.8 (2)	1.3–2.3	HR
L. trichandra	3.2 (12)	1.4–5.4	MR	2.4 (12)	1.0–3.6	MR
L. lanceolata subsp. *sousae*	3.2 (2)	3.0–3.4	MR	2.3 (2)	1.6–2.9	MR
L. diversifolia	3.7 (12)	2.8–5.4	MR	2.4 (10)	1.3–4.1	MR
L. collinsii subsp. *zacapana*	4.1 (3)	3.4–5.0	MS	2.9 (3)	1.4–2.9	MR
L. macrophylla subsp. *macrophylla*	4.1 (2)	3.9–4.3	MS	3.2 (2)	2.5–3.9	MR
L. trichodes	4.2 (2)	3.9–4.4	MS	4.2 (2)	3.3–5.1	MS
L. macrophylla subsp. *istmensis*	4.3 (2)	3.7–4.9	MS	4.0 (3)	3.5–4.3	MS
L. magnifica	4.3 (2)	4.1–4.4	MS	3.3 (2)	3.3–3.4	MR
L. leucocephala subsp. *ixtahuacana*	4.4 (1)	–	MS	–	–	–
L. diversifolia x L. leucocephala	4.5 (9)	3.0–5.8	MS	4.0 (5)	2.3–5.3	MS
L. salvadorensis	4.6 (3)	4.4–4.8	MS	1.5 (3)	1.4–2.1	HR
L. shannonii subsp. *shannonii*	4.6 (4)	3.7–5.3	MS	3.3 (4)	1.5–5.4	MR
L. lanceolata subsp. *lanceolata*	4.7 (4)	4.4–5.2	MS	3.7 (4)	3.1–4.8	MR
L. pulverulenta	4.7 (3)	4.5–4.8	MS	2.6 (3)	2.5–2.8	MR
L. involucrata	4.9 (1)	–	MS	6.1 (1)	–	HS
L. lempirana	5.2 (2)	5.1–5.3	HS	4.4 (2)	4.1–4.8	MS
L. multicapitula	5.2 (2)	5.2–5.3	HS	5.6 (2)	5.3–5.9	HS
L. leucocephala subsp. *glabrata*	5.5 (19)	5.1–5.9	HS	5.4 (15)	4.4–6.6	HS
L. leucocephala subsp. *leucocephala*	5.7 (6)	5.6–5.9	HS	6.0 (4)	5.3–6.8	HS

[1] Psyllid damage rating: 1 = no damage to 9 = blackened stems with total leaf loss (Wheeler 1988)
[2] Resistance categories: see Table 1
[3] Values in parentheses are number of accessions
[4] One accession only, therefore no range

Stability of psyllid resistance

There was a significant relationship between damage scores at Brisbane and Los Baños (r^2 = 0.75) (Figure 5), although the mean damage score was lower at Los Baños (3.8) than at Brisbane (4.1). This gives confidence that the psyllid resistance rankings of the species are robust and sufficiently objective to enable consistency among inumerators. The relationship was also non–linear and gave a greater number of highly and moderately resistant accessions at Los Baños than at Brisbane. This was attributed to the higher psyllid challenge at Brisbane.

It was frequently observed at Brisbane that normally resistant accessions were attacked and showed some damage during periods of extreme psyllid pressure. During periods of lower psyllid pressure, these accessions had few or no psyllids, and were undamaged; more susceptible accessions were damaged at all times. Therefore, periods of low psyllid pressure reduced the expression of differences in psyllid resistance between accessions and increased the number of accessions in the resistant categories. This would explain the early flatness of the relationship between the data from the two sites, and the subsequent steeper slope when more susceptible accessions were compared. The lower psyllid pressure at Los Baños has therefore erroneously classified some moderately resistant accessions as highly resistant, and some moderately susceptible accessions as moderately resistant.

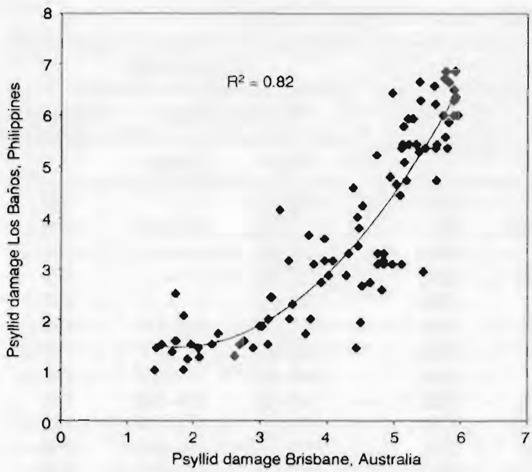

Figure 5. Correlation between psyllid damage ratings (Wheeler 1988) of 116 accessions of *Leucaena* at Brisbane, Australia and at Los Baños, Philippines.

Identifying the mechanisms for psyllid resistance

Resistance to homopterous insect attack in plants is normally achieved by physical or chemical modifications (e.g., midge in sorghum). Physical resistance might occur due to pubescence which prevents the insect from feeding. Induced chemical resistance occurs when insect herbivory results in chemical changes within the plant which deter insects from continued feeding (Walter and Parry 1994).

There has been much interest in the underlying mechanism of psyllid resistance in *Leucaena*. Sorennson and Brewbaker (1987) examimed plant physical, morphological, and some chemical characteristics in psyllid resistant genotypes. They found that twig–pubescence, flower size or colour, leaflet size, mimosine and chromosome number were poorly correlated with psyllid resistance, but speculated that a sticky leaf exudate found on several resistant species may have been related to resistance. This hypothesis has not been further developed.

More recent studies have focussed on the hypothesis that condensed tannins were responsible for conferring psyllid resistance. For a segregating population of *L. pallida* × *L. leucocephala* hybrids, Castillo et al. (1994) found that condensed tannin concentration was significantly and negatively correlated with psyllid damage (r^2=0.31). However, in a re–examination of the same segregating hybrids, Purdy (1996) found no correlations between psyllid resistance and condensed tannins (CT), neutral detergent fibre (NDF), acid detergent fibre (ADF), lignin, leaf nitrogen (N) or low molecular weight phenolics.

In another study, an examination of 16 accessions of *L. diversifolia*, *L. pallida* and *L. leucocephala* revealed a significant correlation between CT and psyllid resistance (r^2=0.41) (Castillo et al. 1997) and concurred with studies of similar accessions by Wheeler et al. (1994). Castillo et al. (1997) reported even stronger correlations with leaf detergent fibre fractions (NDF and ADF) (r^2=0.65 and 0.71 respectively). The authors concluded that condensed tannins may contribute to psyllid resistance by increasing leaf toughness, which together with higher hemicellulose concentrations in cell walls may confer psyllid resistance by making it more difficult for psyllids to feed.

To clarify these relationships, the *Leucaena* foundation collection of 116 accessions at Brisbane, Queensland, Australia (Table 3) was analysed for dry matter digestibility (IVDMD), NDF, ash, N and CT concentrations. These parameters were then correlated with mean PDRs for accessions of *Leucaena* (Table 4).

Table 4. Correlations between psyllid damage ratings and forage quality parameters and for 116 accessions of *Leucaena*.

Parameter	Correlation (r^2)	Model
IVDMD	0.22**	$y=cx^b$
NDF	0.03	$y=cx^b$
Ash	0.03	$y=mx+b$
Condensed tannins	0.28**	$y=mx+b$
Leaf N	0.12**	$y=cx^b$
CT × leaf N	0.27**	$y=cx^b$

Psyllid damage ratings were significantly and positively correlated with IVDMD and leaf N, negatively correlated with CT levels and not correlated with ash and NDF values. The correlation between PDR and CT was similar to those reported by Wheeler et al. (1994) and Castillo et al. (1997). The authors therefore concur with the conclusion of those authors that CTs are not singularly responsible for psyllid resistance in *Leucaena*. For instance, *L. collinsii* subsp. *collinsii* has shown high levels of psyllid resistance but contains no CT.

Conclusions

From more than 10 years of research and management, a detailed profile has been developed of the psyllid problem. Psyllid populations are variable but can build up rapidly in response to an interaction of climatic variables with host plant factors. While the significance of climatic variables varied from site to site, very high and low temperatures appeared to limit psyllid damage as did very dry periods.

Natural enemies of the psyllid, the coccinellid *C. coeruleus* and the parasitic wasp *P. yaseeni*, have been only partially effective in controlling psyllid outbreaks. However, a complete range of psyllid damage responses exists in the *Leucaena* genus from highly resistant to highly susceptible, and there is considerable variation in accession response both between and within species. Quantification of psyllid damage ratings (PDR) showed a loss of potential dry matter production of 25%, 40% and 100% at PDRs of 1, 2 and 6.5 respectively. Chemical studies indicate that resistance to psyllids is associated with the condensed tannin content of tissues but not singularly attributable to it. The underlying mechanisms for resistance are not known, but it is probable that more than one mechanism exists.

Future management of the psyllid problem will depend on the use of resistant accessions in high psyllid challenge areas but the use of high quality susceptible *L. leucocephala* accessions will continue in environments where psyllid challenge is minimised.

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Environmental Hazards of *Leucaena*

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Abstract

The benefits of the cultivation of *Leucaena leucocephala* in various farming systems are now well documented and acknowledged. However, there are two possible environmental hazards associated with the use of leucaena. These are its potential for weediness and its ability to increase soil acidity with consequent increase in toxic aluminium and manganese that could affect production and reduce the crop options for a site. These potential hazards are explored and discussed in this paper. Although the major weed concern in the past has been associated with the use of *L. leucocephala* subsp. *leucocephala* (the 'common' type), there is increasing evidence that *L. leucocephala* subsp. *glabrata* and *L. diversifolia*, which are increasingly used in farming systems, also have invasive traits, together with spontaneous hybrids. The use of bruchid seed beetles could prove to be very effective in greatly reducing the threat of weediness. Sterile triploid hybrids may have many benefits, including the prevention of spread. However, methods of propagation need to be developed before the technology can be widely applied. Soil acidification associated with the growth of nodulated legumes is inevitable. Changes of 1 pH unit to a depth of 60–80 cm have been measured over a 20–25 year period under grazed leucaena pastures. The rate of acidification is greatest from high yielding, pure stands which are cut and removed from the site; where soils are lightly textured and of low buffering capacity, and where pH is neutral to slightly acid, selection of lines with low ash alkalinity and, hence, lower potential for soil acidification, may be possible.

THE benefits to be gained from the introduction and cultivation of *Leucaena leucocephala* to new areas are widely documented and include increased animal production, shade for plantation crops, erosion prevention on sloping lands, and provision of firewood and building materials (Pound and Martínez-Cairo 1983; National Academy of Sciences 1984; Brewbaker 1987; Jones et al. 1992; Hocking 1993). As natural habitats become progressively more fragmented and degraded, agroforestry trees are in increasing demand to create robust utilitarian agroecosystems — the '*brave new ecosystems*' referred to by Cronk (1995) — to meet the needs of human populations (Hughes 1988; Hughes and Styles 1989). However, many of the attributes which confer success in such agroecosystems are by definition also characteristics of weeds. It is therefore not surprising that as well as benefits, introduction of successful agroforestry trees, such as *L. leucocephala*, can also cause problems of weediness. Furthermore, the '*circa situm*' conservation benefits derived from greater use of local tree diversity to create and maintain agroecosystems may be lost through over-reliance on introduced species such as *L. leucocephala*.

In the first part of this paper, the environmental hazard of weediness is discussed. The status of *L. leucocephala* as a weed is reviewed and the potential risks associated with introduction of other species of *leucaena* are assessed by taking *L. leucocephala* as a benchmark for comparison. Protocols for species introductions that incorporate a weed risk assessment are outlined. Other measures that may reduce risks, such as use of seed predators as biocontrol agents, or development of sterile hybrids, are also discussed.

The other hazard considered is soil acidification. Like all nitrogen-fixing legumes, leucaena has the potential to acidify soils on which it is grown. This aspect is discussed from the limited data available for leucaena and from the evidence of long-term studies using other leguminous species.

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Weediness

Leucaena leucocephala

An invasive plant may be defined as 'an alien plant spreading naturally (without direct assistance of humans) in natural and semi-natural habitats, to produce a significant change in terms of composition, structure and ecosystem processes' (Cronk and Fuller 1995). Under this definition, *L. leucocephala* subsp. *leucocephala*, the shrubby '*common*' type, is a widespread and well-known invasive weed. It is spreading naturally and has been reported as a weed in more than 20 countries scattered across all continents except Europe and Antarctica, e.g., in Africa: in Tanzania (Sheil 1994), Cameroon (Duguma 1995), and South Africa (Henderson 1989; Wells et al. 1989; Neser 1994); in Southeast Asia: in the Philippines (Merrill 1912), Java, Indonesia (Macdonald and Frame 1988), Papua New Guinea (Verdcourt 1979) and Malaysia (Corner 1938); several Pacific islands: including Guam (Debell and Whiteswell 1993), Vanuatu (Cock 1984), New Britain and Tonga (Verdcourt 1979) and Hawaii, U.S.A. (Smith 1985; 1989); on several Indian Ocean islands: including Reunion, Mauritius and Rodrigues (Polhill 1990); northern Australia (Lonsdale 1994; Lambert 1996; Jones and Jones 1996); the island of Fernando de Noronha off the coast of Brazil (Felfili and Da Silva 1990); several islands of the Caribbean such as Haiti (Timyan 1996) and Puerto Rico (Little and Wadsworth 1964); in southern Florida (Gordon and Thomas 1997), and Texas ('semi-weedy' in urban areas, Isely 1970, 1973); in the Bahamas; and in the Yucatán Peninsula of Mexico where it is only doubtfully native (McClay 1989; Hughes 1998).

L. leucocephala subsp. *leucocephala* is a weed of open (often coastal) habitats, semi-natural, disturbed, degraded habitats, other ruderal sites (e.g., roadsides, creeks, abandoned fields and waste ground) and occasionally of agricultural land where it has been planted as a shade tree over cacao. In their system of invasive categories, Cronk and Fuller (1995) assigned *L. leucocephala* to their category: '*a serious or widespread weed invading semi-natural or natural habitats which are of some conservation interest*'.

In Florida, it is classified as a Category II weed, defined as a species which has a local distribution and either rapidly expanding populations, or known potential to invade and disrupt native vegetation elsewhere (Gordon and Thomas 1997). In this sense, it is not one of the world's worst weeds and it is not known to invade undisturbed closed forest habitats. For example, in Australia, although a known weed, it is not a proclaimed noxious weed (Parsons and Cuthbertson 1992). However, in many areas it has formed dense monospecific thickets.

In Hawaii, it is reported to be replacing native *Metrosideros-Diospyros* open forest and possibly threatening the Hawaiian endemic *Erythrina sanwichensis* in parts of its range (Cronk and Fuller 1995). It is present on at least five of the islands of the Fernando de Noronha archipelago in Brazil where it is also competing with native island endemics, in this case *Ficus noronhae* and *Oxalis noronha* (Felfili and da Silva 1990).

On the Acra plains of Ghana, a number of rare endemic species of critical conservation concern, including *Commiphora dalzielii* and *Hunteria ghanensis*, occur in areas now severely invaded by introduced trees including *Azadirachta indica* and *L. leucocephala* (W.D. Hawthorne, pers. comm.). Dense monospecific stands, even if not of immediate conservation concern, can render extensive areas of disturbed ground unusable and inaccessible (Cock 1984).

L. leucocephala is therefore an important weed, but by no means the worst weed in the world. This is confirmed by applying protocols designed to assess weed risks of species proposed for introduction, before they are introduced. The weed risk assessment procedure devised and tested by Pheloung (1995) to regulate plant imports to Australia, and subsequently modified for use in New Zealand (Williams 1996), is one of several systems developed recently (for others see Reichard and Hamilton 1997; Tucker and Richardson 1995).

Under the Australian system, plants are scored according to a set of 49 criteria including evidence of weediness elsewhere and a wide range of biological attributes of the plant. Weed Risk Scores were calibrated using 370 known Australian introductions as the basis for assigning one of three categories: '*reject*', '*evaluate further*' or '*accept*' (Pheloung 1995). *L. leucocephala* scored between 2 and 5 (Pheloung 1995; Williams 1996) although Hughes (1998) obtained a slightly higher score of 7 points) scores which all fall within the '*evaluate further*' category. This means that should *L. leucocephala* be proposed for introduction to New Zealand or Australia today, further evaluation would be demanded prior to introduction under new quarantine procedures. Evaluation could consist of repeating the weed risk assessment with updated and more complete information, undertaking an environmental impact assessment and a cost-benefit analysis to justify the risk, and/or ensuring post-entry evaluation in the form of field studies supervised by an expert panel to examine more directly the weed potential and to verify its potential benefits.

The weediness of *L. leucocephala* subsp. *leucocephala* has been attributed to its abundant, precocious (within first year), year-round seed production (Gonzalez et al. 1967), lack of pollinator specificity, its ability to resprout after cutting or burning, the build-up of a persistent seed bank in the soil, its drought tolerance, its ability to form dense impenetrable thickets and its self-compatibility which means that it can spread from seed produced from an isolated tree. Conversely, it is thornless, has no documented allelopathic effects, is highly palatable, is non-climbing in habit, and seed dispersal is largely by gravity with only limited movement of seed on the ground by insects and rodents, or by water along streams (although Jones and Jones (1996) suggest that some seed may survive passage through cattle), a set of traits which may limit its invasiveness to some extent.

Other species of *leucaena*

Given the current interest in introduction of a wider spectrum of species and hybrids of *leucaena* to new areas, some researchers are asking whether these species are likely to be more or less weedy than *L. leucocephala* subsp. *leucocephala* in order to judge the advisability of new introductions. Many authors have highlighted the difficulties of predicting the outcome of species introductions (Cronk 1995; Cronk and Fuller 1995; Hughes 1994; 1995) and as Cronk (1995) suggested it is likely that '*whatever we predict about the future of weeds, the reality is likely to surprise us*'. This is because of three main factors. Firstly, the long-term perspective that is required to take account of possible changes in land use, production goals and management practices is difficult to achieve. Secondly, there is often a lag of up to 100 years between first introduction and emergence of an invasive problem. Thirdly, spontaneous hybridisation between introduced species and native species or other introduced species may give rise to new and potentially weedy hybrids.

Taking *L. leucocephala* as a benchmark for comparison, other species of *leucaena* have been assessed using the Pheloung (1995) weed risk assessment procedures as one way to compare the potential weediness of different species of *leucaena*.

It has been suggested that *L. leucocephala* subsp. *glabrata* is likely to be less weedy than subsp. *leucocephala* (Shelton 1996). No basis for this can be seen, and under the Pheloung (1995) system, both subspecies obtain identical scores except that subsp. *glabrata* has not been recorded as a weed elsewhere, thereby reducing its score. Other systems (e.g., Reichard and Hamilton 1997) suggest stricter scoring for species that are congeneric with known weed species. Subspecies *glabrata* is somewhat less precocious than subsp. *leucocephala*, but even the less seedy varieties such as K636 (cv. Tarramba), still produce prodigious quantities of seed at an early age if allowed to grow ungrazed. Indeed, Hutton and Gray (1959) showed that the '*Salvador*' type (subsp. *glabrata*) produced more pods and seeds per plant than the '*common*' type (subsp. *leucocephala*, referred to by them as the '*Hawaiian*' type).

The fact that subsp. *glabrata* is not recorded as a weed yet is quite possibly because it has only been widely introduced in the past three decades, and is used for fodder, whereas subsp. *leucocephala* has been spreading for more than 150 years. As early as 1912, *L. leucocephala* subsp. *leucocephala* was '*so thoroughly naturalised, common and widely distributed that the casual observer would consider it a native species*' in the Philippines (Merrill 1912). As noted above, it is well-known that 'invasion trajectories' (introduction, naturalisation, facilitation, invasive spread, interaction with other biota, stabilisation) typically span 100 years or more (Cronk 1995; Hobbs and Humphries 1994; Scott and Panetta 1993; Lodge 1993). Subsp. *leucocephala* has had several centuries to become a weed. It seems likely that, given time, subsp. *glabrata* may also naturalise and become weedy.

One other species, *L. diversifolia*, also appears to have all the invasive traits of *L. leucocephala* and does not differ significantly in the weed risk assessment. It is also self-compatible and seeds heavily at an early age. The remaining species of *leucaena* differ from *L. leucocephala* and *L. diversifolia* in being self-incompatible and somewhat less seedy and precocious although this is a matter of degree in that most are still relatively seedy from an early age (1–2 years). Only *L. cuspidata, L. greggii, L. matudae, L. retusa* and *L. salvadorensis* are known to be less precocious, seeding at 2–3 years of age. Further than this, four species, *L. lanceolata, L. pulverulenta, L. shannonii* and *L. trichodes* show marked weedy tendencies, spreading and colonising ruderal sites such as roadsides and abandoned fields and forming dense thickets within their native ranges (e.g., Isely 1970 for *L. pulverulenta* in Brownsville, Texas, USA; Hughes 1998). Given that known weediness elsewhere is a key factor in weed risk assessment (Pheloung 1995), and probably the best predictor of weediness (Scott and Panetta 1993), documentation of the weediness of these four species (Hughes 1998) will be important if they are proposed for new introductions elsewhere. Species are tentatively assigned to one of four weed risk categories taking *L. leucocephala* as a benchmark: 0 = lower risk; 1 = significant risk; 2 = risk as for *L. leucocephala*; 3 = known weed (Table 1).

Table 1. Weediness risk categories of species of *leucaena*.

Known weed	Risk as for *L. leucocephala* subsp. *leucocephala*	Significant risk	Lower risk
L. leucocephala subsp. *leucocephala*	*L. leucocephala* subsp. *glabrata** *L. diversifolia* KX3 hybrid *L. leucocephala* × *L. diversifolia**	*L. collinsii* *L. confertiflora* *L. esculenta* *L. involucrata* *L. lanceolata** *L. lempirana* *L. macrophylla* *L. magnifica* *L. multicapitula* *L. pallida* *L. pueblana* *L. pulverulenta** *L. shannonii** *L. trichandra* *L. trichodes**	*L. cuspidata* *L. greggii* *L. matudae* *L. retusa* *L. salvadorensis*

* Species which show weedy tendencies somewhere within their native range, spreading and colonising ruderal sites such as roadsides and abandoned fields and forming dense thickets in some areas.

Protocols for new species introductions

There is growing awareness of the environmental hazards posed by introduced species in general (Williamson 1996), plants (Cronk and Fuller 1995), and trees in particular (Hughes 1994, 1995; Hughes and Styles 1989). This has prompted calls for a more parsimonious approach to reduce ill-considered and unnecessary introductions through more careful prior assessment of likely benefits and risks (e.g., Lonsdale 1994). The much stricter rules now being applied to regulate new species introductions in New Zealand and Australia rely on a '*guilty-until-proven-innocent*' approach (Pheloung 1995; Hughes 1995). Such systems are likely to be applied more widely in the future. One part of these protocols is more active consideration of alternative native species. In general, it is accepted that introductions should only be considered if no native species is suitable for the purpose for which the introduction is being made (Hughes 1995). It is against this backdrop that potential importers must judge the advisability of new introductions.

Hybrids

Spontaneous hybridisation between an introduced and a native species or between two introduced species can pose new and unpredictable threats of weediness (reviewed by Abbott 1992; Abbott and Milne 1995). This is very much the case for leucaena with its high interspecific crossability (Sorensson and Brewbaker 1994) and known frequency of spontaneous hybridisation (Hughes and Harris 1994, Hughes 1998). There are already several documented cases of spontaneous hybridisation in leucaena following introduction of species to new areas (Hughes and Harris 1994, Hughes 1998). One of these hybrids between *L. leucocephala* and *L. diversifolia* has arisen spontaneously in Mexico, Guatemala, Haiti, Jamaica, Dominican Republic, Papua New Guinea and the Philippines (Hughes and Harris, in press) following cultivation of the parents. This hybrid is self-fertile, produces prodigious quantities of seed from an early age and shows weedy tendencies in secondary vegetation in Veracruz, Mexico. This hybrid has also been created artificially and promoted, as KX3, by the University of Hawaii (Brewbaker and Sorensson 1990; Sorensson 1995). The *L. leucocephala* × *L. diversifolia* hybrid is thus already widely distributed and is potentially as weedy as *L. leucocephala*. Under the Australian Weed Risk Assessment procedures (Pheloung 1995), it scores the same as *L. leucocephala* and *L. diversifolia*. Furthermore, multiple origins of a hybrid, as documented for L. leucocephala × L. diversifolia (Hughes and Harris 1998), provide insurance against extinction, particularly during the early stages of establishment, and may increase the amount of diversity sampled from the parent species (Abbott 1992) further enhancing the weedy risks associated with such hybrids. As an increasing number of species are introduced and tested in field trials there will be many new opportunities for spontaneous hybrids, some of which may also pose threats of weediness. However, not all hybrids produce seed readily. F_1 hybrids between *L. leucocephala* K636 and *L. pallida* K748 produce only small quantities of seed compared with the K636 parent (Shelton, pers. comm.).

Field trials and containment

Introductions are normally made initially into small-scale experimental field trials such as those under way now on a large scale within LEUCNET. It is often assumed that trials leave open the option of eradication if post-entry evaluation indicates cause for concern (IUCN 1987; Cronk and Fuller 1995). However, such trials, which are normal practice in forestry introduction programs, will provide only limited information on invasive tendencies. Furthermore, to be effective in controlling invasive species, trial sites would need to be heavily protected, isolated and closely monitored for several years and in some cases for decades; these conditions are rarely met in practice.

Trial assessments rarely look at the reproductive ecology or seed dispersal and regeneration. There are many cases where a few trees surplus to trial requirements are distributed to farmers, on-farm testing of species is recommended, and trials remain in a neglected state long after assessment is complete, thus providing a long-term source of possible invasives (Sheil 1994).

For *leucaena* species, with their abundant and precocious production of hard-coated seed, most trials will leave behind a soil seed bank that may persist for many years. Seedlings can emerge up to seven (and probably more) years after seeding (Jones and Jones 1996). Often seed is collected from trials by experimental station workers or visitors to plant in other areas or back in their gardens and farms.

In Honduras, putative spontaneous hybrids derived in this way from a species trial have been observed growing on the farm of a station worker 30 km distant. Thus, although trials provide some scope for monitoring and control, and should be pursued with improved monitoring procedures, it is a fallacy that movement of introduced species can be reliably controlled at the stage of initial field testing of new *leucaena* species following current practice.

Once established, leucaena may be hard to control or eradicate (Evenson 1982; Sorensson 1992). Trees have the ability to resprout after fire or other damage. Although leucaena species have highly palatable leaves, trees may be remarkably persistent even when repeatedly grazed close to the ground and are thus hard to control or eradicate through grazing management.

Bruchid seed predators

Introduction of host-specific seed-destroying insects has been used successfully to limit the spread of a number of economically important invasive legume trees in South Africa, reducing the fear that they will become unmanageably weedy and making their continued planting and use acceptable (Neser and Kluge 1986). By reducing seed production below a critical level, populations should eventually decline reducing the 'aggressiveness' of introduced species. Effective seed predation of *Acacia melanoxylon* (Neser 1996) and *Prosopis* species (Zimmermann 1991), two economically important alien invasives in South Africa, has been achieved by introducing host-specific bruchid beetles.

A similar approach has been proposed for *L. leucocephala* in South Africa (Neser 1994; 1996; Tribe 1995). A leucaena seed-feeding bruchid beetle *Acanthoscelides macrophthalmus*, was deliberately introduced to South Africa in 1989 for specificity studies and in 1996 the South African Plant Protection Research Institute applied for permission to release it. The accidental introduction of *A. macrophthalmus* to Queensland, Australia in 1996 (Jones 1996), is viewed overall as a positive influence to restrict further spread of weedy leucaena there (Jones and Jones 1996). Introduction of seed-feeding bruchids might thus make wide-scale use of leucaena more acceptable, although the effectiveness of *A. macrophthalmus* in reducing seed production remains to be assessed.

In their native ranges in Mexico and Central America, leucaena seeds are predated by seven species of bruchid in two genera, *Stator* and *Acanthoscelides*. While the two species of *Stator* are known omnivores that feed on a wide range of mimosoid legume genera, the five species of *Acanthoscelides* feed exclusively on leucaena and have not been recorded on any other host plant genus (Hughes and Johnson 1996). Although different species of *Acanthoscelides* feed on different numbers of host plant species in their native range, host records cannot be taken to indicate specificity elsewhere. However, *A. macrophthalmus* is known to feed on seeds of 18 different species of leucaena and may thus provide some insurance against possible weediness of species other than *L. leucocephala* in Australia and South Africa.

The disadvantages of introducing seed-destroying bruchids for leucaena seed producers are obvious. However, Neser (1994; 1996) proposed that pods in seed orchards can be readily protected from bruchids by insecticide treatment (as pursued for *Acacia mearnsii* in South Africa) or, for smaller quantities, by protecting individual branches with sleeves until harvested. It has also been suggested that greater control over seed production might encourage wider use of improved genetic material.

Psyllids

Although not used deliberately as such, a second 'biocontrol agent' for leucaena, the psyllid *Heteropsylla cubana*, has spread throughout the tropics in the past 15 years. There are few quantitative studies of the ecological impact of the psyllid on weedy populations of leucaena. However, it is clear that it poses an important limitation for growth of *L. leucocephala*.

L. leucocephala, the only species of *leucaena* which has so far become an important weed, is highly susceptible to the psyllid compared to other species of *leucaena*, some of which are highly resistant (Bray 1994; Mullen et al. 1997). Breeding for psyllid resistance and control of the psyllid, either by generalist predators or specialised biocontrol agents, will tend to reduce the impact of the psyllid with time.

Sterile triploid hybrids

The other route to avoid problems of weediness in leucaena that has been proposed is the development and use of seedless, or near seedless triploid hybrids (Dijkman 1950; Brewbaker and Sorensson 1990; Sorensson 1995). The principal advantages of seedless hybrids are the elimination of weediness risks and concentration of photosynthates in leaf and wood rather than in pod and seed production. Seedless hybrids are thus viewed as environmentally-benign for planting in conservation-sensitive environments and agroforestry systems where weediness of seedy *L. leucocephala* can be a problem.

The first sterile, or near-sterile triploid hybrid to be used commercially was the *L. leucocephala* × *L. pulverulenta* hybrid which had arisen spontaneously in Indonesia (Dijkman 1950). Interest in this hybrid arose in Indonesia because of problems of natural regeneration and weediness of seedy *L. leucocephala* when planted as a shade tree over tea and coffee. The sparsely seeding hybrids were noticed and subsequently propagated by grafting (Dijkman 1950). Wider interest in this hybrid elsewhere was driven by attempts to breed low mimosine lines by combining *L. pulverulenta*, with its known low mimosine content with *L. leucocephala* (Gonzalez et al. 1967; Bray 1984; Hutton 1985). However, quite apart from the obvious propagation difficulties, expectations were short-lived due to its overwhelming susceptibility to the psyllid.

A set of other sterile or near-sterile triploid hybrids have been created and have proved to be fast growing, offering diverse combinations of useful traits. The *L. leucocephala* × *L. esculenta* hybrid has been artificially recreated in Hawaii, designated as 'accession' K1000, (Sorensson and Brewbaker 1994; Brewbaker and Sun 1996). The seed sterility of this triploid has been verified in artificial hybrids in Hawaii (Brewbaker et al. 1989; Sorensson 1995) and Colombia (Hutton 1988) and has been attributed to chromosome irregularities observed at meiosis (Hutton and Tabares 1982) and consequent low pollen viability of between 1% and 8% (Hughes and Harris 1994) and 13% (Hutton and Tabares 1982). The *L. leucocephala* × *L. esculenta* hybrid is an extremely vigorous and leafy tree, shows outstanding psyllid resistance, and being seedless, poses no risk of weediness, making it one of the most attractive leucaena hybrids for reforestation, assuming the problems of propagation can be overcome (Brewbaker et al. 1989; Brewbaker and Sun 1996). However, information on its forage quality and resistance to browsing is lacking.

Other seedless triploid hybrid combinations, such as *L. leucocephala* × *L. trichandra* or *L. diversifolia* × *L. pulverulenta* (Hawaii accession K1001) also have the potential to combine high psyllid resistance, cold tolerance and vigour (Sorensson 1995). Triploid hybrids between *L. leucocephala* and *L. trichandra* apparently arose spontaneously in Indonesia (Toruan-Mathius et al. 1995) and have been created in Hawaii (Sorensson 1995). They set few seeds, have good in vitro dry matter digestibility, are highly psyllid-resistant and moderately cool-tolerant (Sorensson 1995; Toruan-Mathius et al. 1995).

Other genetic approaches to reducing weediness might also be proposed. Seediness of *L. leucocephala* may be reduced by selection (e.g., accession K29). Alternatively, it is possible to transfer self-sterility to species such as *L. leucocephala* through hybridisation with species such as *L. pallida*. Some F_1 *L. leucocephala* × *L. pallida* (KX2) hybrids are self-sterile and weakly seedy.

Wider use of sterile or near-sterile triploid hybrids has been prohibited to date by difficulties of propagation. Routine low-tech vegetative propagation or effective hybrid seed orchards (discussed by Bray 1984) would be needed if use of seedless hybrids is to become routine. There is no doubt that abundant local availability of seed has been an important factor contributing to the spread and widespread adoption of improved *L. leucocephala* subsp. *glabrata*. Less seedy, self-incompatible or sterile hybrids or varieties will be much less easy to deliver to farmers and growers.

Soil Acidification

Agricultural and pastoral systems inevitably remove product from the system in terms of crops or livestock. This removal gradually results in an increase in soil acidity compared to a natural ecosystem where product removal is minimal (Williams and Chartres 1991). When legumes are introduced to the system, the rate of acidification can increase.

This is now well documented for grazed temperate/mediterranean pasture systems in Australia where a gradual decrease in soil pH occurs over time. Decreases of 1 unit of pH have been measured over a period of 25 to 50 years in such systems (Haynes 1983). This accelerated rate of acidification with nodulated legumes is due to several causes.

On poor soils, the growth of legume-based pastures results in a fairly rapid rise in organic matter in the surface soil. This results in an increase in the cation exchange capacity (CEC), an increase in exchange acidity and, hence, a decrease in pH in the surface horizon (top 10 cm or so). Acidification deeper in the profile can occur through the net excretion of H_3O^+ ions (protons) from legume roots. This is the outcome of the uptake of excess cations relative to anions in N-fixing legumes and inevitably results in displacement of cations on soil colloids with consequent increase in acidity.

The downward leaching of cations is further promoted by the mineralisation of soil organic matter and subsequent leaching of nitrates contributing to a further decline in soil pH. Although the rate of nitrate leaching would be slower in grass/legume mixtures compared with pure legume stands, appreciable soil acidification can occur in mixtures of legumes (*Stylosanthes* spp.) and C_4 grasses (Jones et al. 1997). Compared with temperate or Mediterranean pastures, the rate of acidification in mixed tropical pastures may have been expected to be lower. Firstly, the rainy season occurs when temperatures support rapid growth of the perennial C_4 grasses with deep root systems and high capacity for nitrate uptake to prevent leaching. Secondly, tropical legumes generally have a lower total cation content relative to temperate legumes resulting in a lower acidifying effect in the rhizosphere (Haynes 1983).

The limited evidence from grazed leucaena/grass pastures, however, indicates that the acidification rate can be as high as that measured in temperate pastures in Australia (Noble and Jones 1997). They reported that the pH in the top 10 cm under a grazed *leucaena/urochloa* pasture growing on a sandy clay loam alluvial soil (Haplic, Eutrophic, Red Demosol (Isbell 1996)) with low buffering capacity (17.7 mmol+H^+/kg) declined by 1 unit over a period of 22 years. Furthermore, significant depression in pH occurred to a depth of at least 70 cm. There were associated losses of the cations Ca^{2+}, Mg^{2+} and K^+ down the profile compared with an all-grass control pasture (Noble and Jones 1997). These changes occurred despite a dense productive grass associate between the 3 m spaced rows of leucaena. Calculations of the excess cations over anions (expressed as ash alkalinity in meq/100 g DM) for *L. leucocephala* shows that values (56–116) can exceed those for temperate legumes such as lucerne.

Similar depressions in soil pH below grazed leucaena pastures have been measured in the sub-tropics and tropics in Australia (A.D. Noble, pers. comm.). The decline in soil pH would be much greater under a cut-and-carry system where leucaena is grown as a monocrop and there is no return of manure or addition of lime.

Leucaena is known to be deep rooting — an attribute which confers drought tolerance. This attribute could, however, lead to acidification over time throughout the soil profile.

In Australia, the greatest development of leucaena for cattle production has occurred in central Queensland on clay soils of high buffering capacity and high pH. Under these situations, the effect of leucaena growth on soil acidity would be minimal. However, growing leucaena on lighter textured neutral or acid soils of low buffering capacity, will inevitably lead to soil acidification. This, in turn, may increase soluble aluminium and manganese and decrease the availability of molybdenum (Haynes 1983). These changes will lead to reduced leucaena growth and reduced growth of any acid-sensitive crop species grown in association with or following the leucaena.

To prevent the soil acidification described here may require the use of lime to counter the acidification wherever leucaena is grown on slightly acid soils of low buffering capacity; or leucaena plantings may need to be restricted to well-buffered, heavy-textured soils with high pH. It may also be possible to select or breed leucaena with low ash alkalinity to reduce the rate of soil acidification.

Conclusions

Optimal use of leucaena genetic resources in forestry and farming systems, will depend as much on clear understanding and recognition of the socio-economic and environmental contexts as on technical or biological advances. *L. leucocephala* is a ubiquitous small, seedy tree in most tropical countries. Whether it is perceived as a valuable asset providing basic products to smallholder farmers, as the salvation for sloping lands, as the 'alfalfa of the tropics' to commercial beef producers, or cursed as an undesirable alien weed, depends on the perspective of the observer and the wider socio-economic and environmental context. The widely varying socio-economic and environmental contexts in which leucaena is used dictate in large part, whether leucaena is perceived as an environmental hazard or an asset.

There is scope for grazing or cutting management of leucaena to prevent seed set; the use of bruchid seed eating beetles and the use of sterile hybrids to overcome the potential for weediness. However, the challenge to reduce soil acidification is a formidable one that may require much research, since in many situations if may not be economic to use lime.

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Low Temperature and Acid Soil Tolerances in *Leucaena*

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Abstract

The prospects for developing low temperature and acid soil adapted cultivars of *Leucaena* are discussed following a review of experiments conducted under the ACIAR *Leucaena* project and related literature. Agronomically useful cold adaptation was identified in some accessions of *L. trichandra*, *L. diversifolia* and *L. pallida*. In addition, the broadly adapted KX2 hybrid accession *L. pallida* K748 × *L. leucocephala* K636 produced high yields in cool environments. Although adaptation is unlikely to significantly improve yields at very low minimum temperatures experienced in sub-tropical, seasonally cold locations, it will improve yields in highland tropical locations where temperatures are continuously cool, but with higher minimum daily temperatures. Accessions in the species *L. trichandra*, *L. diversifolia* and *L. leucocephala* and the KX2 hybrids were identified as having some frost tolerance. Temperatures in the native range of accessions were unreliable predictors of frost and cold tolerance. *Leucaena* accessions were not greatly affected by soil acidity above pH 5.2 provided that aluminium saturation was low. However, at higher aluminium saturation and lower soil pH, growth of *Leucaena* species was severely limited. Best yielding accessions included KX2 and KX3 hybrid accessions and *L. pallida*, although their yields at strongly acid sites may be insufficient to gain adoption by farmers. It is concluded that the *Leucaena* genus does not possess significant adaptation to strongly acid soils.

UTILISATION of *Leucaena leucocephala* (Lam.) de Wit throughout the tropics and sub-tropics, in both developed and developing countries, is testament to the value of this multi-purpose tree-legume and its adaptation to diverse edapho-climatic conditions (Shelton and Jones 1995). For example, *L. leucocephala* is seasonally vigorous on heavy black vertisols, with 700 mm rainfall in subtropical Queensland, Australia, but is also highly productive on free draining alfisols, with 4000 mm rainfall in lowland, equatorial Papua New Guinea.

Because of its high value, farmers and researchers have attempted to extend its adaptation boundaries. However, *L. leucocephala* has been unproductive in acid soils and in cool environments (Shelton and Jones 1995). The *Leucaena* genus contains 22 species (Hughes, these Proceedings) and genotypic adaptation to these growth limitations may exist (Shelton 1997).

Hutton (1981) first reported acid-soil tolerance in *L. trichandra* and *L. diversifolia*, but development of acid-soil tolerant cultivars has been slow, with an acid tolerant hybrid between *L. trichandra* and *L. leucocephala* due for release in 1998 (Wong et al., these Proceedings). Similarly, low temperature adaptation within the genus was reported by Brewbaker

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(1982), who noted the lack of forage tree-legumes well suited to the highland tropics.

A comprehensive collection of *Leucaena* germplasm assembled by the University of Queensland, comprising accessions from the Oxford Forestry Institute, the University of Hawaii and CSIRO, Australia, has enabled a more thorough investigation of acid-soil and low temperature tolerances. This was carried out under the auspices of the ACIAR project "New Leucaenas for Southeast Asian, Pacific and Australian Agriculture" (Shelton 1997), and preliminary results are presented here, together with a brief review of the literature and findings from other research groups.

Cold Temperature Adaptation within the *Leucaena* Genus

Low temperature constraints

Target environments for new cold-tolerant accessions of *Leucaena* range from wet, frost-free equatorial highland sites, such as the Papua New Guinea highlands, with minor seasonal and diurnal fluctuations in mean monthly maximum/minimum temperatures (e.g. 23/13 °C day/night temperatures in summer and 20/10 °C in winter); to sub-tropical, sub-humid sites, such as southern Queensland with large seasonal and diurnal fluctuations in mean monthly maximum/minimum temperatures (e.g., 32/21 °C day/night temperatures in summer and 22/4 °C in winter) and up to 50 frosts/year. Temperatures at these sites are often well below the optimum temperature for growth of tropical legumes of 31 °C reported by Ludlow and Wilson (1971).

Of the two distinct climatic regimes, low temperature may be a greater limitation to growth at highland tropical sites than at subtropical lowland sites, as sub-optimal temperatures for growth occur year-round in the highland tropics (Austin et al. 1997). In contrast, temperatures at subtropical sites may be non-limiting to growth over 7–9 months of the year, although growth will slow significantly or cease during the winter period.

While many species of *Leucaena* are of lowland tropical origin (*L. lanceolata*, *L. macrophylla*, *L. trichodes*, *L. leucocephala*, *L. collinsii*, *L. shannonii*, *L. magnifica*, *L. lempirana*, *L. salvadorenesis* and *L. matudae*), several species are native to cool, high altitude locations (*L. trichandra*, *L. diversifolia*, *L. esculenta*, *L. pallida* and *L. pulverulenta*) and/or higher latitude regions (*L. involucrata*, *L. greggii* and *L. retusa*).

In their native range, *L. retusa* and *L. greggii* regularly experience severe frosting, but these species are of low inherent productivity and therefore of little interest agronomically. More productive species such as *L. trichandra*, *L. diversifolia*, *L. pallida*, *L. esculenta* and *L. pulverulenta* may possess exploitable low temperature adaptation (Hughes 1993). Brewbaker (1982) reported excellent growth of *L. diversifolia* accessions at high altitude in Hawaii. Cold adaptation was also identified in studies in the tropical highlands of southern Ethiopia (Berhe and Tothill 1995) and in contrasting environments in Hawaii (Austin et al. 1997), where *L. diversifolia*, *L. pallida* and to a lesser extent, *L. trichandra* accessions significantly outyielded *L. leucocephala* accessions. There also appears to be considerable cold adaptation in the hybrids *L. pallida* × *L. leucocephala* (KX2) and *L. diversifolia* × *L. leucocephala* (KX3) (Brewbaker and Sorensson 1987; Gutteridge and Sorensson 1992; Swasdiphanich 1993; Castillo et al. 1994; Austin et al. 1997).

Several experiments conducted by the authors to test for the presence of cold and frost tolerance in *Leucaena* are now reported.

Controlled temperature glasshouse experiment

A replicated, controlled temperature glasshouse experiment was conducted at the University of Queensland, Australia in early 1997 to determine the growth responses of 17 accessions of *Leucaena* to low temperature treatments.

Results showed little cold adaptation in the species evaluated, as evidenced by the steep linear response to increasing temperature in Figure 1. Mean DM yields for temperature-limiting treatments (18/13 °C, 23/18 °C and 28/23 °C) were 9, 40 and 67% respectively of the non-limiting treatment (33/28 °C). Some accessions demonstrated higher relative productivity at both 18/13 °C and 23/18 °C temperature regimes. These were the KX3 hybrid, *L. leucocephala* K636, *L. pallida* K953 and *L. pulverulenta* OFI 83/87. At 28/23 °C, the best performing accessions were relatively unaffected by reduced temperature, with *L. lanceolata* OFI 43/85, the KX3 hybrid and *L. leucocephala* K636 producing relative yields of 99, 91 and 85% respectively. However, this temperature regime is well above those of highland tropical and seasonally cold environments.

When the relative yield of accessions was regressed against mean annual temperatures in their native range, there was a significant, negative correlation with relative yield at the 18/13 °C temperature regime (r^2=0.32), but no correlation with relative yields at the 23/18 °C and 28/23 °C. Of the accessions displaying adaptation to low temperatures, *L. pallida* K953, *L. pulverulenta* OFI 83/87 and the *L. diversifolia* K156 parent of the KX3 hybrid have evolved in low temperature environments (Table 1). Similarly K636, the most productive non-hybrid

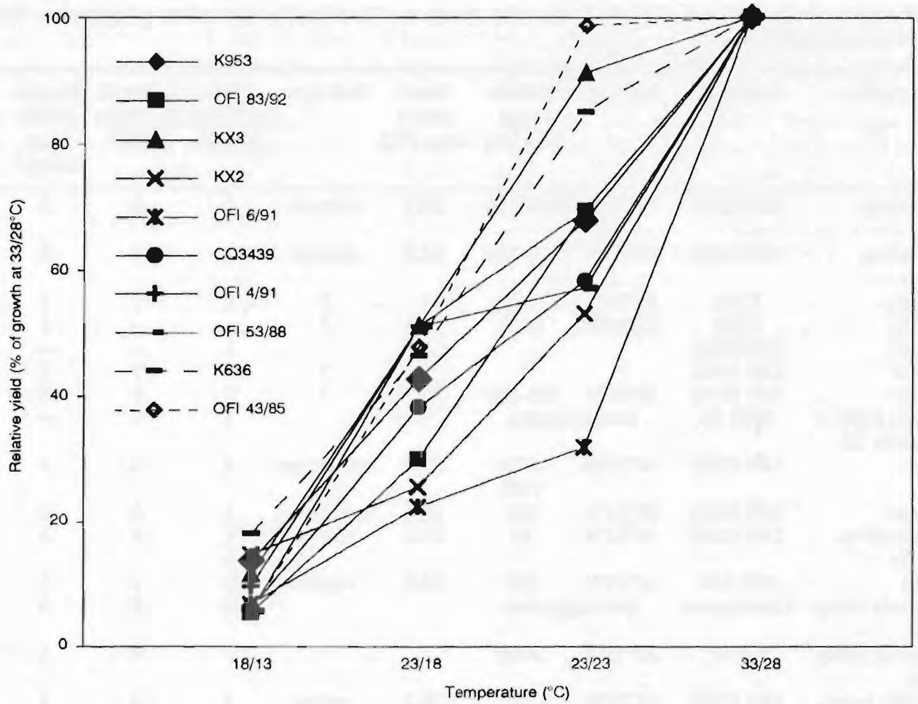

Figure 1. Response of 10 accessions of *Leucaena* to 4 temperature regimes in a temperature controlled glasshouse (17 accessions were evaluated but only 10 are presented). DM yields were expressed as a percentage of yields at the highest temperature.

L. leucocephala accession in the Hawaiian highlands (Brewbaker and Sorensson 1987), and a consistent cool temperature performer in this experiment, was collected at a cool highland location (1575 m altitude) in Mexico (Bray et al. 1997). *L. leucocephala* is of lowland tropical origin and was considered by Hughes (1993) unlikely to possess tolerance to low temperatures.

In summary, there were only minor differences in tolerance among accessions to the lowest temperature regimes but these findings require verification under field conditions. Only the KX3 hybrid, *L. leucocephala* K636 and *L. pallida* K953 displayed consistently high relative performance at sub-optimal temperatures.

Cold adaptation in multi-environment field trials

Several cool temperature environments were included in the multi-environment trial (MET) reported by Mullen, Shelton et al. (these Proceedings), viz., highland tropical sites at Machakos in Kenya and Aiyura in Papua New Guinea, and the winter seasons of 3 subtropical sites in central and southern Queensland (Table 2). This permitted assessment of the growth of 25 accessions of *Leucaena* during cool periods of 4–6 months over a 2-year period.

From cluster analysis, based on accession growth responses to environments, it was apparent that accessions responded differently to highland tropical environments than to seasonally cold subtropical environments (Table 2, Figure 2). In seasonally cold environments where night temperatures were sufficiently cold to stop growth (mean monthly minimum temperatures of coldest months <10 °C), accession yields in the winter and summer seasons were highly positively correlated (r^2>0.80). At least 75% of annual DM production occurred in the warmer months in these environments, and therefore accession selection should be based on hot season performance.

At tropical highland locations, low temperature adaptation was comparatively more important in achieving high annual DM yields because low temperatures persisted year round. Austin et al. (1997) reached similar conclusions based on evaluations conducted in Hawaii and Florida.

Table 1. Passport details (Hughes 1993) and accession group memberships for accessions of *Leucaena* used in low-temperature and acid soil studies.

Species/subspecies	Accession	Latitude	Altitude range (m a.s.l.)	Mean annual temp (°C)	Soil type	Cold accession group [1]	Acid soil accession group [1]	Hughes (1993) frost rating [2]	Revised frost rating [3]
L. collinsii subsp. *collinsii*	OFI 52/88	16°36'N	400–550	24.7	vertisol	4	4	3	2
L. collinsii subsp. *zacapana*	OFI 56/88	15°07'N	100–200	27.3	alluvial	1	6	3	2
L. diversifolia	K156	18°56'N	1225	?	?	2	7	1	1
L. diversifolia	K784	18°52'N	1175	?	?	—	—	1	—
L. diversifolia	CPI33820					1	—	—	—
L. diversifolia	OFI 82/92	?	?	?	?	1	7	1	2
L. diversifolia	OFI 83/92	18°04'N	350–500	21.9	?	5	4	1	2
L. diversifolia K156 × *L. leucocephala* K8	KX3 F2	bred accession				1	4	—	2
L. esculenta	OFI 47/87	18°18'N	1400–1700	21.9	calcareous	4	2	1	3
L. involucrata	OFI 87/92	28°55'N	700	18.6	calcareous	1	6	0	2
L. lanceolata subsp. *lanceolata*	OFI 43/85	16°02'N	10	27.2	alluvial	1	5	3	3
L. lempirana	OFI 6/91	15°17'N	200	24.5	vertisol	1	5	3	1
L. leucocephala subsp. *glabrata*	Cunningham	bred accession				3	5	3	1
L. leucocephala subsp. *glabrata*	K636 [4]	25°15'N	1000	?	?	5	4	3	2
L. macrophylla subsp. *nelsonii*	OFI 47/85	15°59'N	10	28.2	vertisol	4	3	2	3
L. magnifica	OFI 19/84	14°04'N	900–950	24.0	?	2	6	3	2
L. pallida	CQ3439	bred accession				6	1	1	2
L. pallida	K376	17°08'N	1675	?	?	—	—	1	—
L. pallida	OFI 79/92	17°41'N	1900	16.3	?	4	2	1	2
L. pallida (unknown hybrid)	OFI 52/87	18°38'N	2100	17.6	calcareous	4	4	—	1
L. pallida K376 × *L. leucocephala* K8	KX2 F5	bred accession				5	7	—	1
L. pallida K748 × *L. leucocephala* K636	KX2 F1	bred accession				8	—	—	2
L. pulverulenta	OFI 83/87	23°36'N	1000–1500	18.4	calcareous	1	6	1	1
L. salvadorensis	OFI 36/88	13°26'N	480–600	26.5	mildly acidic	2	3	3	3
L. trichandra	CPI46568	?	?	?	?	1	7	2	—
L. trichandra	OFI 4/91	14°12'N	1850–2000	17.3	brown earth	1	7	2	1
L. trichandra	OFI 53/88	14°49'N	1400–1450	21.6	?	7	4	2	1
L. trichodes	OFI 61/88	1°21'N	150–400	24.8	vertisol	1	6	3	3

[1] Accession group memberships from ACIAR multi-environment trials (identified by cluster analysis). For cold temperature memberships refer to Figure 2 and acid soil memberships refer to Figure 3.

[2] Frost tolerance based on climate in native range: 0 = full frost tolerance; 1 = moderate frost tolerance; 2 = minor frost tolerance; 3 = no frost tolerance.

[3] Revised frost tolerance based on data from Queensland and Botswana (ratings as per [2]).

[4] Passport data from collection site, not native range.

Table 2. Climatic characteristics, psyllid pressure and mean accession yields for low temperature environments included in ACIAR multi-environment trials (METs).

Site	Seasons	Rainfall (mm/month)	Max temp. (°C) [1]	Min temp. (°C) [1]	Altitude (m a.s.l.)	Latitude	Psyllid pressure[2]	DM yield (g/m row/month)
Brisbane, Australia	Establishment	91	24.5	14.3	10	27°37'S	3.5	69
	1st winter	40	22.0	10.5			1.9	69
	2nd winter	53	21.7	10.7			3.7	47
Gayndah, Australia	1st winter	39	26.7	12.6	131	25°39'S	1.3	21
Theodore, Australia	1st winter	40	26.9	11.4	150	24°51'S	1.1	10
	2nd winter	78	28.1	13.6			1.0	25
Aiyura, Papua New Guinea	Establishment	194	23.4	13.1	1700	6'15'S	1.5	49
	Period 1	137	23.6	13.5			1.6	68
	Period 2	145	23.2	12.9			2.8	9
Machakos, Kenya	Establishment	22	24.5	11.9	1600	1°58'S	5.3	4
	Warm/wet	70	26.5	13.9			3.8	73
	Cool/dry	5	23.6	10.8			5.9	33

[1] Mean monthly temperature for the environment period.
[2] Based on mean monthly psyllid damage ratings for 6 susceptible accessions.

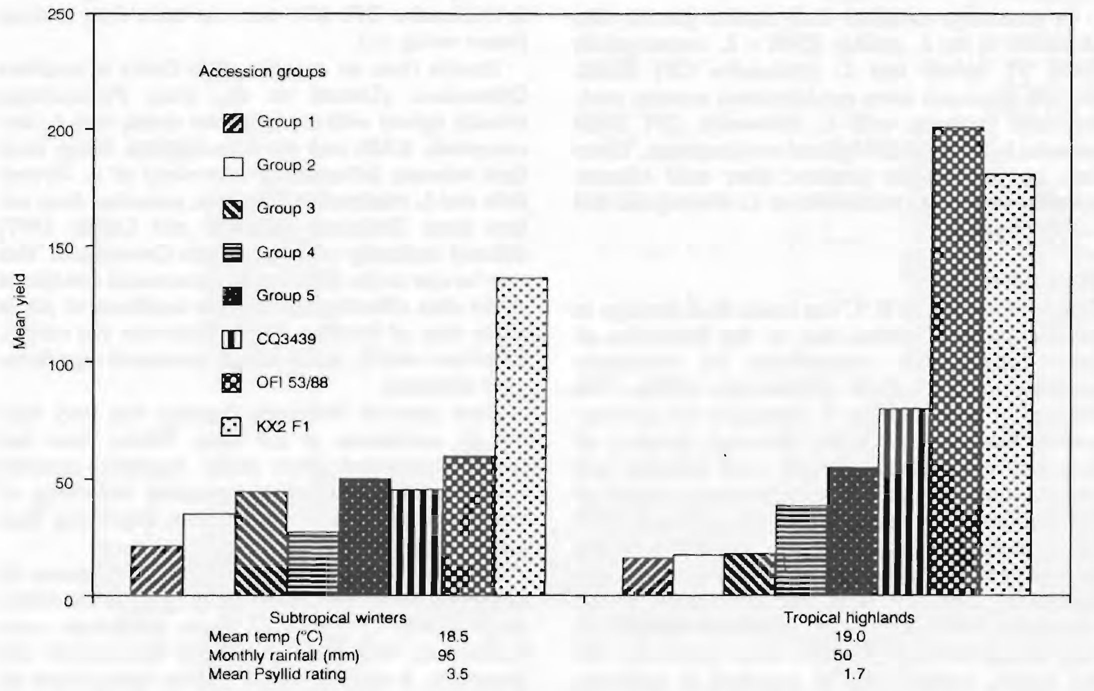

Figure 2. Yield response of *Leucaena* accessions to cool environments included in the ACIAR multi-environment trials (METs). Accession groups and environment groups were identified by cluster analysis (see Mullen, Shelton et al., these Proceedings). Accession group memberships are listed in Table 1.

Only the KX2 F1 hybrid (*L. pallida* K748 × *L. leucocephala* K636) displayed excellent broad adaptation, producing worthwhile yields (>100 g/m row/month or 2000 kg/ha/yr of edible material) in both cool environment groups (Figure 2). *L. trichandra* OFI 53/88 displayed excellent specific adaptation to the continuous low temperatures in highland tropical environments. *L. pallida* accession CQ3439 was of low productivity in the coldest environments, but yielded well in the slightly warmer environments (data not presented).

All other accessions performed relatively poorly in cool environments, including several accessions of *L. trichandra, L. diversifolia, L. esculenta, L. pallida*, and *L. pulverulenta*. This was surprising due to their high altitude origins. *L. leucocephala* K636 and the KX3 hybrid, accessions which displayed some cool tolerance in the glasshouse trial, also performed poorly. However, cold tolerance in accessions of *L. diversifolia* (K778 and K784) and *L. pallida* (K376) was demonstrated in the foundation trial which evaluated 116 accessions of *Leucaena* in southeast Queensland, Australia (Mullen and Shelton, these Proceedings).

In summary, excellent cool season growth was identified in the *L. pallida* K748 × *L. leucocephala* K636 F1 hybrid and *L. trichandra* OFI 53/88. Growth responses were not consistent accross environments however, with *L. trichandra* OFI 53/88 superior in the tropical highland environments. There may be potential to produce other cold tolerant hybrids between *L. trichandra* or *L. diversifolia* and *L. leucocephala*.

Frost tolerance

Temperatures below 0 °C can cause frost damage in tropical pasture species, due to the formation of intracellular and/or extracellular ice ultimately resulting in cell death (Whiteman 1980). The severity of frost damage is dependent on environmental factors such as the rate and duration of freezing, relative humidity and wind velocity, and plant factors such as species adaptation, degree of preconditioning to low temperatures and levels of N (Gates et al. 1973) and P (Bryan et al. 1971). Fluxes in these environmental factors are associated with topography and soil type, and restrictions to air movement, and can result in significant variation in frost damage between plants in close proximity. For this reason, caution must be exercised in assessing frost damage at variable sites. Frost damage occurs at temperatures well below those that stop or severely reduce growth of tropical forages. Frosts may kill plants, but if forage plants survive frost, its most significant effect is loss of leaf for winter feeding.

L. retusa (Long 1992; Glumac 1986) and *L. greggii* (Hughes 1993) are reported to tolerate frosting to –10°C, a temperature which will kill *L. leucocephala* (Long 1992), but these species are poor agronomically. *L. pulverulenta* is reported to be intermediate in its frost tolerance (Glumac et al. 1987), but no information is available regarding the frost tolerance of other species.

Three experiments were conducted to evaluate susceptibility of *Leucaena* accessions to frost damage in central and southern Queensland and in Botswana. At Brigalow Research Station in central Queensland, frost damage, based on leaf fall and stem death to 25 accessions of *Leucaena*, was assessed over 3 winters. Frost damage ratings for newly planted seedlings affected by a late frost (in 1995) differed considerably to ratings for mature accessions (1996 and 1997). In contrast, frost ratings for 1996 and 1997 winters were significantly positively correlated (r^2=0.72). Based on the mean frost damage ratings for the 1996 and 1997 winters, no accessions demonstrated complete resistance to frost damage, but three accessions of *L. diversifolia*, two KX2 hybrids, *L. leucocephala* cv. Cunningham and *L. trichandra* OFI 4/91 were the most frost tolerant (mean rating <1).

Results from an experiment at Dalby in southern Queensland (Dalzell et al., these Proceedings) broadly agreed with the Brigalow result, with *L. leucocephala* K636 and cv. Cunningham being most frost tolerant, followed by accessions of *L. diversifolia* and *L. trichandra*. However, accession frost ratings from Botswana (Karachi and Lefofe 1997) differed markedly with those from Queensland. This may be due to the differing environmental conditions at the sites affecting the relative hardiness of plants at the time of frosting. At the Botswana site only *L. lempirana* and *L. pulverulenta* possessed significant frost tolerance.

Plant survival following frosting was very high for all accessions at all sites. Where frost had severely damaged plant stems regrowth occurred from the crown. Frosting increased branching of arboreal accessions in Queensland, improving their utility as grazing plants.

Hughes (1993) predicted the frost tolerance of *Leucaena* accessions based on climate in the native range (Table 1). However, these predictions were inconsistent with field data from Queensland and Botswana. A revised frost tolerance rating based on data from these field trials is given in Table 1.

In summary, identification of frost resistance from these studies was difficult as frost damage was highly variable between sites. However, frost tolerance may be present in accessions of *L. pulverulenta, L. diversifolia, L. trichandra*, *L. leucocephala*, *L. pallida* and KX2 hybrids. Accessions of *L. macrophylla* subsp. *istmensis*, *L. lanceolata* subsp. *lanceolata*, *L. esculenta*, *L. salvadorensis* and *L. trichodes* were consistently frost susceptible at all sites. Climate in the native range of accessions of *Leucaena* was an unreliable predictor of frost and cold tolerance.

Acid-soil Adaptation in *Leucaena*

The genus *Leucaena* has evolved predominantly on calcareous soils of neutral to alkaline reaction (Hughes 1993) (Table 1). Not suprisingly, *L. leucocephala* is often reported to be intolerant of acid soils and associated infertility factors such as low calcium and phosphorus and high soluble Mn and Al saturation (Blamey and Hutton 1995). It is also thought to be poorly competitive for nutrients in acid soils when compared to acid-adapted native forages (Halenda 1989).

Acid soils cover more than 50% of agricultural lands of the tropics and sub-tropics and are predominantly highly leached, acid-infertile ultisols and oxisols (von Uexkull and Mutert 1993). Tropical acid soils are commonly deficient in Ca, Mg, K, P or Mo and the availability of many of these nutrients decreases as pH drops (Fisher and Juo 1995). Humid-tropical regions, ideally suited for development with *Leucaena* in climatic and socio-economic terms, are commonly limited by strongly acid and infertile soils.

Specific element toxicity and deficiency

The complexity of nutritional growth limitations to *L. leucocephala* was highlighted by Ruaysoongnern (1990), who reported negative effects of low pH, high aluminium and manganese concentrations, low phosphorus and calcium concentrations, and ineffective rhizobial and mycorrhizal symbioses. However, he found that *L. leucocephala* was not affected by acidity until pH dropped below 5.2 (1:5 H_2O), and that the reduction in growth could be attributed to sharply increasing concentrations of Al and Mn in the soil solution.

These findings concur with evidence from field trials in Nigeria (Cobbina et al. 1987) and Ethiopia (Berhe and Tothill 1995), where a range of accessions of *L. leucocephala* grew satisfactorily on acid soils of pH 5.1 (1:1 H_2O) with low Al saturation and high available P levels. However, high Al saturation is common in acid soils (Blamey and Hutton 1995) and can limit growth of *L. leucocephala* at pH levels below 6 (Fox and Whitney 1981; Olvera et al. 1982).

In Hawaii, the toxic effect of high soluble Mn concentrations to the growth of *L. leucocephala* was reported using a liming regime to create a pH gradient from 5.0–7.0 (Fox and Whitney 1981). The growth of *L. Leucocephala* increased linearly with increasing pH, and this was attributed to the sharp decrease in soluble Mn levels up to pH 5.8. The continued yield response from pH 5.8–7.0 was attributed to increased Ca availability.

Poor growth of *Leucaena* species on acid soils is commonly exacerbated by ineffective rhizobial and mycorrhizal symbioses (see Lesueur et al., these Proceedings).

Acid soil adaptation within the genus *Leucaena*

Many researchers have reported poor adaptation of accessions of *L. leucocephala* to acid soils compared to other more acid tolerant species. Survival of *L. leucocephala* in five acid soils (pH range 3.4–5.1) in Sarawak, East Malaysia was very poor (4%) compared to survival of *Acacia mangium* and *Paraserianthes falcataria* (58% and 69%, respectively) (Halenda and Ting 1993). However, an apparently modest level of acid-tolerance in *L. leucocephala* has been exploited in Malaysia, where cv. ML1 significantly outperformed cv. Cunningham on acid soils (Wong et al. 1997) and in Nigeria, where *L. leucocephala* accession K28 produced four times more dry matter than K8 on a mildly acid soil (Cobbina et al. 1987). Some tolerance of acid soils has been reported in other species of *Leucaena* including *L. macrophylla*, *L. shannonii*, *L. diversifolia* (K408 and K454), *L. trichandra* (K145a and CPI46568) and *L. pallida* (CPI85891) (Hutton 1981, Bray et al. 1997).

Hutton (1990) initiated a breeding program in 1979 to develop acid tolerant leuacenas based on hybrids of *L. diversifolia* and *L. trichandra* with *L. leucocephala* (Hutton and Chen 1993). Selection of four filial generations was carried out in a virgin oxisol (pH 4.5 with 85% Al saturation) in Brasil between 1982 and 1987 (Hutton 1990) and subsequently six generations were produced in Malaysia on three acidic soil types between 1986 and 1995 (Wong et al. 1997). In Brasil, approximately 60% of second, third and fourth generation segregating hybrid populations were vigorous, achieving 1.5–2.5 times the height and girth of cv. Cunningham. Hutton (1990) concluded that the acid-soil tolerance of the selected *L. diversifolia* and KX3 hybrids was due to greater tolerance of selected lines to the inhibitory effects of high exchangeable Al, thus allowing increased Ca uptake by plant roots.

Subsequently in Malaysia, the best hybrids, 40-1-18, *L. diversifolia* × *L. leucocephala* and 62-6-8, *L. trichandra* × *L. leucocephala*, outperformed cv. Cunningham, but were not consistently more productive than *L. leucocephala* cv. ML1. Edible fraction and DMDs were similar to cvv. ML1 and Cunningham but the hybrids had higher tissue Ca levels and were marginally more psyllid tolerant. This work has recently lead to the release of 2 cultivars based on the lines 40-1-18 (forage and wood production) and 62-6-8 (forage production) (Wong et al., these Proceedings).

Multi-site evaluations in acid-soil environments

Five acid soil sites were included in the multi-environment trial (MET) reported by Mullen, Shelton et al. (these Proceedings). At Sungei Putih in North Sumatra, Indonesia, the soil was mildly acid with low Al saturation, whereas soils at 4 sites in Vietnam, Philippines and Laos, were more acidic, with moderate to high Al saturation and low base saturation (Table 3). Yields of 24 accessions of *Leucaena* were assessed in 14 discrete environment periods during a 2-year evaluation period. Cluster and principal components analyses (Mullen, Shelton et al., these Proceedings) were used to identify specific adaptation to acid soil environments.

Mean yields were highest at Sungei Putih (>240 g/m row/month) and were comparable to yields achieved in highly productive environments in the MET, indicating that acidity factors at this site (pH 5.4 and Al saturation 2%) did not limit growth of *Leucaena* accessions. Bray et al. (1997) also reported excellent yields of *Leucaena* accessions at this site. In contrast, growth of leucaenas in more strongly acid environments was greatly depressed (Figure 3). At Bac Thai, Nam Suang, and Tanay, mean yield of all accessions was approximately 5 g/m row/month, whereas a slightly higher mean yield was achieved at Ha Tay (29 g/m row/month). Soils at the Ha Tay site contained high P concentrations (17 ppm Colwell) compared to the other strongly acid sites, despite similar pH and high Al saturation. This may have accounted for the superior growth at this site.

At the Tanay site in the Philippines, mean survival of 24 accessions of *Leucaena* was only 15% in unlimed plots. This site was characterised by high Al saturation (67%) and low soil pH (4.4, 1:5 in H_20). Application of 3 t/ha of lime reduced Al saturation to 49% and raised pH to 4.9, and although plant survival increased to 80%, growth of accessions was very poor. This result is consistent with the findings of many authors (Ruaysoongnern et al. 1989; Hutton 1990; Kerridge 1991) and confirm the severe effects of high exchangeable Al on survival and growth of *Leucaena*. The critical Al saturation percentage at which *Leucaena* accessions cease to produce worthwhile yields remains to be defined.

At Ha Tay, *L. pallida* CQ3439, *L. esculenta* OFI 47/87, *L. pallida* OFI 79/92, *L. macrophylla* OFI 47/85 and *L. salvadorensis* OFI 36/88 from accession groups 1–3 (Table 1) were the highest yielding accessions (average yield 48 g/m row/month) (Figure 1), producing 4 times the yield of cv. Cunningham. These accessions displayed above-average broad adaptation in the METs, but the yields achieved at Tanay, Bac Thai and Nam Suang were very low (average 6 g/m row/month).

There was poor stability of yield of accessions across strongly acid sites (Tanay, Bac Thai and Nam Suang). For example, *L. macrophylla* OFI 47/85 and *L. salvadorensis* OFI 36/88 were the most productive accessions at Nam Suang (average 14 g/m row/month), but were less productive at Tanay and Bac Thai. At the latter sites, *L. pallida* CQ3439, *L. diversifolia* K156 and *L. trichandra* OFI 4/91 were most productive (average 12 g/m row/month), but these accessions were very low yielding at Ha Tay and Nam Suang (2 g/m row/month). Only at the limed Ha Tay site were potentially useful yields achieved. Here, *L. pallida* CQ3439 produced 180 g/m row/month DM, outyielding the next best leucaenas by twofold and cv. Cunningham by sixfold. Bray et al. (1997) reported a similar result for *L. pallida* CPI85891 grown at acid soil sites in Australia and Indonesia.

Unfortunately, the high yielding KX2 F1 hybrid was included at only one acid soil site (Tanay) due to seed shortage, but the authors speculate that yields would have been at least as good as the best accessions. At Tanay, KX2 F1 was the highest yielding accession, outyielding cv. Cunningham by at least tenfold. However, ultimately it is probable that yields of less than 100 g/m row/month (approx. 2000 kg edible DM/year) will be considered insufficient to gain widespread adoption of a forage species by farmers. It is therefore unlikely that any accessions of *Leucaena*, incluing the KX2 F1, can achieve yields of this magnitude in the strongly acid soil environments of this study.

Prospects for developing acid-soil tolerant *Leucaena*

The development of acid soil tolerant *Leucaena* cultivars clearly represents a major challenge for a genus that has evolved in neutral to alkaline soils. Genotype × environment interaction studies indicated that the best yielding accessions of *Leucaena* possessed general vigour or broad adaptation rather than specific adaptation to acid soils. It is unfortunate that the hybrids of Hutton and Chen (1993) were not evaluated in the multi-site trials, but the available data suggest that they will not exceed the productivity of *L. pallida* accessions or the KX2 F1 hybrid. Although a degree of acid tolerance in *L. leucocephala* accessions ML1, K28 and K636 was identified in other studies, the productivity of these

Table 3. Soil (0–15 cm) and climate characteristics and environment group memberships for ACIAR multi-environment trial acid soil sites.

Country	Site	Environment	Soil pH (1:5 H_2O)	P (mg/kg Colwell)	CEC[1] (meq/100g)	Al sat'n (%)	Mean temp (°C)	Monthly rainfall (mm)
Philippines	Tanay (limed)	Establishment	4.7	10	6.6	38	24.1	283
		Year 2	4.7	10	6.6	38	23.8	105
	Tanay (unlimed)	Establishment	4.4	3	2.7	68	24.1	283
Vietnam	Ha Tay (limed)	Establishment	nda	nda	nda	nda	24.0	289
		1st hot season	nda	nda	nda	nda	27.2	240
	Ha Tay (unlimed)	Establishment	4.8	17	3.3	68	24.0	289
		1st hot season	4.8	17	3.3	68	27.2	240
Vietnam	Bac Thai	Establishment	4.9	6	2.4	39	23.3	110
		1st hot season	4.9	6	2.4	39	27.7	275
Laos	Nam Suang	Establishment	4.6	3	1.3	71	26.9	150
		1st wet season	4.6	3	1.3	71	27.8	333
Indonesia	Sungei Putih	Establishment	5.4	5	3.9	2	26.0	112
		1st wet season	5.4	5	3.9	2	26.0	130
		1st dry season	5.4	5	3.9	2	25.5	113
		2nd wet season	5.4	5	3.9	2	26.0	130

[1] Cation exchange capacity.

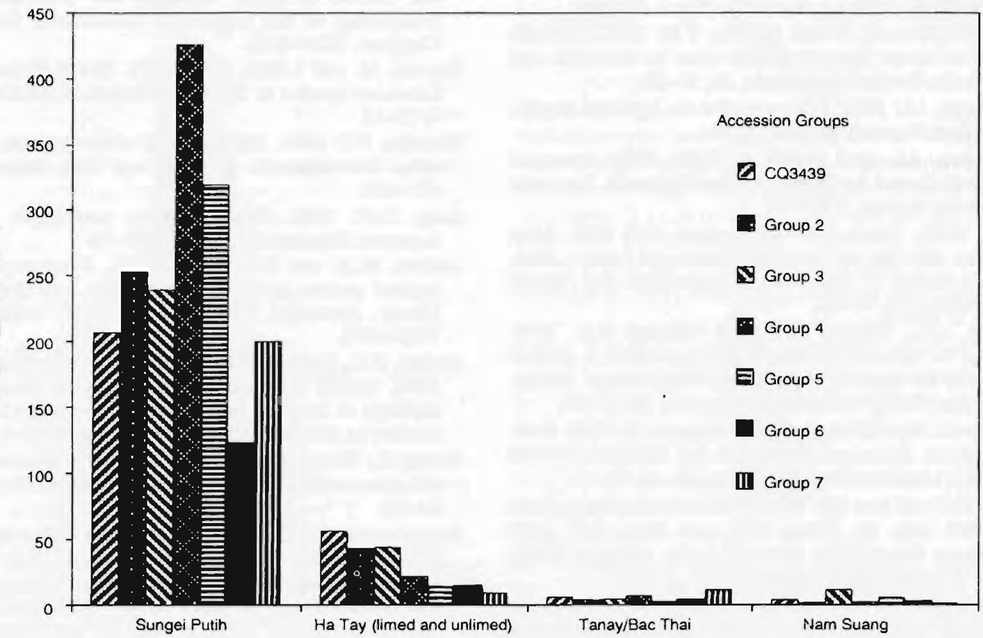

Figure 3. Yield response of *Leucaena* accessions to acid soil environments included in the ACIAR multi-environment trials (METs). Accession groups and environment groups were identified by cluster analysis (see Mullen, Shelton et al., these Proceedings). Accession group memberships are listed in Table 1.

accessions in strongly acid soils is likely to be low, leading to unsatisfactory yields 'on farm'.

Ultimately the value of leucaenas growing on acid soils will be gauged by their productivity and nutritive value in relation to more genuinely acid adapted forage shrub/tree legumes such as *Cratylia argentia*, *Desmodium rensonii*, *Calliandra calothyrsus* and *Gliricidia sepium*.

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Developing *Leucaena* Hybrids for Commercial Use

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Abstract

Leucaena breeding strategies in Hawaii and Brazil are based on tetraploid-level crosses using *Leucaena leucocephala*, *L. pallida* and *L. diversifolia* germplasm in various combinations. The objectives of the Hawaiian and Brazilian programs are to capitalise on heterosis of growth, psyllid-resistance, cold tolerance, and acid-soil tolerance. Hawaiian breeding objectives include increasing biomass yield, psyllid resistance for lowlands and cooler temperature tolerance for the upland tropics and subtropics. Brazilian objectives are largely associated with developing lines that have cold and acid-soil tolerance.

SPECIES from the *Leucaena* genus are fast growing neotropical trees and shrubs used for forage, green manure and fuelwood (Sorensson and Brewbaker 1994). There are 22 recognised species in the genus (Hughes 1997) an increase from 12 recognised species as recently as 1987 (Brewbaker 1987). Interspecific crossibility among 15 *leucaena* species is high with 77% of 118 combinations (reciprocals combined) producing viable seeds (Sorensson and Brewbaker 1994).

Interspecific hybridisation of *Leucaena* produces vigorous hybrids resulting in highly adaptable varieties that expand the range in which the plant can be grown (Austin et al. 1997). The predominantly grown species of *Leucaena*, is *L. leucocephala* (Brewbaker et al. 1989). However, *L. leucocephala* only reaches its full potential in psyllid-free lowland environments. Interspecific F_1 hybrids between *L. pallida* × *L. leucocephala* and *L. diversifolia* × *L. leucocephala* have increased biomass productivity and environmental adaptability. In Hawaii, the average yield of 14 interspecific F_1 hybrids (*L. pallida* × *L. leucocephala*) taken over seven harvests in an 18-month period was 24.0 t/ha/yr, and was four times higher than *L. leucocephala* (Brewbaker and Sun 1996). Austin et al. (1997) reported that the F_1 hybrid *L. pallida* K748 × *L. leucocephala* K636 significantly outyielded K636 not only in psyllid-infested lowlands, but also in cool tropical uplands. The advanced KX3 F_3 selections from the cross between *L. diversifolia* K156 × *L. leucocephala* K636 also outyielded K636 in the cooler uplands in the same study (Austin et al. 1997).

KX3 selections tolerate cold well in subtropical Brazil (de Freitas et al. 1995), and form the basis of a major breeding effort to identify cold tolerant *Leucaena* lines (de Freitas et al. 1991). Coincidentally, *L. diversifolia* also has genes for acid-soil tolerance (Hutton 1981) and KX3 hybrids between *L. diversifolia* × *L. leucocephala* have shown improved acid soil tolerance compared to the *L. leucocephala* parents (Hutton 1989).

Strategies for Developing Commercial Hybrid *Leucaena*

There are three major bottlenecks for expanding *Leucaena* production worldwide. These are psyllids, cold climates and low pH soils. The three most widely used polyploid *Leucaena* species (*L. diversifolia*, *L. leucocephala* and *L. pallida*) can be used to overcome these bottlenecks to produce F_1 hybrid and synthetic seed through judicious breeding and selection. Strategies should encompass either F_1 hybrid seed production, developing synthetic varieties

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through advanced selection, and direct use of interspecific F_1 hybrids via vegetative propagation.

Genetic variability for psyllid resistance in the genus is extensive. Resistant species include *L. pallida*, *L. esculenta* and *L. collinsii* subsp. *collinsii* (Austin et al. 1996; Glover 1987; Wheeler and Brewbaker 1989). The polyploid *L. pallida* is best suited for developing psyllid-resistant hybrids with *L. leucocephala* as observed in earlier studies (Austin et al. 1997). An added bonus of this cross is that it has greater cool temperature tolerance.

There are basically two types of cold tolerance that need to be considered when breeding cold tolerant *Leucaena* cultivars. The first is to breed trees for cooler environments with no frost hazard such as high elevational tropical locations. *Leucaena pallida* and *L. diversifolia* both impart cool temperature tolerance to their hybrids (Austin et al. 1997). The other cold-weather environmental constraint is located in the subtropics where the growing season for *Leucaena* is restricted by frosts and spring regrowth is relatively slow until warmer temperatures initiate budding. Since psyllids are not a major threat in subtropical environments where winter temperatures can dip below freezing (Austin et al. 1996), an intraspecific breeding approach using *Leucaena leucocephala* is a good method for developing highly vigorous and nutritious forage types.

The final environmental constraint in *Leucaena* breeding programs is acid soils below pH 5.0. *Leucaena* species and hybrids differ with respect to acid-soil tolerance (Hutton 1985; Oakes and Foy 1984). Some polyploid *L. diversifolia* lines are acid-soil tolerant (Hutton 1981) and hybrids between *L. diversifolia* × *L. leucocephala* have shown improved acid soil tolerance compared to the *L. leucocephala* parents (Hutton 1989). Breeding programs that target acid-soil tolerance can concurrently focus on cool temperature tolerance since some *L. diversifolia* lines impart both characteristics.

Bottlenecks to Commercial F_1 Hybrid Seed Production

In order to assure hybrid seed quality, the self-incompatibility (SI) of the female plant must be durable. Earlier efforts to produce F_1 hybrid seed have not succeeded because the SI mechanism somehow broke down. Bray and Fulloon (1987), working on the cross between grafted SI *L. pulverulenta* and *L. leucocephala,* produced an average of 15% hybrid seed over three years. In Hawaii, efforts to produce F_1 hybrid seed between SI *L. pallida* and *L. leucocephala* met with similar results. The cross between grafted SI *L. pallida* K953 and *L. leucocephala* K636 was only 27% hybrid, while the cross between grafted SI *L. pallida* K804 (an arboreal accession) and *L. leucocephala* K636 produced 81% hybrid seed (Brennen pers. comm.).

The same SI breakdown occurred in Australia where a small percentage of the cross between grafted SI *L. pallida* K748 and *L. leucocephala* K636 were F_1 hybrids (Shelton pers. comm.). There is a small chance that grafting may breakdown the SI mechanism and allow for self-pollination in these examples. What is more likely is pollen mentoring, which is self-pollination after the SI mechanism has broken down because of outcrossing.

The SI mechanism in *Leucaena* is reported to be gametophytic (Brewbaker 1982). Gametophytic incompatibility involves the presence of the same S-allele in pollen and style; when the S-allele is not matched in the style, fertility occurs (Brewbaker 1982). Pollen mentoring breaks down the SI mechanism of the plant whenever pollen from an outside *Leucaena* source comes in contact with the stigma. In effect, the outside pollen source opens the gate for self-pollination. This could be tested by examining seed from individual outcrossed pods with morphological characteristics such as Sorensson and Brewbaker (1994) employed. Maybe the only reliable method to assure purity of F_1 seed production is through male-sterility.

A second bottleneck concerning hybrid seed production is cloning. However, recent advances in Hawaii have helped eliminate this as a serious bottleneck. In Hawaii, a reliable cloning technique has been developed for many *Leucaena* species and F_1 hybrids. (Sun et al., these Proceedings). This improved technique has allowed the HARC-UH breeding program to develop clonal (non-grafted) seed orchards. Cloning can be used to capture F_1 hybridity by cloning superior F_1 field-tested trees. These trees can form the basis of a mother-plant system which can produce thousands of hybrid clones much like what is done in Eucalyptus plantations.

Another management bottleneck is compatibility of flowering to produce F_1 hybrid seed. In order to produce hybrid seed both parents must flower simultaneously. In Hawaii, flowering compatibility has been found between SI KX2 F_1 (*L. pallida* × *L. leucocephala*) and one *L. leucocephala* pollen donor. The authors are currently producing a three-way cross from this orchard whose progeny will have a 25% *L. pallida* and 75% *L. leucocephala* genetic makeup.

Commercial Clonal Seed Orchards

The Hawaiian breeding strategy encompasses both advanced (synthetic) and F_1 hybrid seed production. The breeding program has developed several seed sources that proliferate in a variety of environmental gradients. This has been achieved through the development of four clonal *Leucaena* seed orchards at Kunia, Hawaii (21° 21′ N, 155° 02′ W). Orchards are based on superior clonal material from trees that have been tested under many environments.

Orchard 1 is a F_6 composite called KX2 OHANA from the original cross between *L. pallida* K376 × *L. leucocephala* K8. This composite was derived from intense selection for psyllid resistance and vigorous regrowth to yield clones from 15 families (Austin 1995). The composite has excellent psyllid-resistance, handles intensive, rotational cattle grazing, and was selected for forage production in tropical low to mid-elevation environments.

Orchard 2 produces F_2 composite seed from six clonal intraspecific *L. leucocephala* F_1 hybrids. The original *L. leucocephala* parents were selected from several field tests and are composed of the F_1 hybrid combinations K397 × K565, K584 × K636, K608 × K565, K608 × K397 and K397 × K608. This composite was developed for subtropical locations like Texas and Australia. The composite yields 70% higher than K636 under forage management in Hawaii (Austin et al. unpub.)

Orchard 3 was developed to produce F_1 hybrid seed that is 75% *L. leucocephala* and 25% *L. pallida*. This orchard is made up of three distinct self-incompatible clonal F_1 hybrids based on *L. pallida* × *L. leucocephala* parentage: (K748 × K636, K748 × K584 or K748 × K481) which are crossed to an isozymically different *L. leucocephala* pollen donor (either K397 or K608). This cross will have superior forage characteristics in comparison to the KX2 cultivar OHANA, while maintaining the psyllid-resistance and cool temperature tolerance of the less forage-like *L. pallida*.

Orchard 4 capitalises on the male sterility of *L. diversifolia* K785 which, when crossed to *L. leucocephala* K636, will produce a new line of KX3 F_1 hybrids. KX3 F_1 progeny are fast-growing trees suited to lowland and cooler upland tropical environments. This line of hybrids may also do well in frost-prone areas of Southern Brazil.

Brazilian strategies are aimed at producing a synthetic composite of advanced KX3 selections at Eldorado do Sol, Brazil (30° 05′ S, 51° 39′ E) which show good cold tolerance and rapid recovery after winter (minimum temperatures in 1994 and 1995 were 8.8 °C and 7.2 °C, respectively). Testing in cooler areas has allowed researchers to identify several families with cold temperature tolerance. Five plants observed in the winters of 1994 and 1995 maintained 75% to 100% of their leaves (Simioni et al. 1997). It is envisioned that recurrent selection over years will eventually produce cold-tolerant plants for Southern Brazil.

Conclusions

The three major limitations (psyllids, cold climates, and acid soils) of *Leucaena* production can be overcome with use of interspecific F_1 hybrid and advanced selections of the hybrid. New *Leucaena* varieties have been produced that expand the range in which *Leucaena* can traditionally be grown. Commercial hybrid seed production is feasible and currently practiced in both Hawaii and Brazil on limited acreage. Further research must be conducted to assure hybrid purity and reliability of crosses.

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Rhizobium Specificity in *Leucaena*

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Abstract

Knowledge of the specificity of *Leucaena* for strains of rhizobia that form effective N-fixing associations is confined mostly to *Leucaena leucocephala*. However, recognition of the agroforestry potential of other species has stimulated an assessment of rhizobial requirements of all 22 species in the genus. In N-free systems, *Leucaena* exhibits very significant genotype interactions with rhizobial strains that form effective symbioses. Specificity for effectiveness was observed both between and within species. In two glasshouse experiments, all tested rhizobial strains formed nodules with all species, but the level of effectiveness, based on plant dry weights, ranged from totally ineffective to more effective than plants supplied with mineral nitrogen. Plant dry weight and nitrogen content responses were used to place host genotypes into three broad similarity groups. No strain of *Rhizobium* was universally effective on all host accessions, although several reasonably wide spectrum strains were identified and recommended for field testing. Need-for-inoculation field experiments should be used to assess the effectiveness of background rhizobial strains and when found to be unsatisfactory, newly planted *Leucaena* should be inoculated with suitable *Rhizobium*. Strain CB3060 has demonstrated an intrinsic competitive ability in the field, but other elite strains (CB3126 and LDK4), identified in glasshouse trials require field testing. The main factors affecting nodulation and N_2 fixation are identified as: 1) soil acidity and phosphorus deficiency; 2) high levels of nitrate-N in the soil; 3) moisture stress combined with high temperatures; and 4) the effects of defoliation. The importance of these observations to establishment of *Leucaena* in new areas, especially in acid soils, is discussed in relation to selection of suitable strains for successful early nodulation and plant growth.

TREE legumes are economically important in agroforestry systems, reducing inert gaseous N_2 to organic forms in symbiosis with the root-nodule bacteria (RNB), *Rhizobium*. In this way, they enable the legume to produce nitrogen-rich forage that may be used as green manure for other crops or which can be substituted for purchased protein concentrates in livestock feeds. Most of the fixed nitrogen is returned to the soil *via* animal excreta, root exudates and decaying leaf matter.

Leucaena leucocephala is the most widely studied and used nitrogen fixing legume tree species, especially for animal production and alley cropping systems in tropical countries (NAS 1984). However, the susceptibility of *L. leucocephala* to the psyllid insect (Mullen, Gabunoda et al., these Proceedings) and its poor adaptation to acid soils and low temperatures (Brewbaker and Sorensson 1990) have stimulated increasing interest in lesser known species of *Leucaena*.

Leucaena is a member of Mimosaceae and, as far as is recorded, all 22 species are known to nodulate with RNB (Allen and Allen 1981). With the exception of *L. leucocephala*, there is very little information available regarding the specificity or genotype interaction between the various species and accessions and effective strains of *Rhizobium*. *L. leucocephala* forms effective nitrogen fixing symbioses with fast-growing, acid-producing rhizobia (Allen and Allen 1981; Trinick 1968). In this respect, it can be grouped with other woody legume trees such as *Calliandra calothyrsus*, *Prosopis juliflora* and *Gliricidia sepium* (Turk and Keyser 1992; Lesueur et al. 1996). Although nodulated effectively by some of the same strains of *Rhizobium*, these legumes are moderately specific in their rhizobial requirements

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(Date and Halliday 1980). Thus, in the absence of effective soil strains or in the presence of ineffective strains of rhizobia, inoculation with appropriate rhizobia can improve establishment and yield (Singleton et al. 1992). The efficiency of the nitrogen-fixing symbiosis between *L. leucocephala* and *Rhizobium* is an intrinsic characteristic of the species or more exactly of the plant genotype × rhizobial strain combination (Dommergues 1995). It is, therefore, reasonable to expect similar specificities between and within the other species of *Leucaena*. As the potential of these additional species in agroforestry is now recognised, it is important that a more detailed knowledge of their rhizobial strain requirements is obtained.

This paper examines the rhizobial specificity requirements of the genus *Leucaena*, and some of the more important factors affecting nodulation and N_2 fixation in the field.

Host-Strain Interactions in N_2-Fixing Symbiosis

Species-strain interactions

In a recent glasshouse study in Australia, 27 accessions of *Leucaena* were evaluated for effective N_2 fixation with 13 strains of *Rhizobium* (Mullen et al. 1998). Two major species groups were identified based on effectiveness response indices (Figure 1). Group A contained 16 accessions, 8 of which (7 species and 1 hybrid) associated effectively with 10 or more strains, and Group B with 11 accessions, 3 of which (2 species and 1 hybrid) were highly specific and nodulated effectively with only 1 or none of the strains. Proximity of the accessions in their native range (geographic distribution) did not influence species groupings. Strain CB3126 formed the greatest number of effective associations (22) (Table 1) and the widely-used strain CB3060 (also known as TAL1145) was equally broad spectrum (21 effective associations) across the range of species. Strain NGR8 and 6 other strains were effective on at least 16 accessions of *Leucaena*. Strain MS111, although recommended for its performance in acid soils (Wong et al. 1989), was much less effective and on fewer species. Only strain CB3299, representing rhizobia from northern Australia, failed to form any effective associations.

In a similar glasshouse study in France, Lemkine and Lesueur (these Proceedings) assessed the effectiveness of 14 species of *Leucaena* with 7 rhizobial strains. Strain CB3060 maintained its good performance but strain LDK4 from Kenya was superior (12 of 14 accessions effective). Strain MS111 was again less effective and with fewer species (Table 2). When examined for efficiency of nitrogen fixation (nitrogen fixed/nodule dry weight) the species separated into three groups (Table 3), but no relationship

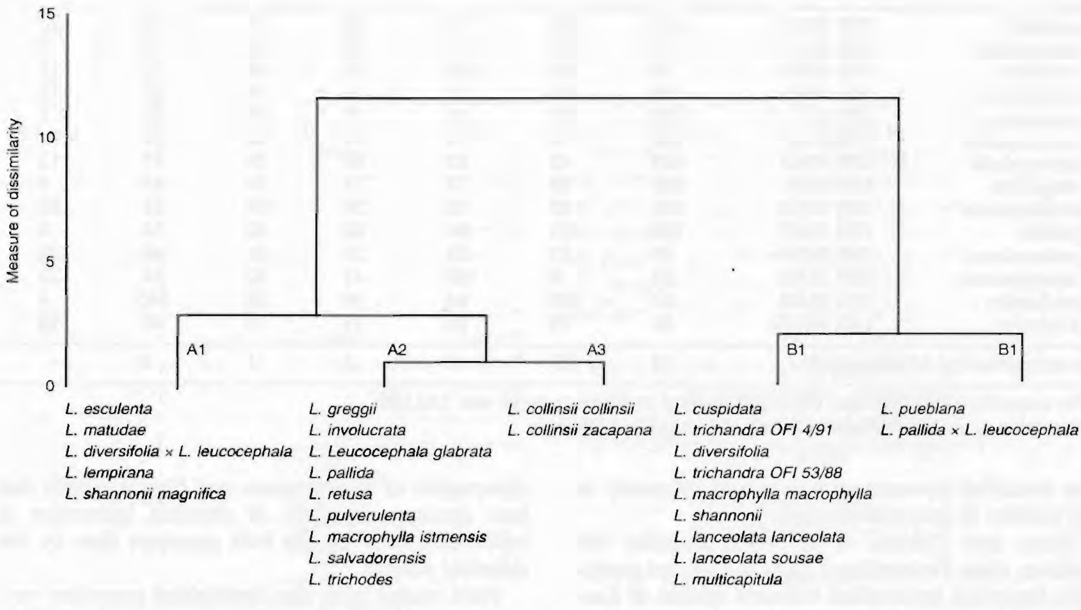

Figure 1. Dendrogram of accession groupings from cluster analysis, based on the level of association with 13 strains of *Rhizobium*.

Table 1. Growth responses of 16 accessions of *Leucaena*, grown in an N-free system, to six strains of *Rhizobium* (Source: Mullen et al. 1998). Data are presented as percentages of weight of plants inoculated with the most effective strain for each accession.

Species	Accession	CB3216	CB3060	NGR8	NifTAL	MS111	CB3299	Uninoc. Control*
L. collinsii	OFI 52/88	69	69	100	72	29	11	15
L. diversifolia+	OFI 83/92+	80	80	58	74	58	14	13
L. esculenta	OFI 47/87	98	82	100	86	50	18	24
L. lanceolata	OFI 43/85	99	46	59	100	40	14	13
L. lempirana	OFI 6/91	100	83	76	78	45	12	8
L. leucocephala	cv. Cunningham	91	96	100	76	60	9	17
L. macrophylla	OFI 47/85	100	45	87	80	54	9	12
L. magnifica	OFI19/84	98	65	61	100	49	16	16
L. multicapitula	OFI 87/92	92	97	61	100	44	17	14
L. pallida	OFI 52/87	100	98	96	99	69	13	13
L. pulverulenta	OFI 83/87	100	91	61	79	44	14	12
L. salvadorensis	OFI 36/88	100	49	73	78	51	15	18
L. trichandra	OFI 53/88	100	100	96	100	40	17	14
L. trichodes	OFI 61/88	100	67	83	93	61	24	23
L. pallida × *L. leucocephala* F5 hybrid		89	83	100	68	53	10	17
L. diversifolia × *L. leucocephala* F2 hybrid		87	93	100	68	66	10	11
No. accessions (of 27) effective‡		22	21	17	17	2	0	

* Equivalent values for +N controls ranged from 65 to 130
+ For accession OFI83/92 the best performing strain was CB3522
‡ Accession-strain interactions of ≥80% are considered effective

Table 2. Growth responses of 14 accessions of *Leucaena*, grown in an N-free system, to six strains of *Rhizobium* (Source: Lemkine and Lesueur, these Proceedings). Data are presented as percentages of weight of plants inoculated with the most effective rhizobial strain for each accession.

Species	Accession+	LDK4	CCR10	CB3060	CCK13	PJ12	MS111	Control
L. collinsii	OFI 52/88	100	57	72	49	39	47	10
L. diversifolia	OFI 83/92	62	87	100	59	25	28	4
L. esculenta	OFI 47/87	74	66	100	51	64	31	12
L. lanceolata	OFI 43/85	100	76	72	71	39	66	25
L. lempirana	OFI 6/91	100	71	53	71	19	33	7
L. leucocephala	79/02348	100	0	72	91	86	85	14
L. macrophylla	OFI 47/85	100	42	82	90	58	47	12
L. magnifica	OFI19/84	100	89	78	75	34	54	9
L. multicapitula	OFI 87/92	100	82	72	59	59	61	23
L. pallida	OFI 52/87	100	53	84	82	62	54	6
L. pulverulenta	OFI 83/87+	90	57	51	35	61	40	22
L. salvadorensis	OFI 36/88	84	0	100	41	42	44	23
L. trichandra	OFI 53/88	84	100	64	70	36	845	4
L. trichodes	OFI 61/88+	85	95	66	73	73	60	10
No. accessions (of 14) effective‡		12	5	5	3	1	2	

+ For accessions OFI83/87 and OFI61/88 the best performing strain was TAL582
‡ Accession-strain interactions of ≥80% are considered effective

was identified between groupings and proximity to one another in their native range.

These data (Mullen et al. 1998; Lemkine and Lesueur, these Proceedings) show strong and practically important interactions between species of *Leucaena* and strains of rhizobia for effective nitrogen fixation, and they provide strong support for the observation of Somasegaran and Martin (1986) that host genotype × strain of rhizobia interaction is influenced more by the host genotype than by the rhizobial partner.

Field studies have also highlighted accession variation for N_2 fixation. Sanginga et al. (1990a) reported significant differences in the percentage of

Table 3. *Leucaena* accession groups based on efficiency for N2 fixation in association with 7 strains of *Rhizobium* (nitrogen fixed/nodule dry weight) (source: Limkine and Lesueur, these Proceedings).

High N_2 fixation potential	Intermediate N_2 fixation potential	Low N_2 fixation potential
L. leucocephala 79/02348	*L. collinsii* OFI 52/88	*L. multicapitula* OFI 87/92
L. macrophylla OFI 47/85	*L. diversifolia* OFI 83/92	*L. pulverulenta* OFI 83/87
L. magnifica OFI 19/84	*L. esculenta* OFI 47/87	*L. salvadorensis* OFI 36/88
L. pallida OFI 52/87	*L. lanceolata* OFI 43/85	
L. trichodes OFI 61/88	*L. lempirana* OFI 6/91	
	L. trichandra OFI 53/88	

nitrogen derived from atmospheric N_2 (% Ndfa ranged from 37% to 74%) for accessions of *L. leucocephala*. Provided that strains such as CB3126 and LDK4 are ecologically competent and able to form nodules in field situations, they provide a potential for increased N-fixation for a range of species of *Leucaena*. Strain CB3126 is known to persist for 3 years and forms a high proportion of nodules on *Desmanthus virgatus* (Brandon et al. 1998). However, its performance in acid soils is not known.

Rhizobium specificity within species of _Leucaena_

The efficiency of the nitrogen-fixing symbiosis between strains of *Rhizobium* and host legumes is dependent on both the host plant and the microbial partner. As with herbaceous and shrub legumes, tree legumes have varying degrees of specificity.

This variability was observed in *L. leucocephala* cv. Cunningham when it was inoculated with 135 strains of rhizobia that originated from Mexico, Colombia, Antigua, Hawaii and Australia (Figure 2) (R.A. Date, unpublished data). Since these plants were grown in an N-free system, the plant dry weights can be used as an index of the effectiveness of the strains used to inoculate the plants. Assuming that these strains represent regional populations of rhizobia for leucaena in each of the countries, it is evident that new sowings of *L. leucocephala* would need to be inoculated with an effective strain of rhizobia to obtain early nodulation, establishment and growth in those areas represented by the ineffective strains.

A similar diversity in response was obtained for *L. diversifolia* inoculated with 14 strains of different origins (Bahij and Lesueur, unpublished data). In addition, responses varied with different accessions of *L. diversifolia*. Strain CCR20B was less efficient than strain ORS800 on accession 94/10175 but the responses were reversed with accession 92/9283 (Figure 3). Variation of this kind in *L. leucocephala* and *L. diversifolia* and in their rhizobial partners appears common to all species of the genus. Further studies aimed at documenting the extent of this type of variation across the genus is recommended.

Inoculation of Leucaena in Field Conditions

Lack of nodulation following introduction of *L. leucocephala* to new areas has been observed in Australia (Norris 1973; Bushby 1982a), Malaysia (Wong et al. 1989), Thailand (Homchan et al. 1989), Nigeria (Sanginga et al. 1989), the eastern plains of Colombia (Halliday and Somasegaran 1983) and Kenya (Shepherd et al. 1996). This poor nodulation occurs due to the absence or scarcity of compatible rhizobia in the soil. Field studies have demonstrated that the early growth of *L. leucocephala* can be improved significantly by inoculation with specific *Rhizobium* (Norris 1973; Bushby 1982a; Wong et al. 1989; Homchan et al. 1989; Sanginga et al. 1989). However, in several instances the growth differences between inoculated and uninoculated plants were not evident 1–2 years after sowing (Homchan et al. 1989; Bushby 1982a; Norris 1973). Where growth of uninoculated plants is satisfactory this may indicate the presence of effective background strains in the soil. However, loss of benefit from inoculation with an effective strain may be due to poor adaptation to soil conditions and to competition from ineffective indigenous rhizobial strains. Locations such as the eastern Colombian Llanos (Halliday and Somasegaran 1983) and Nigeria (Sanginga et al. 1994) are wholly dependent on inoculation with effective strains for good growth and the maintenance of those growth differences. In Nigeria, introduced rhizobia were recovered in the nodules of plants 10 years after the original inoculation. Surviving strains were equally effective as the original inoculum and accounted for 95% or more of the nodules formed (Sanginga et al. 1994).

In soils where leucaena is sparsely nodulated because the number of resident soil strains is low (Bushby 1982a), and where *L. leucocephala* has not previously been cultivated (Halliday and Somasegaran 1983; Sanginga et al. 1989) it is necessary to inoculate with the appropriate strains of *Rhizobium*. The inoculum strain must have an intrinsic competitive ability to form nodules and to colonise root systems readily (Dart, 1994). Moawad and Bohlool

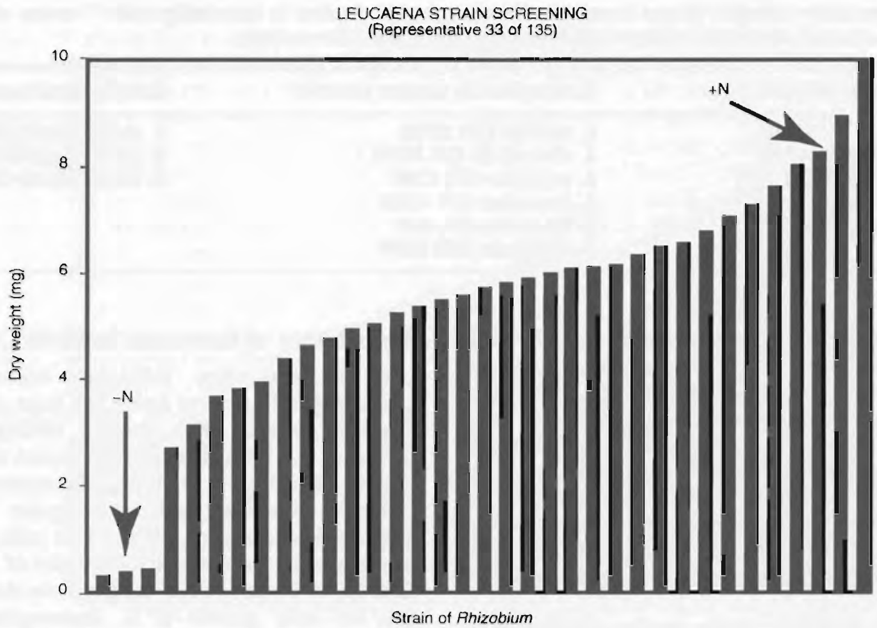

Figure 2. Dry matter yield of *L. leucocephala* cv. Cunningham grown in an N-free system with a representative set (33 of 135) of strains of *Rhizobium* originating from Mexico, Antigua, Colombia, Hawaii and Australia.

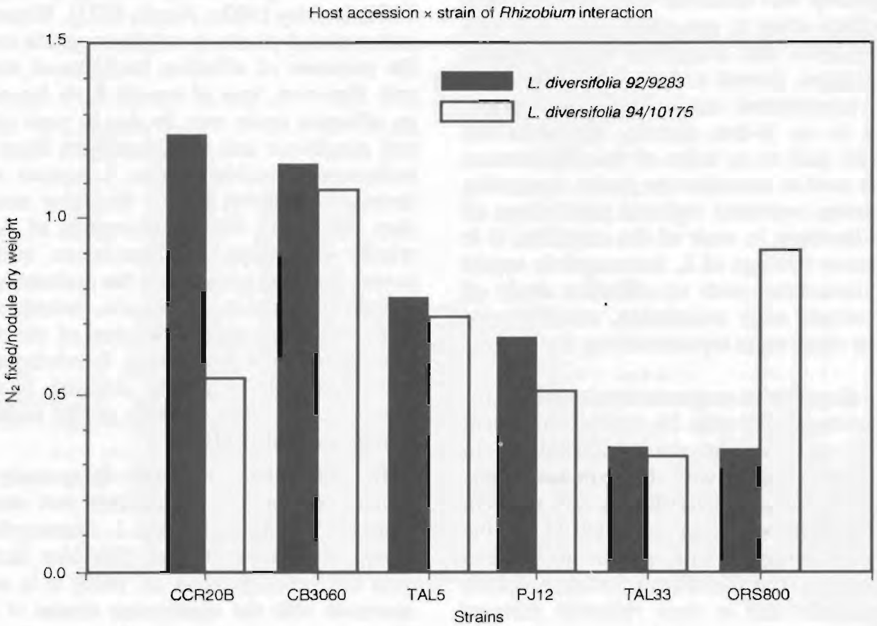

Figure 3. Nodule efficiency of two accessions of *L. diversifolia* grown in an *Rhizobium*-free system with six effective, or partially effective, strains of *Rhizobium*.

(1984), Homchan et al. (1989), Wong et al. (1989) and Somasegaran and Martin (1986) advocated the utilisation of the *Rhizobium* strain CB3060 (=TAL1145) as an elite strain for *L. leucocephala* and *L. diversifolia* due to its high capacity for nitrogen fixation, excellent competitive ability in the presence of indigenous rhizobia and its adaptation to acid soils. Some researchers prefer to use a mixture of strains of rhizobia for field inoculation. For example, the Oxford Forestry Institute and the NIFTAL Project of the University of Hawaii distribute a mixed inoculum containing three strains (one of which is CB3060) with all seed lots of *Leucaena* (Hughes 1993).

Factors Affecting Nodulation and N_2 Fixation

L. leucocephala has a high N_2-fixing potential (>30–50 g N_2 fixed/tree/year; Dommergues 1995) but the actual amount of N_2 fixed in the field is lower than the N_2-fixing potential and may be negated altogether by environmental constraints (O'Hara et al. 1988; Danso et al. 1992). The four main limiting factors are: 1) soil acidity combined with a deficiency in soil phosphorus; 2) effect of available N in soil; 3) moisture stress combined with elevated temperatures; and 4) effect of defoliation.

1. Soil acidity and phosphorus availability

Aluminium toxicity and phosphorus deficiency are recognised as the main factors affecting the growth of *L. leucocephala* in acid soils (Almeida et al. 1981; Duguma et al. 1988; Mullen, Castillo, et al. these Proceedings). There has been some debate as to whether acidity *per se* has more effect on the host plant roots or on the associated rhizobia responsible for nodulation and nitrogen fixation. Halliday and Somasegaran (1983) described the results of selection programs in Colombia and in Hawaii in which they identified new strains of *Rhizobium* with high levels of tolerance to soil acidity. One of these strains CB3060 (=TAL1145) was found to be more competitive for nodulation (Moawad and Bohlool, 1984) than other selected or indigenous strains. However, despite the effective nodulation, plants in plots at pH 4.5 remained less developed than neighbouring plants in plots limed to pH 6.0 (Halliday and Somasegaran 1983). These data suggest that the poor performance of leucaena in acid soils can be attributed to the leucaena-plant genome, providing the rhizobial partner is acid tolerant, rather than to its rhizobial partner. Ruaysoongnern (1990) reported the opposite result using a mixed inoculum of CB81, a moderately acid-tolerant strain of *Rhizobium*, and NGR8, an acid-intolerant strain.

Phosphorus fertilisation and liming of soil also affect N supply via symbiosis but experimental results are not always clear. Brandon and Shelton (1997a, 1997b) failed to obtain a response to lime in moderately acid soils, whereas Ruaysoongnern (1990) found a positive response. A combined application of lime and phosphorus in three soils in Nigeria significantly enhanced growth of *L. leucocephala,* but the magnitude of the responses varied with soil type (Duguma et al. 1988). High rates of lime (2000 ppm in a pot experiment) limited growth of plants in one of the soils, but in general, lime and phosphorus interacted positively (synergistically) resulting in significant improvement in plant growth. It is highly likely that the responses to lime were in fact responses to improved nodulation and nitrogen fixation. Unfortunately, Duguma et al. (1988) did not provide data regarding the nodulation of the plants. Norris (1973) showed that nodulation of *L. leucocephala* in field conditions was improved when seed was lime-pelleted. Sanginga et al. (1989) noted that *L. leucocephala* needed about 80 kg/ha P for good establishment in Nigerian soils, especially when it is effectively nodulated. This high demand for phosphorus by *L. leucocephala* for both normal growth and nodulation, is supported by more recent work by Brandon and Shelton (1997a; 1997b) and Brandon et al. (1997). Another important aspect of this problem is the demonstrated dependence of *L. leucocephala* on mycorrhizal associations for improved P supply (Habte and Manjunath 1987; Shepherd et al. 1996; Brandon and Shelton 1997a, 1997b). Phosphorus deficiency can be overcome by phosphorus fertilisation and/or selection of species or accessions of *Leucaena* tolerant to low phosphorus soils. Large differences in growth and P use efficiency within eleven accessions of *L. leucocephala* were observed by Sanginga et al. (1991). These differences were crucial at early growth stages and suggest that selection of *L. leucocephala* accessions tolerant to phosphorus deprivation deserves further investigation.

2. Effect of available soil nitrogen

The inhibitory effect of plant available nitrogen on nodulation and N_2-fixation is common in most symbiotic nitrogen fixing associations. However, the extent of the inhibition is highly variable and reflects the extent to which both the host legume and the rhizobial strain are tolerant of nitrogen in respect to nodulation (Vessey and Waterer 1992; Dommergues 1995; Sanginga et al. 1995). There is little specific information available for leucaena, although it is presumed that the presence or absence of nodules largely reflects level of available nitrogen under non-defoliated stands. That is, as N accumulates in the soil, dependency on nodule-N declines, but then returns when the soil N levels decline. Such an hypothesis is supported by the evidence that N_2-fixation of well-nodulated *L. leucocephala* was reduced by 50% with 40 or 80 kg/ha of nitrogen fertiliser (Sanginga et al. 1988); that *L. leucocephala* obtained 80% of its nitrogen from fixation (pNdfa) at 12 and 18 months, but only 70% at 24 months (Parrotta et al. 1994, 1996); and that as available soil nitrogen accumulated in a *L. leucocephala* plantation, symbiotic nitrogen-fixing activity declined steadily and ceased within 6 years of planting (Van Kessel et al. 1994). If this observation reflects the general situation in the *Leucaena* genus then agronomic solutions may need to be devised to limit this inhibition. Defoliation management by grazing and cutting may be sufficient, but it may be possible to exploit the variation between species (and even accessions), to select or breed genotypes with greater tolerance to soil N as suggested by Sanginga et al. (1992) for *Gliricidia sepium*.

3. Moisture and high temperature stresses

Although leucaena is described as a species that performs well in rainfall environments from 650 to 3000 mm, soil moisture appeared to be a major limitation to growth of *L. leucocephala* at two inland sites (Theodore and Gayndah) in southeast Queensland, with mean annual rainfall of approximately 725 mm (Brandon and Shelton 1997a). This seems contrary to the fact that leucaena is naturalised in regions of Hawaii that receive only 300 mm annual rainfall (Brewbaker et al. 1985) and reports that it is very drought tolerant even during establishment (Swasdiphanich 1992). However, none of these reports described the nodulation status of leucaena under these dry conditions. In dry soils, infection is restricted because normal root hairs are not present but instead appear short and stubby and inadequate for infection by rhizobia (Lie 1981). In addition, nodules initiated under dry conditions are generally retarded and do not develop (Bordeleau and Prevost 1994). Similarly, nitrogen fixation is inactivated rapidly if moisture stress exceeds 20% of nodule fresh weight (Sprent 1971) but is restored without structural damage if this value is not exceeded. Plants with active nodule meristems, such as in leucaena, are able to resume growth quickly when the water stress is removed.

L. leucocephala is described as a tropical species requiring warm (25–30 °C) day temperatures for optimum growth (Brewbaker *et al.* 1985). The optimum temperature for nodulation and nitrogen fixation by most rhizobia ranges between 25–30 °C (Bushby 1982b; Trinick 1982). Data specific to leucaena are very few, however, the optima for nodulation and nitrogen fixation are near 25 °C (R.A. Date, unpublished data). In an N-free medium at 25 °C, plants were nodulated 8–13 days after sowing inoculated, pregerminated seed. When these plants were then exposed to root temperatures of 25, 30 and 35 °C, all at the same shoot temperature of 25 °C, nodulation and growth decreased significantly as root temperature increased (Table 4). For seedling plants, this effect is ameliorated by the presence of the cotyledons at 30 °C, but not at 35 °C. Temperatures in the root zone of tropical soils frequently exceed 30 and 35 °C for extended periods (Eagles and Date, unpublished data). The effects are not so marked for plants receiving mineral nitrogen.

Table 4. Effects of root temperature and source of N on growth of seedling *Leucaena leucocephala*.

Treatments	Root temperature	Dry weight (mg)
Cotyledons present, *Rhizobium* inoculated	25 °C	209
	30 °C	201
	35 °C	150
Cotyledons present, NO_3-N supplied	25 °C	284
	30 °C	223
	35 °C	229
Cotyledons removed, *Rhizobium* inoculated	25 °C	174
	30 °C	129
	35 °C	114
Cotyledons removed, NO_3-N supplied	25 °C	217
	30 °C	186
	35 °C	200

4. Effects of defoliation

The influence of periodic defoliation on nodulation is not well documented (Sanginga et al. 1990b; Fownes and Anderson 1991). Snoeck (1996) observed that when the aerial parts of *L. leucocephala* were cut, there was a substantial decrease in the quantity of nodules after different periods. In a more detailed study, Kadiata et al. (1997) observed that 16 months after planting nodule dry weight decreased by 12% in plants defoliated successively at 4, 8 and 12 months, compared to non-defoliated plants, but by as much as 54% if defoliated only once at 12 months. Cumulative data values for nodule dry weight could well show significant increases since new nodules will form and existing nodules will regrow in response to top regrowth after defoliation. Snoeck (1996) has shown that almost three months were necessary for the quantity of nodules and nitrogen fixing activity to return to the predefoliation level. Acetylene reduction assay on defoliated plants of *L. leucocephala* was markedly reduced compared to non-defoliated plants (Eriksen and Whitney 1982).

Future Research

The development of commercial cultivars of *Leucaena* has increased in momentum in recent years with the screening of large collections of lesser known accessions (Mullen and Shelton, these Proceedings) and the release of hybrid accessions in Malaysia (Wong et al., these Proceedings) and USA (Austin et al., these Proceedings). Research to date has highlighted *Leucaena* accession × rhizobial strain interaction for effective N_2 fixation and hence the necessity to identify elite rhizobial strains for these new cultivars. While there exist several rhizobial strains with broad effectiveness in the genus, e.g., CB3060, CB3126 and LDK4, these strains were only moderately effective in association with an agronomically important hybrid accession (Mullen et al. 1998). The identification of rhizobial strains, tolerant of acid soil conditions, that associate effectively with acid tolerant hybrid accessions is of immediate necessity.

Much of the accession × strain interaction work with *Leucaena* has been carried out under controlled conditions in the glasshouse. It is essential that the field competency of such strains is determined under field conditions. The authors recommend that simple need-to-inoculate trials (Date 1977) should be an essential prerequisite for rhizobial strain evaluation. Such trials should be done in the target area. This requirement is paramount as new cultivars are released about which rhizobial strain requirements are unknown. It is especially important as the adaptation boundaries of *Leucaena* and its rhizobial partners are stretched. The ability to form nodules in the presence of high levels of soil nitrogen, to compete with any native rhizobia, and to survive as free-living organisms as nodules 'cycle' on the root system is recognised as the most important criteria.

Where successful introduction of a new cultivar is dependent on simultaneous introduction of a suitable rhizobial partner, methods of inoculation are important. Improved survival of the inoculum rhizobia on the seed and the development of technologies that optimise rhizobial growth in the soil and infection of the host plant are aspects that deserve renewed investigation.

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Poster Papers
Wood

Wood Density and Yield in the Genus *Leucaena*

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Abstract

Despite acute fuelwood shortages occurring throughout the developing world, relatively little is known of the wood quality of important multi-purpose tree genera such as *Leucaena*. To address this knowledge shortfall, 33 accessions of *Leucaena*, representing 18 taxa, were assessed for wood density from samples collected from *Leucaena* evaluation trials in Guatamala, Philippines and Australia. Density was chosen as a measure of wood quality as it is easily assessed and is directly related to other wood quality characteristics such as compressive and tensile strength and calorific value. Wood densities of accessions were generally consistent across sites, with *L. shanonni*, *L. collinsii* subsp. *zacapana* and *L. magnifica* accessions having the highest wood densities and *L. multicapitula* and *L. pulverulenta* having the lowest wood densities. Although wood density of accessions was uncorrelated with accession wood yield, *L. salvadorensis* and *L. collinsii* subsp. *zacapana* accessions produced high yields of dense wood.

FOR many farmers, the principal product from agroforestry trees, and especially *L. leucocephala*, is fodder for ruminant livestock. Accordingly, greater research effort has been directed towards improving leaf yield and quality than towards wood production. Nevertheless, wood produced on farms is an important output. For example, in 1994, Asia was able to meet only 33% of its fuelwood requirement with serious shortfalls occurring in Myanmar, Malaysia, Indonesia, China, Cambodia and Bhutan (Anon. 1996). However, there has been little attempt to quantify wood quality and, to a lesser extent, productivity in most agroforestry tree species.

Comprehensive exploration and seed collection programs covering a trees' native range are expensive and time consuming, and few organisations are in the position to fund, or provide expertise to embark on this initial phase of a species introduction program. This situation has meant that agroforestry tree evaluation programs are frequently initiated with seed from only a small number of well-known species. This approach may exclude potentially useful closely related species from entering evaluation programs. While *L. leucocephala* has been promoted heavily throughout the tropics, the remaining species within the genus, which exhibit a diversity of growth and quality characteristics, and are valued and exploited by farmers within their native ranges (Hughes 1993), remain largely unknown.

Wood of *L. leucocephala* is described as being strong, light-weight and easy to work (National Research Council 1984; Rao 1984; Van Den Beldt and Brewbaker 1985). It has been utilised for products ranging from fuelwood to higher value items such as furniture, flooring and carvings (J.L. Brewbaker, pers. comm.), and for pulp and industrial energy production (Pottinger and Hughes 1995). Detailed assessments of wood quality are usually undertaken by subjecting large, defect free samples of mature stem wood to a series of mainly destructive tests. Fortunately, timber properties of most value to farmers, including compressive and tensile strength and calorific value, are related directly to density (Pension and De Zeeuw 1980; Zobel 1980) and can be measured relatively easily from small samples of wood. Van den Beldt and Brewbaker (1985) reported that *L. leucocephala* produced wood of medium density. MacDicken and Brewbaker (1982) recorded

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a specific gravity (SG) of between 0.45 and 0.55, a value that compares favourably with other commonly grown fuelwood species such as *Gliricidia sepium* (0.5–0.6; Withington et al. 1987), *Albizia* spp. (0.45–0.59; Chundoff 1984), *Calliandra calothyrsus* (0.51–0.78; National Academy of Sciences, 1980; B. Duguma, unpublished data) and *Prosopis juliflora* (0.7; National Academy of Sciences 1980), considered one of the best fuelwood species.

The calorific value of *L. leucocephala* is comparable to other fast-growing non-resinous hardwoods (Pottinger and Hughes 1995), and some interest has been shown in exploiting this attribute in combination with its rapid growth rate. Only in the Philippines, however, have extensive dendrothermal energy schemes based on *L. leucocephala* been developed, and these have met with mixed success (Brewbaker 1987). Wood of *L. leucocephala* has excellent pulping qualities for the production of printing and writing paper (Brewbaker 1987; National Research Council 1984) but is unsuitable for heavy construction due to its low durability and susceptibility to termite attack (Bagwan 1983).

Although it is unlikely that any of the lesser known *Leucaena* species will match *L. leucocephala* in terms of its forage quality, the same cannot be said of wood quality or productivity. Within the native range of the genus, stretching from southern Texas through Mexico and Central America to Peru, several *Leucaena* species are preferred to *L. leucocephala* for both construction and fuel (Hughes 1993).

This paper reports on the wood density and yield of a range of species in the genus *Leucaena*.

Materials and Methods

Field trials selected for inclusion in the study were established for the purposes of assessment of wood or forage biomass. The majority of trials in the Leucaena R & R Network (LEUCNET) were established principally to investigate the production of animal fodder, and comprised four replications of ten-tree line plots with 50 cm between trees and 3 m between rows. Some were established principally to investigate wood production and utilised a range of designs based on block planting, determined largely by the number of trees available. Selection of the three trials for investigation of wood density was based on the large range of taxa included in these trials. The trials employed in the productivity study were those for which results of measurement of woody biomass were available (Table 1).

For the wood density evaluation sections of stem approximately 15 cm in length of a range of taxa (Table 2) were cut at 1.3 m from the base of either two or three trees of each taxon in each of the two replications in the trial. The sections were air-dried, de-barked, conditioned to 12% relative humidity, and the length, diameter and weight of each sample were measured. Analyses of variance were performed on mean values of density of each accession at each site.

Table 1. LEUCNET trials used in the study.

Trial location	Organisation managing trial	Principal trial objective	Study for which trial was used
Redland Bay, Queensland, AUSTRALIA	School of Land and Food, University of Queensland	Leaf biomass	Wood density
La Soledad, Comayagua, HONDURAS	Forest Conservation & Tree Improvement Project (CONSEFORH)	Wood biomass	Wood density and productivity
Dahod, INDIA	Kribhco Indo-British Rainfed Farming Project	Leaf and wood biomass	Wood productivity
Jhansi, Utta Pradesh, INDIA	National Research Centre for Agroforestry	Wood biomass	Wood productivity
Makoka, MALAWI	International Centre for Research in Agroforestry (ICRAF)	Wood biomass	Wood productivity
Lae, PAPUA NEW GUINEA	PNG University of Technology	Leaf biomass	Wood productivity
Markham Valley, PAPUA NEW GUINEA	Department of Agriculture & Livestock	Leaf biomass	Wood productivity
IRRI, Los Baños, PHILIPPINES	Forages for Smallholders Project	Leaf biomass	Wood density and productivity
Tabora, TANZANIA	ICRAF	Wood biomass	Wood productivity
Chiang Mai, THAILAND	Faculty of Agriculture, University of Chiang Mai	Leaf biomass	Wood productivity
Chipata, ZAMBIA	ICRAF	Wood biomass	Wood productivity
Dombashawa, ZIMBABWE	ICRAF	Wood biomass	Wood productivity

Table 2. Density measurement of the *Leucaena* accessions used in the study

Species	Seed source			Mean density (g/cm³)				
	OFI ID. No.	Provenance	Country	Australia	Philippines	Honduras	Mean	SE
L. collinsii subsp. *collinsii*	51/88	Chacaj, Huehuetenango	Guatemala	0.71	0.71	0.69	0.70	0.0067
L. collinsii subsp. *zacapana*	18/84	Puerto de Golpe, Progresso	Guatemala	0.72	0.88	0.87	0.82	0.0506
L. collinsii subsp. *zacapana*	56/88	Gualan, Zacapa	Guatemala	0.76	0.76	0.90	0.81	0.0456
L. collinsii subsp. *zacapana*	57/88	El Carrizal, Chiquimula	Guatemala	0.85	0.73	0.95	0.84	0.0636
L. diversifolia	45/87	Corral Falso, Veracruz	Mexico	0.66	0.70	0.70	0.69	0.0133
L. diversifolia	46/87	Xalapa, Veracruz	Mexico	0.44	0.71	0.67	0.61	0.0847
L. diversifolia	K156*	Univ. of Hawaii	USA	0.42	0.62	0.72	0.59	0.0870
L. esculenta	47/87	San Marin Pachivia, Guerro	Mexico	0.71	0.68	0.72	0.70	0.0123
L. esculenta	48/87	Tiringucha, Michoacan	Mexico	0.60	0.65	0.68	0.64	0.0234
L. hybrid	52/87	San Pedro Chapulco, Puebla	Mexico	0.66	0.65	0.67	0.67	0.0076
L. lanceolata var. *lanceolata*	43/85	San Jon, Oaxaca	Mexico	0.65	0.73	0.75	0.71	0.0306
L. lanceolata var. *lanceolata*	44/85	Escuinapa, Sinaloa	Mexico	0.65	0.80	0.70	0.72	0.0442
L. lanceolata var. *sousae*	50/87	Cacalote, Oaxaca	Mexico	0.69	0.80	0.77	0.75	0.0388
L. lanceolata var. *sousae*	51/87	Puerto Angal, Oaxaca	Mexico	0.75	0.72	0.73	0.74	0.0116
L. leucocephala subsp. *glabrata*	32/88	Operation Double Harvest	Haiti	0.56	0.68	0.69	0.65	0.0424
L. leucocephala subsp. *glabrata*	45/88	Operation Double Harvest	Haiti	0.55	0.64	n/a	0.60	0.0425
L. leucocephala subsp. *glabrata*	K636*	Univ. of Hawaii	USA	0.61	0.63	0.59	0.61	0.0111
L. macrophylla subsp. *macrophylla*	55/88	Vellecitos, Guerrero	Mexico	0.74	0.74	0.69	0.72	0.0164
L. macrophylla subsp. *istmensis*	47/85	San Isidrs Llano Grande, Oaxaca	Mexico	0.50	0.66	0.64	0.60	0.0519
L. magnifica	19/84	El Rincon, Chiquimula	Guatemala	0.75	0.86	0.88	0.83	0.0388
L. magnifica	58/88	Quetzaltepeque, Chiquimula	Guatemala	0.68	0.84	0.78	0.77	0.0482
L. matudae	49/87	Mezcala	Mexico	0.77	0.84	0.58	0.73	0.0779
L. multicapitula	81/87	Los Santos, Azuero	Panama	0.38	0.58	0.56	0.51	0.0652
L. pulverulenta	83/87	Altas Cumbres, Tamaulipas	Mexico	0.49	0.52	0.65	0.55	0.0481
L. pulverulenta	84/87	South Texas, Texas	USA	0.62	0.61	0.66	0.63	0.0155
L. salvadorensis	17/86	La Garita, Chouluteca	Honduras	0.84	0.70	0.81	0.78	0.0422
L. salvadorensis	34/88	Yusguare, Chouluteca	Honduras	0.73	0.69	0.80	0.74	0.0321
L. shannonii	26/84	Comayagua, Comayagua	Honduras	0.79	0.92	0.87	0.86	0.0401
L. shannonii	53/87	Champoton, Campeche	Mexico	0.82	0.79	0.85	0.82	0.0164
L. trichandra	35/88	Zambrano, Francisco, Morazan	Honduras	0.52	n/a	0.70	0.61	0.0885
L. trichandra	53/88	Los Guates, Guatemala	Guatemala	0.73	0.72	0.71	0.72	0.0068
L. trichodes	2/86	Cuicas, Tragal	Venezuela	0.56	0.62	0.59	0.59	0.0196
L. trichodes	61/88	Jipijapa, Manabi	Ecuador	0.61	0.79	0.68	0.69	0.0500

Wood production was measured by individual trial managers largely following the methodology of Stewart et al. (1992). As the age of trials, trial composition, planting design, harvesting interval and harvesting method varied among experiments, direct comparison between trials was not appropriate. Instead, the rank of each taxon in each trial was weighted around the mean according to the number of accessions in the experiment, and a mean score across trials calculated, thereby enabling assessment of performance across sites.

Results

Significant variation ($P<0.001$) was recorded in wood density among taxa at each of the three sites included in the study, and also among the mean densities recorded over the three sites (Table 2). Significant correlations ($P<0.001$) were also evident in ranking between the three sites.

Taxa with the highest wood densities over the three sites were *L. shannonii*, *L. collinsii* subsp. *zacapana* and *L. magnifica* for which the best accessions had densities of 0.83 g/cm^3 or higher. The lowest densities were recorded for *L. multicapitula* (0.50 g/cm^3) and *L. pulverulenta* 83/87 (0.52 g/cm^3) (Figure 1). Significant intraspecific variation in wood density was recorded for *L. esculenta*, *L. pulverulenta*, *L. trichandra* and *L. trichodes* (Table 2).

The mean wood productivity assessment over 11 sites revealed the highest scores for *L. salvadorensis*, *L. leucocephala*, *L. macrophylla* subsp. *istmensis* and *L. collinsii* subsp. *zacapana* (Figure 2).

Differences in trial designs, composition and age meant that productivity data for trials established principally for wood production were difficult to compare. However, results indicate that where *Leucaena* species are planted at spacings of 1.5–3 m on sites where rainfall was not limiting, wood yields of most productive accessions were over 18 t/ha/yr after three years can be expected.

The rank correlation between wood productivity scores and mean wood density was not significant ($r^2 = 0.11$). The trials in Honduras and Philippines provided the opportunity to compare ranking between wood productivity and density for individual sites and both produced non-significant relationships ($r^2 = 0.07$ and 0.07 respectively).

Discussion

Comparison of values of wood density between studies are complicated by both the age of the sample (Gourlay et al. in press; Hossain et al. 1991; Sood 1995) and the method of measurement. However, broad comparisons between experiments are possible. In this respect it is interesting to note the similarity in mean density recorded for *L. leucocephala* recorded in this study (0.61 g/cm^3), with that recorded by Brewbaker (1987) (0.5–0.6 g/cm^3) and by Gourlay (unpublished data from samples supplied by H.M. Shelton) (0.64 g/cm^3). Furthermore, the mean density for *L. leucocephala* recorded in this trial was below the average recorded for all species (0.7 g/cm^3), reflecting the low regard for its wood when compared with other species in the genus in their native ranges (Hughes 1993).

Given the wide variation in tree form within the genus and the comprehensive representation of that diversity in the three trials assessed for wood density, it is not surprising that a highly significant variation in wood density was recorded between taxa. In addition, the strong overall correlation between sites was largely expected given the general high degree of genetic control of wood characteristics in angiosperms (Zobel and van Buijtenen 1989). Of perhaps greater interest was the performance of the most promising taxa on each site. In this respect, each of the taxa that comprised the overall top ten for wood density (Table 3) occurred in the top ten on each site except in four instances.

Table 3. The top ten ranking accessions for mean wood density and yield.

Rank	Density	Rank	Yield
1	*Leucaena shannonii* (26/84)	1	*Leucaena salvadorensis* (34/88)
2	*Leucaena collinsii* subsp. *zacapana* (57/88)	2	*Leucaena salvadorensis* (17/86)
3	*Leucaena magnifica* (19/84)	3	*Leucaena leucocephala* subsp. *glabrata* (32/88)
4	*Leucaena shannonii* (53/87)	4	*Leucaena macrophylla* subsp. *istmensis* (47/85)
5=	*Leucaena collinsii* subsp. *zacapana* (18/84)	5	*Leucaena pallida* (79/92)
5=	*Leucaena collinsii* subsp. *collinsii* (45/88)		
5=	*Leucaena collinsii* subsp. *zacapana* (56/88)		
		6	*Leucaena collinsii* subsp. *zacapana* (18/84)
		7	*Leucaena leucocephala* subsp. *glabrata* (K636)
8	*Leucaena salvadorensis* (17/86)	8	*Leucaena collinsii* subsp. *zacapana* (57/88)
9	*Leucaena magnifica* (58/88)	9=	*Leucaena collinsii* subsp. *zacapana* (56/88)
10	*Leucaena lanceolata* var. *sousae* (50/87)	9=	*Leucaena lanceolata* var. *lanceolata* (43/85)

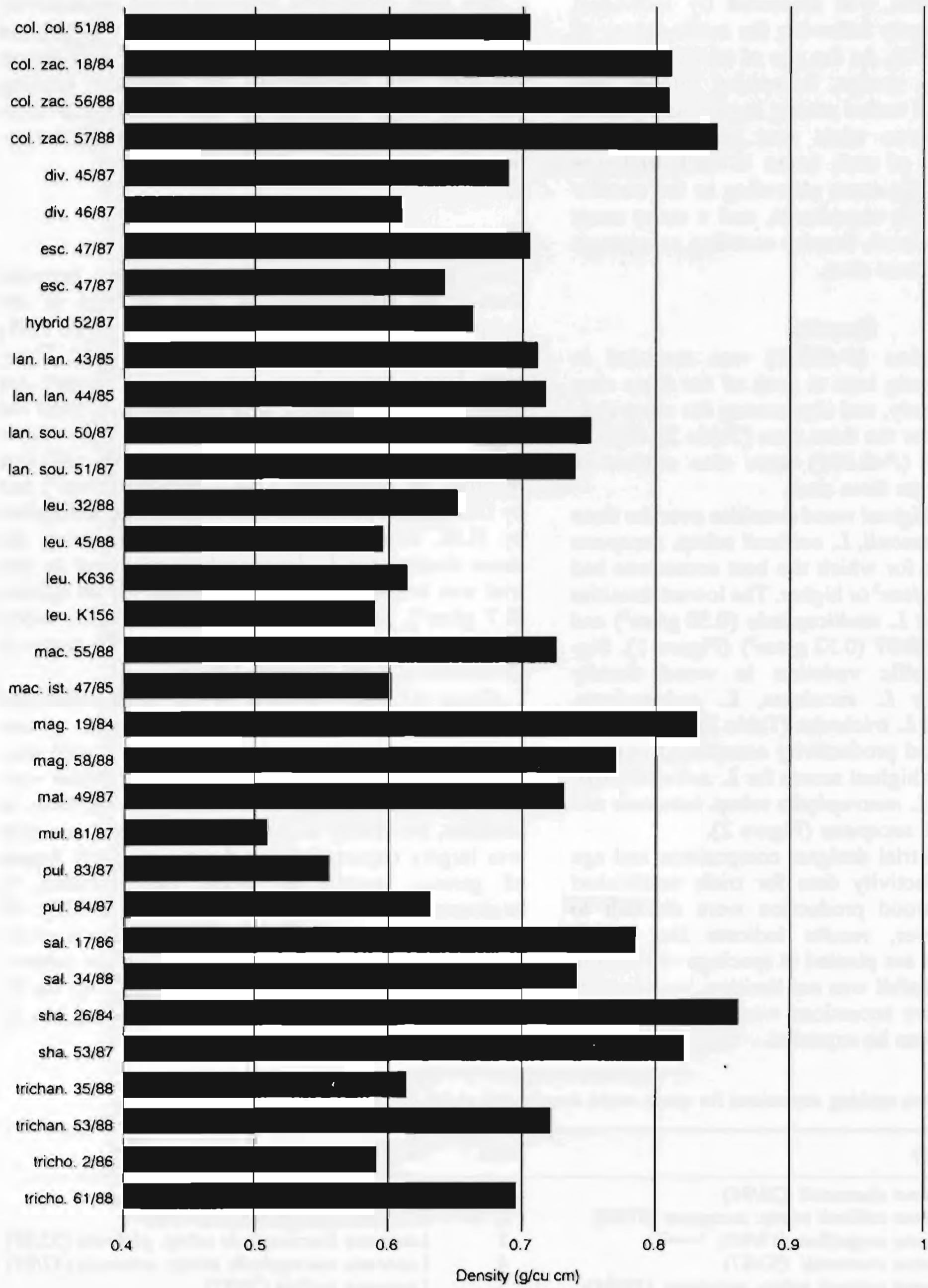

Figure 1. Mean wood density of 33 *Leucaena* accessions grown at three sites (LSD 0.031).

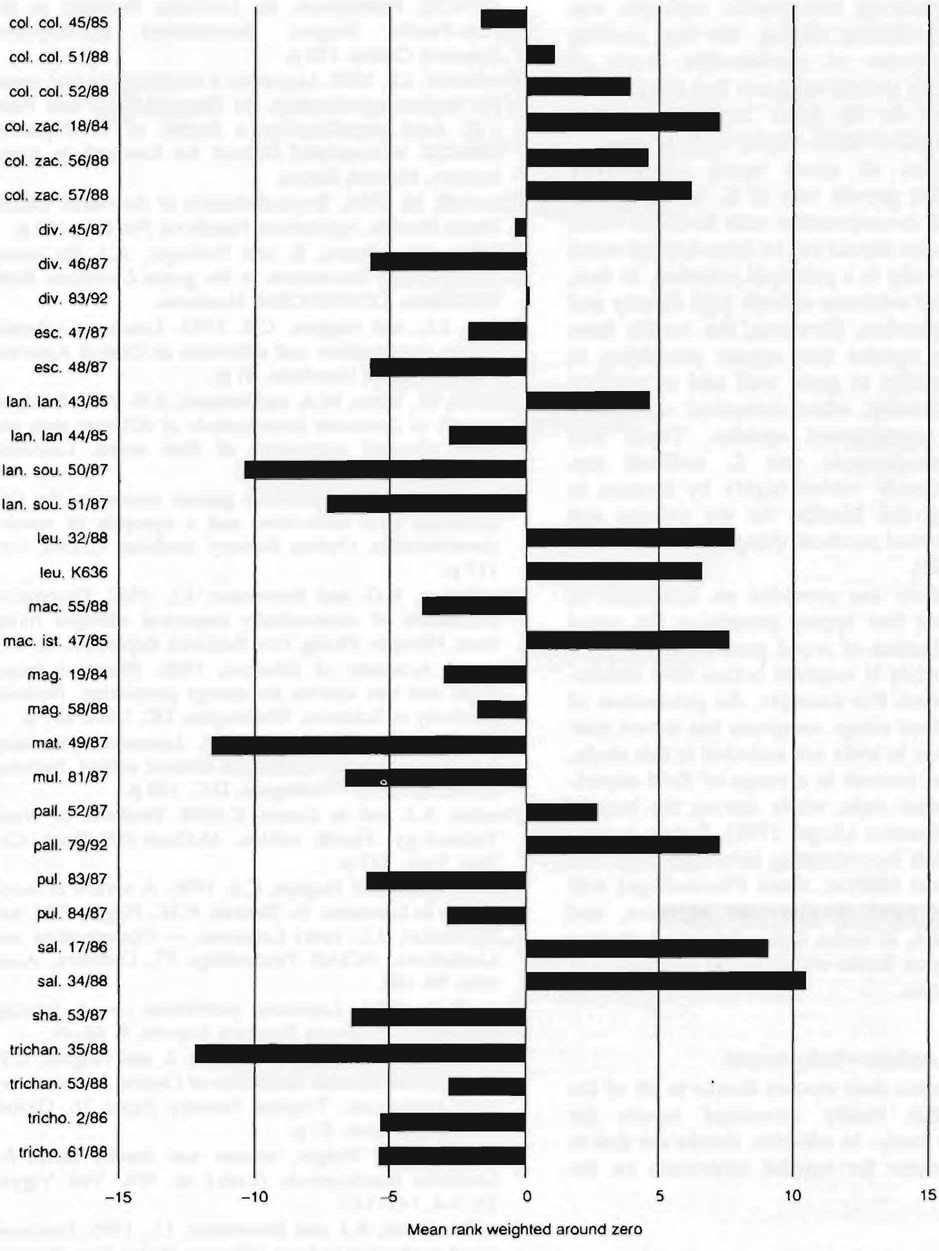

Figure 2. Mean wood production score of 34 *Leucaena* accessions grown at 11 sites.

While no significant intraspecific variation was found in wood density among the top ranking species, the presence of considerable levels of variation in certain species suggests that selection of provenance may be of great importance when attempting to improve wood density in *Leucaena*.

The assessment of mean wood productivity revealed the good growth rate of *L. leucocephala*, but when viewed in conjunction with its lower wood density, this species should not be favoured for wood production if density is a principal criterion. In fact, few taxa provided evidence of both high density and good wood production. However, the results have highlighted two species that appear promising in terms of their ability to grow well and to produce wood of high density, when compared with commonly grown agroforestry species. These two species, *L. salvadorensis* and *L. collinsii* ssp. *zacapana* are already valued highly by farmers in Central America and Mexico for the volume and quality of their wood products (Hughes 1993; Hellin and Hughes 1993).

While this study has provided an indication of *Leucaena* species that appear promising for wood production, evaluation of wood productivity from a wider range of trials is required before firm conclusions can be drawn. For example, the production of wood by *L. collinsii* subsp. *zacapana* has shown considerable variation in trials not included in this study, being among the poorest in a range of field experiments in Southeast Asia, while among the best in trials in Latin America (Argel 1998). Future assessment of field trials incorporating information on tree form (Mullen and Shelton, these Proceedings) will assist scientists, rural development agencies, and ultimately farmers, to make better informed choices for tree planting on farms where wood production is the principal output.

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Wood Anatomy of Four Strains of *Leucaena leucocephala*

A. Ella[1]

Abstract

Wood samples were taken from three accessions of *Leucaena leucocephala* subsp. *glabrata* (K8, K28, and K67) and one of *L. leucocephala* subsp. *leucocephala* (K21). Comparisons were made between general characteristics, anatomical descriptions and wood properties. The results indicated the difficulty of the specific identification of the woods of the four strains based on macro-anatomical structures. Many characteristics were common both in the gross and minute wood features. However, slight differences were apparent in some microscopic features, viz., vessel tangential diameter, length of vessel members and height of multiseriate rays. However, these differences were not sufficient to permit subspecies identification or to separate accessions within subspecies.

LEUCAENA *leucocephala* is a fast-growing leguminous tree species. Its growth rate can be extremely high and its ability to fix nitrogen makes it one of the highest yielding and highest quality legumes. Its leaves average over 4% nitrogen in dry weight and few plants appear to be able match its annual yields of high quality forage.

As a species, *L. leucocephala* is divided into two subspecies, subsp. *leucocephala* and subsp. *glabrata*. The common type of *L. leucocephala* in the Philippines, known as ipil-ipil, is *L. leucocephala* subsp. *leucocephala*, while the faster-growing 'giant' types introduced during the 1970s (known as giant ipil-ipil or leucaena) are classified as *L. leucocephala* subsp. *glabrata*.

With the intensification of industrial plantations in the Philippines, it is important to examine the wood anatomy of the fast-growing species and relate their anatomical findings with other wood properties to evaluate further their potentialities. The growth and development of the different strains of giant ipil-ipil have been studied here and abroad. Results indicated that its mean annual increment has been estimated to be from 24 to 312 cubic metres per hectare per year or 13 to 150 bone-dry metric tonnes per year, depending probably on the site quality and the strain involved (Bawagan et al. 1978)

Studies on giant ipil-ipil, however, were mostly on the use of wood as fuel, and the leaves as swine and poultry feeds. The wood structure was not given much attention.

The importance of the study on the anatomy of wood is attributed to the fact that the behaviour of wood depends mainly on its microscopic and submicroscopic structures. The strength, gluing, permeability, shrinkage and swelling, pulping, machining and other properties of wood depend mostly on the anatomical characteristics of wood. Therefore, benchmark information on the wood anatomical characteristics of the species is desirably important to serve as one of the bases in the utilisation of *Leucaena*.

The objectives of the work reported here were firstly to see if observable differences in wood characteristics existed between subspecies, and secondly to see if differences existed within *L. leucocephala* subsp. *glabrata*.

Materials and Methods

Field sampling

Three lines of *L. leucocephala* subsp. *glabrata* (K8, K28 and K67) and one of *L. leucocephala* subsp. *leucocephala* (K21) were used in this study. Two trees of each line (4-year-old coppice regrowth) were randomly selected from the gene bank of the

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Institute of Plant Breeding, University of the Philippines at Los Baños College, Laguna and Southern Luzon Polytechnic College, Lucban, Quezon Province. From each tree, a disc sample about 5 cm thick was taken at breast height and brought to the laboratory.

Laboratory procedure

Each disc sample was divided into four quadrants. From each quadrant, one block specimen or a total of four wood blocks per disc per tree was taken from the heartwood portions.

The wood blocks were trimmed and designed in such a way that the tree planes (cross, tangential and radial sections) were truly represented. These were softened in boiling water until waterlogged for microtome sectioning. The standard staining technique and microscopic slide preparation were in accordance with Johansen (1940). Wood chips were macerated by use of the Franklin method (1945); that is, a mixture of equal parts of 60% glacial acetic acid and hydrogen peroxide (20% by volume) for measurement of isolated elements, e.g., vessels (height and diameter; and size of intervessel and ray-vessel pittings) and fibres (length, diameter, lumen width and cell-wall thickness).

Macroscopic observations included the physical properties and gross features of the wood with unaided eye or with the use of a 20X hand lens. Microscopic observation, on the other hand, was carried out using an ordinary light research microscope with amplification of 80X and 400X.

Details for macroscopic examination followed those of Tamolang et al. (1961) and Dadswell et al. (1947). Microscopic observations and descriptions followed those of Tamolang et al. (1963), which cited important anatomical references as a guide for describing wood. The terminologies used were in accordance with the 'IAWA List of Microscopic Features for Hardwood Identification' (1989).

Description

Macroscopic features

Sapwood was lighter-coloured than heartwood, which was creamy yellow to medium brown; grain straight; **texture** was moderately fine to fine; **figure** was mottled due to colour; no distinct taste and odour; glossy; moderately hard and moderately heavy.

Growth rings were distinct, marked by darker-coloured latewood bands. Pores were indistinctly visible to the naked eye, diffuse, round to oval solitary and had radial multiples of 2–5 commonly arranged in oblique pattern; reddish deposits and other dark contents were present along some vessel lines on longitudinal sections. Axial parenchyma were slightly visible to the naked eye, typically vasicentric to aliform and confluent. Rays were narrower than pores. **Fibres** were moderately dense to dense.

Microscopic features

Growth rings were indistinct; **vessels** were mostly solitary consisting about 80%, radial multiples about 15%, and clusters about 5% in K8; about 73% solitary, 25% radial multiples and 2–5% clusters in K28 and K67; and 75%, radial multiples at 16% and 9% clusters in K21. There were few to moderately few, 2–8, mostly 3-6 per mm^2 in K8 and K21, but few to moderately numerous, 2–10, mostly few to moderately few, 2–8 per mm^2 in K28 and K67, round to oval. They were moderately small to moderately large in K8 (73–246 microns), K21 (103–200 microns) and K67 (95–210 microns) and moderately small to medium-sized in K28 (72–140 microns) with average tangential diameters of 119 microns (K8), 140 microns (K21), 130 microns (K67), and 105 microns (K28). Deposits were present mostly reddish in colour. Vessel elements were extremely short to medium-sized in K8 (140–607 microns, av. 403); K21 (123–683 microns, av. 384) and K28 (138–636 microns, av. 351) and very short to medium-sized in K67 (208–664 microns, av. 546).

Perforation plates were simple with horizontal to oblique end walls. Intervessel pits were small to medium-sized 4–9 (av. 6) microns in diameter, alternate and vestured.

Axial parenchyma was vasicentric to slightly aliform and confluent. Rhomboidal crystals in chambered parenchyma cells.

Rays were few to numerous, 3–8 per mm (av. 6) in K8, and few-to-moderately numerous in K28 (3–7 per mm, av. 5); K21 (3–5 per mm, av. 4) and K67 (2–7 per mm, av. 5); homocellular consisted of procumbent cells. Mostly multiseriates up to 5 cells wide, commonly 2–3; very fine to medium-sized, 21–45 microns in K8, K21 and K67, and very fine to moderately fine 24–48 microns in K28; extremely low in K8 (0.045–0.254, av. 0.121 mm), in K21 (0.057–0.158, av. 0.120 mm) and K67 (0.046–0.471, av. 0.147 mm) and extremely low to very low (0.093–0.676 mm, av. 0.318 mm), in K28. Uniseriates were very few; extremely fine to very fine; extremely low, 2–20 cells high in K8, 2–16 in K21 and K28, and 2–22 in K67. Ray vessel pittings were similar to intervessel pits. Deposits found in some rays.

Fibres were libriform and septate; very short to moderately long (0.4–1.72 ram, av. 1.11 mm) in K8, K21 (0.49–1.17 mm, av. 1.08 mm) and K67 (1.06–1.33 mm av. 1.14 mm); and mostly moderately short to medium-sized (0.80–1.45, av. 1.12 mm) in K28. They were thin-walled, the lumen width averaged 0.015 mm in K8, 0.0097 mm in K28, 0.017 mm in K21 and 0.011 mm in K67 and was greater than the thickness of walls (av. 0.0041 mm in K8 and K21, 0.0047 mm in K28 and 0.005 mm in K67) with an average fibre diameter of 0.024 mm, 0.025 mm, 0.0194 mm and 0.022 mm in K8, K21, K28 and K67 respectively.

Discussion

Generally, the wood microscopy of four strains of giant ipil-ipil, viz., K8, K21, K28 and K67 showed common physical and anatomical features. They offered no distinction with regards to gross and structural characteristics. However, slight variations were visible in the number of radial pore multiples, vessel tangential diameter, length of vessel members, and height of multiseriate rays.

Based on the results of the study, specific identification of the woods of the four strains of giant ipil-ipil based on macro-anatomical structure is rather difficult. They lack significant anatomical characters to differentiate them and the observed minor quantitative variation cannot be used when trying to separate them.

To confirm the findings and/or to determine the anatomical variation within samples and strains, if any, it is suggested that a more extensive and comprehensive study of their anatomical structures, using other samples, representing various age classes, be undertaken.

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Accession evaluation

Agronomic Evaluation of the *Leucaena* Foundation Collection: 1. Subtropical Australia

B.F. Mullen and H.M. Shelton

Abstract

The dry matter (DM) productivity of 116 *Leucaena* accessions was evaluated in sub-tropical Australia during a 2.5-year period. Harvests were timed to coincide with warm/wet and cold/dry seasons and data were analysed to compare growth in these environments. Twelve accession groups were identified by cluster analysis. Group 1 contained three *Leucaena leucocephala* × *L. pallida* F1 hybrid accessions that were very highly productive in all environments. Accession Groups 2 and 3 were also broadly adapted but at a lower yield level than Group 1 accessions. Growth of *L. leucocephala* accessions was severely checked by psyllids in warm/wet environments. Five groups, comprising 66 accessions, were poorly productive in all environments. *L. leucocephala* accessions were very tolerant of regular cutting, but accessions of *L. involucrata* and *L. greggii* experienced high mortality. Both psyllid insect attack and defoliation management tended to increase branchiness. However, species such as *L. magnifica* and *L. lempirana* were inherently arboreal, whereas *L. leucocephala* subsp. *leucocephala* and *L. multicapitula* were inherently well branched. Considerable intraspecific variation in tree form was evident in *L. leucocephala* subsp. *glabrata*, *L. pallida*, *L. diversifolia* and *L. trichandra*.

A PRIMARY objective of the research program on New Leucaenas for Southeast Asian, Pacific and Australian Agriculture (ACIAR Project 9433) was to evaluate the agronomic potential of the *Leucaena* genus in terms of dry matter (DM) productivity and adaptation to growth limiting factors, such as the psyllid insect and low temperatures. A comprehensive collection of *Leucaena* accessions was sourced principally from the Oxford Forestry Institute, with additional accessions from the University of Hawaii and CSIRO, and planted at two sites: Brisbane, Southeast Queensland, Australia and Los Baños, Luzon Province, Philippines (Gabunada and Stür, these Proceedings). A subset of this collection, representative of all important taxa, was selected for evaluation in multi-environment trials at 18 sites in seven countries and results are presented in Mullen, Shelton et al. (these Proceedings).

This report presents preliminary results from the foundation collection evaluation at Brisbane.

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Materials and Methods

Site

The Brisbane site has a fertile, free-draining Krasnosem soil. From soil analysis, no limitations to growth of effectively nodulated *Leucaena* were expected. Climate is subtropical with summer-dominant rainfall (1200 mm annually) (Figure 1).

Germplasm and sampling procedures

One hundred and sixteen *Leucaena* accessions (Table 1) were raised in polybags, inoculated with *Rhizobium* strain CB3060, and subsequently planted into the field in March 1995. Single-row plots 5 m long were planted with seedlings at 50 cm spacing. A randomised block design with two replicates was used. Trees were not cut during a 10-month establishment period. The DM productivity of trees was determined by harvesting the 6 central plants of each plot to 50 cm above ground-level. Dry matter was separated into edible and wood fractions and data were converted to DM/m row/ month. Harvests were scheduled to determine DM productivity within "environment" periods (e.g. warm/wet or cold/dry) and continued until September 1997. Psyllid damage

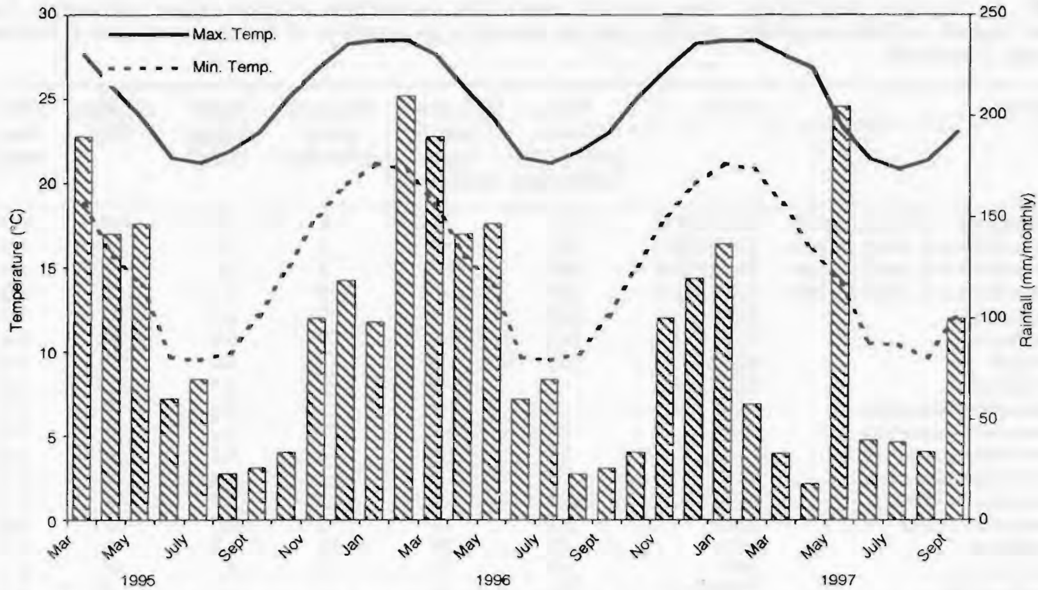

Figure 1. Mean monthly maximum and minimum temperatures and monthly rainfall at Brisbane, Australia, over the experimental period.

Table 1. Accession identification, warm and cold season DM productivity, accession group membership from cluster analysis, psyllid susceptibility, mortality and tree form for 116 accessions of *Leucaena* evaluated at Brisbane, Australia.

Accession	ID No.	Warm season growth (g/m row/month)	Cold season growth (g/m row/month)	Accession group mem'ship[1]	Psyllid damage rating[2]	Mortality (%)	Tree form rating[3]
L. collinsii collinsii	51/88	221	41	4	1.8	25	4.0
L. collinsii collinsii	52/88	163	39	8	2.1	5	3.8
L. collinsii zacapana	18/84	156	30	8	3.4	30	2.3
L. collinsii zacapana	56/88	64	17	9	5.0	10	2.5
L. collinsii zacapana	57/88	119	41	11	4.0	15	4.0
L. confertiflora	88/94	39	37	12	2.3	30	4.0
L. confertiflora	87/94	43	9	12	1.5	40	2.4
L. cuspidata	83/94	108	40	8	2.1	5	3.8
L. diversifolia	K778	244	94	3	2.8	5	3.3
L. diversifolia	83/92	189	85	3	3.2	5	3.8
L. diversifolia	K802	206	75	5	3.0	0	3.1
L. diversifolia	105/94	156	57	5	4.5	10	4.1
L. diversifolia	104/94	206	71	6	2.9	0	3.0
L. diversifolia	K784	215	83	6	3.0	5	3.6
L. diversifolia	82/92	90	65	10	5.1	0	3.6
L. diversifolia	126/92	102	61	10	4.5	0	4.5
L. diversifolia	K156	106	75	10	5.4	5	3.3
L. diversifolia	46/87	134	66	10	3.7	5	4.1
L. diversifolia	45/87	130	44	11	3.1	0	4.5
L. diversifolia	106/94	83	54	11	5.0	5	3.1
L. diversifolia × *L. leucocephala*	K156xK500	97	59	10	5.6	0	4.3
L. diversifolia × *L. leucocephala*	98/94	107	60	10	5.3	15	3.5
L. diversifolia × *L. leucocephala*	99/94	78	77	10	5.8	5	4.3
L. diversifolia × *L. leucocephala*	K156xK8	101	86	10	5.1	0	3.6
L. diversifolia × *L. leucocephala*	K156xK636	110	86	10	5.1	10	3.8

Table 1. Accession identification, warm and cold season DM productivity, accession group membership from cluster analysis, psyllid susceptibility, mortality and tree form for 116 accessions of *Leucaena* evaluated at Brisbane, Australia. (continued)

Accession	ID No.	Warm season growth (g/m row/month)	Cold season growth (g/m row/month)	Accession group mem'ship[1]	Psyllid damage rating[2]	Mortality (%)	Tree form rating[3]
L. diversifolia × L. leucocephala	KX3F491-2	166	90	6	3.7	0	4.0
L. diversifolia × L. leucocephala	KX3F492-4	247	110	3	3.6	0	4.0
L. diversifolia × L. leucocephala	KX3F491-6	213	117	3	3.0	0	4.5
L. diversifolia × L. leucocephala	KX3F491-3	318	137	3	3.6	5	4.0
L. esculenta	48/87	123	10	9	1.4	10	3.3
L. esculenta	47/87	148	14	9	1.9	20	3.6
L. greggii	82/87	12	2	12	1.4	55	3.5
L. involucrata	87/92	8	1	12	4.9	85	3.8
L. lanceolata lanceolata	43/85	98	34	11	5.2	0	3.9
L. lanceolata lanceolata	44/85	84	15	12	4.7	5	4.0
L. lanceolata lanceolata	134/92	95	15	12	4.5	10	3.8
L. lanceolata lanceolata	90/92	83	10	12	4.4	20	4.0
L. lanceolata sousae	51/87	214	43	4	3.0	5	2.9
L. lanceolata sousae	50/87	180	16	8	3.4	15	2.8
L. lempirana	6/91	93	39	11	5.3	5	3.8
L. lempirana	5/91	63	23	12	5.1	10	2.1
L. leucocephala	CPI90814	143	96	7	5.9	0	4.5
L. leucocephala	CPI58396	115	96	7	5.9	10	4.0
L. leucocephala	CPI91953	101	66	10	5.7	0	4.6
L. leucocephala	CPI85176	126	71	10	5.4	0	5.0
L. leucocephala glabrata	K636	169	111	6	5.1	0	2.5
L. leucocephala glabrata	K584xK636F3	176	80	6	5.1	0	3.4
L. leucocephala glabrata	K584xK636F2	145	106	6	5.2	0	3.5
L. leucocephala glabrata	139/92	148	99	6	5.7	0	3.5
L. leucocephala glabrata	145/91	148	79	6	5.7	5	3.8
L. leucocephala glabrata	102/94	147	89	7	5.6	0	2.9
L. leucocephala glabrata	136/92	121	94	7	5.9	0	4.9
L. leucocephala glabrata	Cunningham	136	99	7	5.6	5	4.5
L. leucocephala glabrata	94/92	113	69	10	5.4	0	2.0
L. leucocephala glabrata	K584	126	78	10	5.6	0	3.0
L. leucocephala glabrata	19/81	115	71	10	5.8	0	3.4
L. leucocephala glabrata	121/92	116	85	10	5.4	0	3.5
L. leucocephala glabrata	CPI33821	97	68	10	5.4	0	4.4
L. leucocephala glabrata	K8	107	84	10	5.6	0	4.8
L. leucocephala glabrata	91/92	109	58	10	5.8	0	5.0
L. leucocephala glabrata	45/88	127	61	10	5.7	5	4.1
L. leucocephala glabrata	32/88	124	68	10	5.3	5	4.5
L. leucocephala glabrata	K8	86	92	10	5.8	5	5.0
L. leucocephala glabrata	30/93	63	43	11	5.9	0	4.5
L. leucocephala ixtahuacana	4/117/92	187	91	7	4.4	30	4.8
L. leucocephala leucocephala	133/92	90	68	10	5.9	0	4.9
L. leucocephala leucocephala	147/92	65	51	11	5.9	0	4.8
L. leucocephala leucocephala	K997	62	35	12	5.6	5	5.0
L. macrophylla isthmensis	47/85	196	42	5	3.7	15	3.0
L. macrophylla isthmensis	39/89	162	39	8	4.9	10	3.6
L. macrophylla macrophylla	55/88	212	35	5	3.9	15	4.3
L. macrophylla macrophylla	132/92	135	28	8	4.3	5	3.9
L. magnifica	19/84	164	49	8	4.4	15	2.0
L. magnifica	58/88	171	59	8	4.1	15	2.4
L. matudae	49/87	129	5	9	1.7	10	3.0
L. multicapitula	81/87	104	19	8	5.3	35	4.6
L. multicapitula	86/87	72	25	12	5.2	35	4.0
L. pallida	78/92	194	53	4	2.0	0	3.8
L. pallida	K376	239	41	4	1.7	5	3.6
L. pallida	CPI91309	184	45	4	1.8	5	4.1

Table 1. Accession identification, warm and cold season DM productivity, accession group membership from cluster analysis, psyllid susceptibility, mortality and tree form for 116 accessions of *Leucaena* evaluated at Brisbane, Australia. (continued)

Accession	ID No.	Warm season growth (g/m row/month)	Cold season growth (g/m row/month)	Accession group mem'ship[1]	Psyllid damage rating[2]	Mortality (%)	Tree form rating[3]
L. pallida	CQ3439	251	70	4	2.4	10	2.6
L. pallida	79/92	249	25	4	3.1	15	3.1
L. pallida	52/87	112	20	8	4.6	10	4.3
L. pallida	K953	111	20	8	3.8	20	3.6
L. pallida	44/87	112	5	9	1.7	0	3.1
L. pallida	92/94	88	40	11	3.6	0	4.5
L. pallida × *L. leucocephala*	KX2F592-3	205	74	6	3.2	0	4.3
L. pallida × *L. leucocephala*	KX2SPCP	196	106	3	3.8	0	4.4
L. pallida × *L. leucocephala*	K806xK636	423	125	1	2.6	0	4.1
L. pallida × *L. leucocephala*	K748xK636	393	167	1	2.7	0	2.4
L. pallida × *L. leucocephala*	K748xK636b	351	170	1	3.0	5	2.3
L. pallida × *L. leucocephala*	K748xK584	439	223	1	2.6	10	2.5
L. pueblana	125/92	186	9	8	2.0	5	3.4
L. pueblana	34/89	113	7	9	1.4	0	3.1
L. pulverulenta	22/86	68	39	11	4.8	0	3.8
L. pulverulenta	83/87	62	55	11	4.8	5	3.1
L. pulverulenta	84/87	62	44	11	4.5	5	4.6
L. retusa	23/86	85	10	12	1.7	25	2.3
L. salvadorensis	36/88	141	26	5	4.5	35	3.0
L. salvadorensis	7/91	130	37	11	4.4	10	2.6
L. salvadorensis	34/88	93	30	11	4.8	30	2.5
L. shannonii	135/92	170	45	8	3.7	0	3.0
L. shannonii	141/92	200	39	8	4.8	20	3.3
L. shannonii	53/87	73	25	11	5.3	5	4.5
L. shannonii	26/84	103	31	11	4.7	15	4.4
L. trichandra	53/88	302	107	2	1.4	0	3.0
L. trichandra	35/88	203	96	3	1.8	10	4.3
L. trichandra	CPI46568	110	54	5	1.7	10	2.0
L. trichandra	3/91	135	37	8	3.5	0	3.6
L. trichandra	137/92	112	38	8	2.0	15	3.8
L. trichandra	131/92	124	14	8	3.1	20	4.4
L. trichandra	128/92	149	6	9	2.3	35	3.8
L. trichandra	CPI33820	200	75	10	3.3	0	2.6
L. trichandra	4/91	97	59	10	4.7	20	3.4
L. trichandra	138/92	72	21	12	3.9	30	4.6
L. trichandra	140/92	51	18	12	4.3	35	4.8
L. trichodes	2/86	139	9	8	3.9	5	2.1
L. trichodes	61/88	64	8	12	4.4	20	3.0

[1] Accession Group membership from cluster analysis (Figure 2); [2] Mean psyllid damage to accessions at Brisbane, Australia (see Mullen, Gabunada et al., these Proceedings); [3] Tree form, 1=single stemmed arboreal, 3=branched, weak apical dominance, 5=heavily branched, no apical dominance.

ratings were collected monthly using the scale of Wheeler (1988). Plant mortality was assessed in January 1997. Tree form was assessed prior to the second harvest using a 1–5 ratings scale, where 1 = single stemmed and strongly arboreal, 3 = branched with weak apical dominance and 5 = heavily branched with no apical dominance.

Environments and data analysis

Two distinct 'environments' were identified at the Brisbane site from long-term weather data. These were a warm/wet period of 7.5 months receiving 136 mm/month rainfall and mean day/night temperatures of 28/19 °C from mid-October to the end of May, and a cold/dry period of 4.5 months receiving 43 mm/month rainfall and mean day/night temperatures of 23/15 °C from June to mid-October. Two and three harvests were taken during the warm/wet periods of 1996 and 1997 respectively, and single harvests were taken during the cold/dry periods. The establishment period, from March 1995 to January 1996, unavoidably spanned environments.

Accessions were grouped, according to their DM response to each environment, by a hierarchical, agglomerative clustering technique (Williams 1976), using S-Plus data analysis software. For this analysis, data were environment standardised to remove the effect of environment means from the analysis, and thereby compare the ordination of genotypes across environments to identify specific adaptation (Fox and Rosielle 1982). Accession group data presented in Figure 2 are derived from actual (non-standardised) data. Total, rather than edible DM yields were used for these analyses.

The relationship between edible DM production and total DM production were investigated by regression analysis.

Results and Discussion

Twelve accession groups (Table 1 and Figure 2) and 3 environment groups (Figure 2) were identified by cluster analysis. Environments were grouped into cold seasons, warm seasons and establishment period, indicating that variation existed among accessions in their response to these environments. Mean warm season, cold season and establishment yields were 188, 70 and 86 g/m row/ month respectively. Results from controlled temperature studies (Mullen, Castillo et al., these Proceedings) indicated that the optimum temperature for growth of *Leucaena* was approximately 33/28 °C day/night. Both warm and cold season temperatures at Brisbane were well below these temperatures.

Broad adaptation

Three interspecific F1 hybrid accessions of *L. pallida* × *L. leucocephala* subsp. *glabrata* (known as KX2 F1 hybrids) (Accession Group 1) were very high yielding and broadly adapted, outperforming all other accessions in all environments (Figure 2). Mean warm and cold season yields were 441 and 173 g/m/row/ month respectively. These hybrids were produced by hand pollination at the University of Hawaii, and although they are self-fertile, the F2 and subsequent generations segregate strongly into highly variable populations of lower yield potential. For this reason, methodologies for production of commercial quantities of F1 hybrid seed require development and this is clearly a research priority. Methods are currently being developed for production from vegetative cuttings (see Dick et al. and Sun et al., these Proceedings).

Accession groups 2 and 3 were also broadly adapted to the test environments, producing yields of approximately 60% of Group 1 accessions. Group 2 was a single accession group containing the highest yielding non-hybrid accession, *L. trichandra* OFI

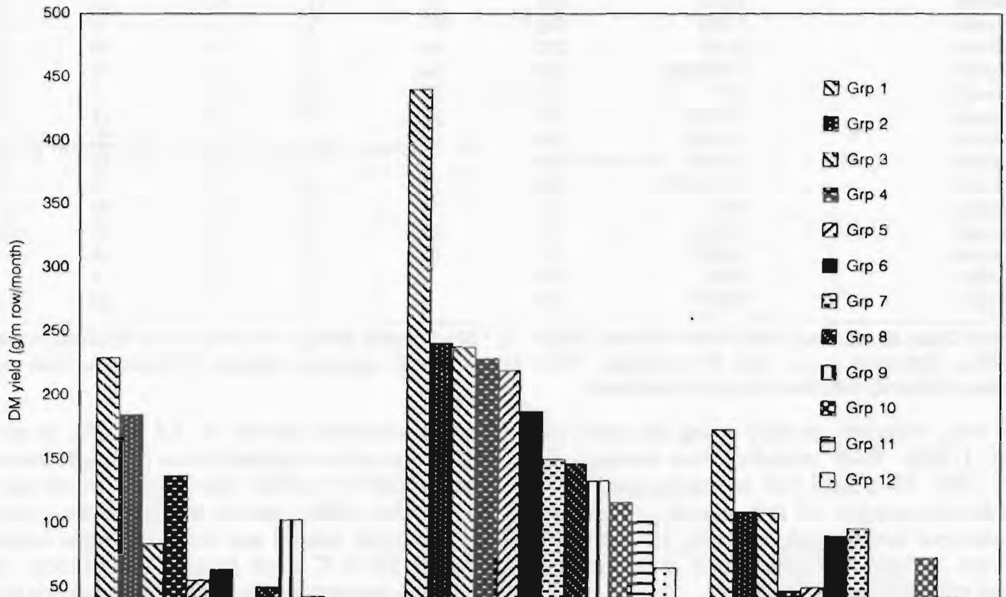

Figure 2. Performance of 12 *leucaena* accession groups during establishment and in warm and cold seasons.

53/88. This accession was identified in multi-environment trials (METs) as being specifically adapted to cold environments (Mullen, Shelton et al., these Proceedings).

Accession group 3 contained advanced generation KX2 F4 and KX3 F5 (*L. pallida* × *L. leucocephala* subsp. *glabrata*) hybrid accessions that were developed from seed of self compatible plants, and were heavily selected for high DM yield, psyllid resistance and uniformity over 4–5 generations. The most productive Group 3 accession was KX3 91-3, producing mean warm and cold season yields of 318 and 137 g/m row/month respectively. Preliminary in vitro herbage quality estimates indicate that all KX2 and KX3 hybrid accessions are high quality forages (Dalzell et al., these Proceedings). The highest yielding non-hybrid accessions in Group 3 were *L. diversifolia* K778 and *L. trichandra* OFI 35/88 (Table 1).

Other accession groups of interest included Groups 6 and 7 which contained the 11 most productive accessions of *L. leucocephala*, of which accession K636 was the highest yielding. Psyllid susceptibility severely limited the productivity of these groups during establishment and in warm seasons and their higher relative performance during the cold seasons was probably more related to the lower cold season psyllid pressure rather than to cold adaptation.

Warm season adaptation

Accession group 4 consisted predominantly of *L. pallida* accessions that established rapidly and were productive in the warm season but were poorly adapted to cold. Of these, accession CQ3439 was the most productive. This result is in agreement with the MET data, in which *L. pallida* was identified as being productive at sub-optimal temperatures but not at cold season sub-tropical temperatures (Mullen, Shelton et al., these Proceedings). Group 5 was dominated by accessions of *L. diversifolia* and *L. macrophylla* and were similarly adapted as Group 4, yielding relatively well in the warm seasons but being slow to establish.

Low yielding accessions

Groups 8, 9, 10, 11 and 12 contained 66 accessions of consistently low productivity, producing mean warm and cold season yields of 112 and 34 g/m/row/month respectively. These accessions were highly variable in their psyllid resistance. Groups 11 and 12 were least productive and contained accessions of *L. greggii*, *L. retusa*, *L. involucrata*, *L. multicapitula*, *L. salvadorensis*, *L. shannonii*, *L. lanceolata*, *L. pulverulenta*, and *L. confertiflora*.

Accession group 10 contained 23 psyllid susceptible accessions dominated by *L. leucocephala* (12 accessions), *L. diversifolia* (5 accessions), and segregating KX3 hybrids (5 accessions). As with Groups 6 and 7, the comparatively higher cold season yields of Group 10 accessions were more related to low psyllid pressure rather than to cold adaptation.

Performance of MET accessions

Representative accessions included in the METs were consistently the best performing accessions of their species in the Brisbane evaluation. This was an important result as the restricted number of accessions evaluated in the MET naturally led to speculation as to whether superior accessions had been omitted. The agronomic superiority of MET accessions was also reported for the Los Baños evaluation (Gabunada and Stür, these Proceedings).

Production of edible DM

A strong positive linear correlation (r^2=0.97) was found between edible DM production and total DM production (Figure 3), so that the highest yielding accessions in terms of total DM also produced the most edible DM. The relationship appeared to be curvilinear at high total DM as leaf fall occurs at long harvest intervals reducing the relative leaf proportion. Bray et al. (1988) reported that the wood component of *Leucaena* accessions increasingly dominated DM production above a leaf:stem ratio of 1:1. However, clear differences have been identified between accessions in their inherent leafiness (authors, unpublished data). These results highlight the necessity to consider factors of tree form and inherent leafiness, in addition to production of edible DM when selecting trees for use as forages.

Psyllid damage

The Brisbane site experienced high psyllid pressure (damage ratings >2.5) for up to 8 months of each year during the experiment (see Mullen, Gabunada et al., these Proceedings). Pressure was lowest during

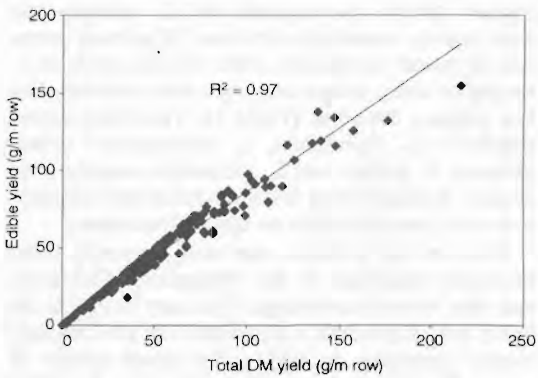

Figure 3. Relationships between production of edible DM and production of total DM for 116 accessions of *Leucaena*.

late-winter/early-spring. This period was characterised by low temperatures, low rainfall and low relative humidity. Psyllid pressure during other times of the year was periodically reduced by discrete climatic events such as intensive rainfall or 3–5 days of hot, dry winds. Accession specific details of susceptibility/resistance, derived from psyllid damage ratings, are presented in Table 1. A comprehensive review of psyllid resistance in the *Leucaena* genus is presented in Mullen, Gabunada et al. (these Proceedings).

Plant mortality

Species varied greatly in their tolerance of regular defoliation (Table 1). Low levels of plant mortality (<5% mean mortality for species) occurred in *L. leucocephala*, *L. diversifolia*, *L. pueblana*, *L. pulverulenta*, *L. cuspidata* and KX2 and KX3 hybrids. Of these species, *L. leucocephala* subsp. *glabrata* had the lowest mortality levels (mean 1%), and this is reflected in the excellent grazing tolerance of commercial cultivars such as Cunningham. Species intolerant of the defoliation regime were *L. confertiflora*, *L. greggii*, *L. involucrata* and *L. multicapitula*, with mean mortalities of 35%, 55%, 85% and 35% respectively. Other species were intermediate in their mortality levels. Intraspecific variation in defoliation tolerance was high in *L. trichandra*, which ranged from 0% to 35% mortality for accessions such as OFI 53/88 and OFI 140/92 respectively. Similar intraspecific variation was recorded for *L. collinsii*, *L. lanceolata*, *L. pallida* and *L. shannonii*. Accessions experiencing high levels of mortality under regular defoliation management are clearly unsuited to forage or fuelwood production.

Tree form

All accessions were multi-branched following the initial coppicing, but while species such as *L. leucocephala* subsp. *leucocephala* and *L. multicapitula* were heavily branched with over 10 primary stems and no apical dominance, other species, such as *L. magnifica* and *L. lempirana*, were more arboreal with few primary branches (Table 1). Tree form varied widely in *L. diversifolia*, *L. leucocephala* subsp. *glabrata*, *L. pallida* and *L. trichandra*, ranging from apically dominant with few large secondary branches to heavily branched with no apical dominance.

Trees at the Brisbane site were generally more branched compared to the Philippines (Gabunada and Stür, these Proceedings). This may be due to the heavy psyllid pressure at Brisbane, with psyllids constantly damaging or killing the apical shoots of plants. The change in tree form following the initial coppicing indicated that defoliation management has considerable potential to alter tree form. For example, the highly productive KX2 F1 hybrids were initially apically dominant with 1–3 primary branches, but with repeated cutting they became heavily branched.

Tree form is an important consideration in selection of a multipurpose tree, but the desirable form varies with farming systems. In Australia heavily branched, low growing accessions are required for in situ grazing by cattle, whereas in many developing countries more arboreal accessions may be preferred to supply both fuelwood and cut-and-carry forage.

Conclusions

The outstanding broad adaptation of *L. pallida* × *L. leucocephala* F1 hybrid accessions, demonstrated in multi-environment trials (Mullen, Shelton et al., these Proceedings), was confirmed in this study. These KX2 F1 hybrid accessions were extremely high yielding in both warm and cold seasons at Brisbane. Methodologies for the commercial production of these hybrids, either from seeds or cuttings, is an important research priority.

Growth of *L. leucocephala* accessions was severely checked by psyllids in warm/wet environments. High DM productivity and psyllid tolerance were identified in other species, including accessions *L. trichandra* OFI 53/88 and *L. pallida* CQ3439. Sixty-six of the 116 accessions evaluated were poorly productive in all environments.

A strong linear relationship was identified between total DM yield and edible DM yield, so that high forage yields were produced by accessions producing the most total DM. However tree form and inherent woodiness varied among accessions and were recognised as important characteristics, in addition to yield, for selection of forage accessions.

Acknowledgments

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Agronomic Evaluation of the *Leucaena* Foundation Collection: 2. Humid Tropics in the Philippines

F.G. Gabunada Jr.[1] and W.W. Stür[1]

Abstract

An agronomic evaluation of 113 accessions of *Leucaena* species and 12 accessions from other tree legume genera was carried out on a fertile soil in the humid tropics at Los Baños, Philippines from July 1995 to December 1997. Trees were characterised in terms of growth habit, psyllid tolerance and yield. Yield of the best species was high and psyllid pressure at the site was low to moderate. The most productive accessions were KX2 F1 hybrids, followed by a KX3 F4 hybrid and accessions *of L. leucocephala*. Yield of other, non-hybrid *Leucaena* species was much lower. There was a strong correlation between yield during establishment and yield during the subsequent regrowth periods. However, some opportunities exist to select for higher seedling growth. Low psyllid damage among the 10 most productive species was recorded for KX2 hybrids, *L. salvadorensis*, *L. collinsii* and *L. pallida*. *Gliricidia sepium* cv. Monterrico had a higher yield of edible material than the best accessions of all species other than the *Leucaena* hybrids and *L. leucocephala*.

THE *Leucaena* foundation collection planted at Los Baños, Philippines, was one of two sites established as part of ACIAR Project 9433 'New Leucaenas for Southeast Asian, Pacific and Australian Agriculture'.

The objective of the evaluation was to characterise the entire foundation collection of *Leucaena* species in terms of yield and tolerance to psyllids, when managed for forage production under regular cutting, in a fertile, high rainfall, tropical environment.

Methods

A total of 125 accessions was evaluated, including 113 accessions of *Leucaena*, 3 accessions of *Gliricidia sepium*, two accessions of *Flemingia macrophylla*, two accessions of *Calliandra calothyrsus*, and one accession each of *Albizia lebbek*, *Cratylia argentea*, *Indigofera anil*, *Tipuana tipu*, and *Zapoteca tetragona*.

The experiment was laid out as a randomised complete block (RCB) with two replicates. Ten plants of each accession were planted in 5 m long rows with 0.5 m between plants. Accessions were planted end-to-end with no extra spacing between plots (accessions). The spacing between rows was 3 m. Seedlings were inoculated with a multi-strain rhizobium, applied by watering two weeks after germination and were transplanted into the field two months after sowing in September 1995.

Trees that did not establish successfully were replanted between October 1995 and February 1996. Following a 10-month establishment period, dry matter productivity was assessed by cutting plants to 50 cm above ground level every 3–4 months until November 1997. Psyllid damage was assessed monthly using an empirical score of 1 to 9 developed for the LPT trials in Hawaii (Wheeler and Brewbaker 1990).

The experimental site was located at the International Rice Research Institute in Los Baños, Laguna, Philippines (14°13'N, 121°15'E; 23 m above sea level). The soil is a heavy, brown clay loam, which is prone to waterlogging during periods of heavy rainfall. It is fertile with low N and poor drainage being the only factors limiting growth. Long-term rainfall averages 2100 mm/year with four months per year when monthly rainfall is less than 100 mm.

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Results and Discussion

Establishment and growth

Yield at harvest 1 represents growth for the first year of establishment and may be seen as an indicator of seedling growth. Growth during the first year was extremely variable both between and within species, with the highest yield (432 g/m/month) occurring within the KX2 hybrids. The only other accessions reaching more than 50% of the highest yielding KX2, were either other hybrids or *L. leucocephala* entries. The best *L. leucocephala* accession produced 82% of the yield of the highest yielding KX2 accession. Among other species, the highest yield during the first year of growth was obtained by accessions of *L. salvadorensis*, followed by *L. collinsii*, *L. pallida* and *L. shannonii*.

Dry matter production

Overall, yields were high (maximum 37 t/ha/year) showing the potential of *Leucaena* when grown on fertile soils in the humid tropics.

The most productive species consistently were *Leucaena* KX2 F1 hybrids. Later generation hybrids had much lower yields, showing the loss of hybrid vigour in subsequent generations. An exception was a *Leucaena* KX3 F4 hybrid (K156 × K8 [tree 91-13]), which produced higher yields than pure lines and all other higher-generation hybrids (Table 1). This hybrid also had a low mean psyllid damage rating, and thus deserves close consideration particularly for high psyllid-pressure environments. The intra-specific *L. leucocephala* F1 hybrid produced slightly higher yields (4%) than the parents but was as susceptible to psyllid damage as either parent. Among inter-specific hybrids, KX2 hybrids had lower psyllid damage than KX3 hybrids.

Among non-hybrids, accessions of *L. leucocephala* produced by far the highest yields. The best *L. leucocephala* accessions had 18% lower yield than the highest yielding F1 hybrids during establishment and 27% during the subsequent cutting period. This appears to reflect the low to moderate psyllid pressure experienced at Los Baños, but also indicates that hybrid vigour of the best crosses is relatively small. The highest yielding *L. leucocephala* accessions were cv. Tarramba (K636) and K584 (data not presented).

The best accessions of other *Leucaena* species (*L. macrophylla*, *L. salvadorensis* and *L. pallida*) produced 70% or less of the yield of the best *L. leucocephala* accessions (based on harvests 2–6). Of these three alternative species, *L. macrophylla* had slow establishment. However, all three species may provide alternatives to *L. leucocephala* in high psyllid-pressure or low soil fertility environments. The higher percentage of edible material of *Gliricidia sepium* cv. Monterrico resulted in a higher edible yield than the best accessions of all species other than the *Leucaena* hybrids and *L. leucocephala*.

There were a few accessions/species that failed to persist indicating poor adaptation to the environmental conditions at the site. These included the species *L. greggii*, *L. confertiflora*, *L. cuspidata*, *L. retusa*, *L. matudae*, *L.* hybrid (OFI 52/87), and some accessions of *L. pallida* and *L. trichandra*. *Calliandra calothyrsus* also persisted poorly. Extensive periods of waterlogging during early establishment may have contributed to the early demise of some species.

Psyllid damage

Psyllid pressure at the site was low to moderate, with an average psyllid damage score of 1.8 across all accessions and 2.9 for the 10 most susceptible accessions. There were no strong relationships between psyllid damage and climate characteristics. Psyllid damage fluctuated with long periods of no damage in both the wet and the dry season (see Mullen et al, these Proceedings). All *Leucaena* species recorded some psyllid damage during the experimental period with *L. leucocephala* and *L. involucrata* recording the highest average damage (Table 1). The lowest mean damage rating was recorded in *L. salvadorensis* and *L. pallida*.

Slow establishment is one of the main factors limiting the adoption of tree legumes (Shelton and Jones 1995). There was considerable variation in early growth between and within species, indicating that there is scope for selecting for higher seedling growth among highly productive accessions.

Species with the highest yield at harvest 1 were either *Leucaena* hybrids or accessions of *L. leucocephala*. The correlation between yield at harvest 1 and subsequent productivity was high (r=0.80) indicating that early growth may possibly be used for selection of high yielding accessions.

Conclusions

Leucaena leucocephala has shown clearly that it is the premier tree legume in areas with high soil fertility, high rainfall and low to moderate psyllid pressure. F1 interspecific hybrids offer the opportunity to increase yields by 20%–30% and to provide more stable yields in areas where psyllid pressure is moderate to high. Other *Leucaena* species may warrant consideration in areas with high psyllid pressure and low soil fertility. Other tree legume genera such as *Gliricidia sepium* may provide an alternative to *Leucaena* in areas where *L. leucocephala* or *Leucaena* hybrids are not adapted.

Table 1. Yield, persistence, and psyllid damage of *Leucaena* species and hybrids tested.

Species[1]	Highest yielding accession	Dry matter yield g/month/m row			
		Harvest 1	Harvest 2–6	Persistence (%)	Psyllid damage (1–9)[2]
L. collinsii (5)	OFI 56/88	86	396	100	1.9
L. confertiflora	OFI 87/94	<1	0	0	1.2
L. cuspidata	OFI 83/94	<1	0	0	1.1
L. diversifolia (14)	CPI 33820	95	404	100	1.8
L. esculenta (3)	OFI 48/87	67	245	100	1.1
L. greggii	OFI 82/87	<1	0	0	1.0
L. involucrata	OFI 87/92	13	83	85	2.8
L. lanceolata (6)	OFI 44/85	72	391	100	2.2
L. lempirana (2)	OFI 6/91	130	286	95	2.2
L. leucocephala (8)	cv Tarramba	234	687	100	2.4
L. macrophylla (4)	OFI 47/85	62	487	90	1.7
L. magnifica (2)	OFI 58/88	32	225	95	1.6
L. matudae	OFI 49/87	<1	22	35	1.1
L. multicapitula	OFI 86/87	124	336	100	2.1
L. pallida (5)	K953	168	448	65	1.5
L. pueblana	OFI 34/89	18	109	89	1.1
L. pulverulenta (3)	OFI 84/87	3	187	100	2.1
L. retusa	OFI 23/86	<1	0	0	1.7
L. salvadorensis (3)	OFI 7/91	206	485	85	1.1
L. shannonii (4)	OFI 141/92	154	387	100	1.6
L. trichandra (9)	OFI 3/91	119	250	95	1.3
L. trichodes (2)	OFI 2/86	23	190	95	1.6
Hybrid KX2: *L. pallida* × *L. leucocephala* (4)	K748-1 × K584 F1	205	937	100	1.1
Hybrid KX3: *L. diversifolia* × *L. leucocephala* (7)	K156 × K8, tree 91-13 (F4)	306	760	80	1.3
Hybrid: *L. leucocephala* × *L. leucocephala* (2)	K584 × K636 F1	294	720	90	2.5
Leucaena hybrid	OFI 52/87	159	275	30	1.5
Albizia lebbek		22	153	100	1.0
Calliandra calothyrsus (2)		69	53	45	1.0
Cratylia argentea	CIAT 18516	2	75	90	1.0
Flemingia macrophylla (2)	CIAT 17403	126	238	100	1.0
Gliricidia sepium (3)	cv Monterrico	27	366	95	1.0
Indigofera anil		101	283	90	1.1
Tipuana tipu		10	36	83	1.0
Zapoteca tetragona		28	33	90	1.0

[1] When multiple accessions were tested within a species or hybrid the number tested is shown in parentheses.
[2] 1 = no damage, 9 = severe damage.

Acknowledgments

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Agronomic Performance of New *Leucaena* Species and Hybrids in the Philippines

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Abstract

Twenty five *Leucaena* species, provenances and hybrids were evaluated for psyllid resistance, plant growth and biomass production at three locations in the Philippines with diverse agro-ecological conditions. Eleven accessions were highly resistant to the leucaena psyllid, but all three *L. leucocephala* lines were highly susceptible. Among the lesser-known species only *L. involucrata* showed a high degree of susceptibility. There were strong indications that resistance may also vary within species. The hybrids of *L. leucocephala* × *L. pallida* (KX2 hybrid) and *L. macrophylla* subsp. *istmensis* 47/85 were fast growers and they were the most productive among the highly psyllid-resistant accessions across sites. No definite trend regarding plant growth and yield was obtained on all other remaining accessions across sites indicating the importance of matching the species with the environments. In the absence of psyllids, the *L. leucocephala* cultivars performed well. None of the newer species exhibited strong tolerance to highly acidic soils.

LEUCAENA *leucocephala* has been one of the most productive and versatile multi-purpose tree legumes available to tropical agriculture. In its native range, it has been used by man for several millennia, and continues to be conserved and cultivated by farmers from Texas to Peru. From this region, it has spread to most countries of the tropical world.

In the Philippines, *L. leucocephala* has long been a vital and integral part of smallholder agriculture where it is used mainly as a source of fodder and fuelwood. The arrival of the psyllid insect (*Heteropsylla cubana*) in late 1985 devastated many of *L. leucocephala* plantings and stimulated the search for other multi-purpose trees (MPT). However, almost all of the promising MPT species failed to surpass the versatility and fodder quality (intake, digestibility) of *L. leucocephala*. Hence, there are strong reasons to re-examine the *Leucaena* genus and to develop some of the lesser-known species for the benefit of the farming systems and rural communities of the country.

This study aimed to evaluate the agronomic performance of different *Leucaena* accessions under different agro-ecological conditions of the country. Another objective was to identify psyllid-resistant provenances and hybrids which also have desirable agronomic characteristics.

Materials and Methods

Location

The study was conducted in three different locations: ITCPH, Lipa, Batangas; NSWRRC, Tanay, Rizal; and PLPC, Palayan, Nueva Ecija.

The International Training Center on Pig Husbandry (ITCPH) in Lipa, Batangas (13° 9′ N; 121° 25′E) is approximately 84 km south of Manila. Elevation is around 312 m above sea level (asl). The soil, a silty loam, is deep and friable, fertile and well-drained. The pH is 5.9 (1:5 in H_2O) with organic carbon, phosphorus and potassium contents of 1.6%, 67 mg/kg and 1.53 meq/100g, respectively. The area has a tropical climate with a mean annual rainfall of 1898 mm. The dry season (<25 mm monthly rainfall) from January to April is relatively short. Mean monthly maximum/minimum temperature is 32/23 °C.

The National Soil and Water Resources Research Center (NSWRRC) in Tanay, Rizal (14° 36′ N, 121° 21′ E) is about 80 km east of Manila. Elevation is 550 metres asl with slope variations from 20% to

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39%. The site has distinct dry (December to April) and wet (May to November) seasons. Average annual rainfall is 2791 mm. Mean monthly maximum/minimum temperature is 28/20 °C. The soil, an Ultisol, is highly acidic with a pH of 4.4 (1:5 in H_2O), low in calcium (2.3 meq/100 g) and phosphorus (10 mg/kg). Aluminium content is relatively high at 3.2 meq/100 g.

The Palayan Livestock Production Center (PLPC) is located in Palayan, Nueva Ecija (15 °N 121 °E) approximately 160 km north of Manila. Elevation is about 50 metres asl. The area has 5 months dry (November to April) and 7 months of wet (May to October) seasons. Mean annual rainfall is 1866 mm with maximum and minimum temperature of 33/22 °C. Mean relative humidity is 78%. The soil is a heavy clay, and grey brown in colour. Soil pH is 6.3 (1:5 in H_2O) with 1.0 mg/kg nitrate nitrogen, 14 mg/kg phosphorous and 0.33 meq/100 g potassium contents. *Imperata cylindrica* and *Saccharum spontaneum* form the dominant vegetation of the area.

Treatments and design

The experiment was laid out in a randomised complete block design with 3 replications, except at the Tanay site which had only 2 replicates due to seed limitation. Treatments were the *Leucaena* spp. and hybrids shown in Table 1. Two rates of lime application (0 lime and 3 tons/ha) were imposed as additional treatments in Tanay. Each accession was planted in a single row plot. There were 10 trees per plot planted 50 cm apart and rows were 3 m apart.

Seedlings were grown in polyethylene bags for about 2–3 months depending on sites before transplanting. The newly planted seedlings were provided with water 3 times/week during the dry season at the rate of 1 L/plant/application. Manual weeding was conducted regularly.

Field measurements and sampling procedures

Psyllid damage

Psyllid ratings were taken on a monthly basis using an empirical scale of 1 to 9 developed by the Nitrogen Fixing Tree Association (Wheeler 1988). The results were averaged and only those months where mean damage score across accessions was >2 were analysed.

Dry matter yield.

Following the intial harvest, done when the trees were approximately 1-year-old, a total of 7, 2 and 6 destructive harvests were conducted respectively at Lipa, Tanay and Palayan for the duration of the trial. Harvests were carried out periodically depending on the amount of coppice regrowth. The last harvest at all sites was conducted in November 1997.

In each harvest period, four representative trees from each plot were cut to 50 cm height. Harvested plant materials were weighed fresh and immediately separated into edible (leaf + stem ≤5 mm diameter) and non-edible (stems and branches >5 mm diameter) fractions and weighed. Sub-samples (*c.* 300 g) were oven-dried at 70 °C for 5 and 7 days respectively for the leaf and stem fractions. Immediately after harvest, all the remaining trees were cut at 50 cm height to maintain a uniform stand.

Results and Discussions

Establishment and survival

Weather conditions during the early establishment period at all sites were favourable for plant growth. Seedling mortality was nil at Lipa and Palayan but at Tanay there were high mortality rates of the unlimed plants ranging from 70%–90% depending on species. Improvement of soil pH from 4.4 to 4.9 (1:5 in H_2O) and reduction in aluminium saturation from 67% to 49% were attained at Tanay with lime application. The attained values however were still far from the critical pH level of >5.5 and aluminium saturation of <20% for the leucaena. In the limed treatments, the majority of entries had high survival rates, ranging from 70–100%, except for the KX3 hybrid (35%), *L. involucrata* 87/92 (60%) and *L. lanceolata* 43/85 (65%) (Castillo et al. 1997b).

Psyllid damage

Psyllid damage was consistently low at Tanay and Palayan for the duration of the trial. Hence, only the data at Lipa (where high psyllid pressure was observed on several occasions) are presented. Psyllid damage was high during the months of October to February, a period when rainfall and temperature were very suitable for the growth of the accessions. No attempt however was made to measure the correlation of the climatic factors with psyllid damage. Nevertheless, it is clear as has been pointed out by Bray (1994) that climatic conditions favourable for the growth of leucaena also favour the multiplication of the psyllid insect.

The mean psyllid damage ratings of the different accessions are shown in Table 1. Based on the resistance categories by Mullen et al. (this Proceedings) 11 of 24 accessions were highly resistant (rating: 1–2) while 4 entries were either moderately susceptible (rating: 4–5) or highly susceptible (rating: 5–9) to psyllids. Included in the highly resistant group were the *L. pallida*, *L. diversifolia*, *L. collinsii*, *L. macrophylla*, *L. trichandra* and the KX2 hybrid. The two KX2 hybrids and *L. macrophylla* were the most productive among the highly resistant

Table 1. Psyllid damage ratings and edible dry matter production over an 18-month period of 25 *Leucaena* species and hybrids in the Philippines.

Entry	Psyllid damage score[1] (Lipa)	Edible dry matter (g/m of row)		
		Lipa (7 harvests)	Tanay (2 harvests)	Palayan (6 harvests)
L. leucocephala cv. Tarramba	4.6	1367	421	1098
L. leucocephala cv. Cunningham	4.6	1020	4	1116
L. leucocephala cv. Peru	5.5	1155	1185	1250
L. collinsii 52/88	1.1	1412	5	235
L. collinsii subsp. *zacapana* 56/88	3.5	500	4	na
L. diversifolia 82/92	1.7	500	407	60
L. diversifolia 4/91	2.3	310	457	328
L. diversifolia 83/92	1.2	919	7	88
L. diversifolia K156	2.8	714	945	261
L. esculenta 47/87	1.0	1054	69	601
L. involucrata 87/92	5.0	158	1	202
L. lanceolata var. *lanceolata* 43/85	2.5	1544	55	905
L. lempirana 6/91	na	na	na	738
L. macrophylla subsp. *istmensis* 47/85	1.6	2444	504	977
L. magnifica 19/84	1.3	911	1	275
L. pallida CQ3439	1.2	1374	250	717
L. pallida 79/92	1.0	1412	189	631
L. pulverulenta 83/87	2.7	427	79	397
L. salvadorensis 36/88	3.2	907	40	na
L. trichandra 53/88	1.0	1421	122	na
L. trichodes 61/88	3.0	298	1	103
L. sp. unknown hybrid 52/87	2.3	1064	381	862
L. leucocephala K636 × *L. pallida* K748 (KX2 F1)	1.0	4810	1095	na
L. leucocephala K636 × *L. pallida* K376 (KX2 F5)	1.6	2518	611	na
L. leucocephala K8 × *L. diversifolia* K156 (KX3 F2)	3.5	17	1	564

[1] Wheeler 1988

accessions. All *L. leucocephala* lines were susceptible. Hence, there is a little scope for selecting psyllid resistant lines in this species. The new cultivar Tarramba (K636) exhibited tolerance rather than resistance to psyllids. It produced many axial branches when growing tips were damaged. Among the less-known species, *L. involucrata* was the only accession that exhibited a high degree of susceptibility to the psyllid insect.

There were strong indications that psyllid resistance may also vary within species as has been reported by Bray (1994) and Castillo et al. (1997a). This is evidenced by the considerable variation in leaf damage scores within *L. collinsii* and the *L. diversifolia*. Likewise, the KX2 hybrid was more resistant to the psyllid than the KX3 hybrid as previously reported by Castillo et al. (1997a).

Dry matter (DM) production

Edible dry matter (EDM)

The total EDM production over two wet seasons and one dry season is shown in Table 1.

At Lipa, EDM production of the KX2 F1 hybrid was outstanding at all harvests. The KX2 F5 hybrid and *L. macrophylla* 47/85 also yielded well.

At Palayan, none of the new species was able to surpass the yield performance of the *L. leucocephala* lines probably due to nil psyllid pressure in the area. This is important in view of the higher feeding value of leucaena relative to other less-known species as has been reported elsewhere. The top yielding group also included the *L. macrophylla* 47/85, *L. lanceolata* 43/85, the hybrid 52/87, and the two *L. pallida* accessions. The KX2 hybrids were not planted at this site.

At Tanay, because of the high plant mortality on the unlimed plots, only the limed treatment was harvested. Yields were extremely variable. *L. leucocephala* cv. Peru, the KX2 F1 and F5 hybrids and *L. diversifolia* K156 responded best to the acidic conditions and longer cutting intervals at this site.

All of the most productive species were able to tolerate the cutting interval of 60–75 days imposed at Lipa and Palayan and remained productive during the study period. However, it must be remembered that these yield data have been obtained from only an 18-month period. Longer term evaluation is needed.

Total dry matter

Since total dry matter production was closely related to EDM, data are not presented. However, it is worth noting the exceptional wood production of the KX2 F1 hybrid at Lipa (5425g) compared to the next highest yield of 2118g.

Conclusions

The KX2 F1 hybrid exhibited excellent seedling growth, was resistant to psyllids, and was the most productive entry. However, a considerable decline in biomass production was noted in the KX2 F5 generation. *Leucaena* in developing countries such as the Philippines is used mainly as a source of fodder and fuelwood and the KX2 F1 hybrid appears very promising for this situation. Its wide adoption and utilisation in the region, however, would depend on the development of simple and low cost methods of vegetative propagation.

L. macrophylla 47/85 is also one of the highly productive and psyllid resistant species identified in this study. It exhibited broader adaptation relative to other new species as evidenced by its high rate of seedling growth and biomass production in the high psyllid environment of Lipa, in highly acidic soil of Tanay and under moisture stress at Palayan. Further studies are required on the management and feeding value of this large-leaflet species to confirm its value.

In the absence of psyllids, none of the new species outyielded the currently available cultivars of *L. leucocephala*.

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Evaluation of Sixteen *Leucaena* Provenances for Biomass Production, Drought Tolerance and Psyllid Resistance in Sri Lanka

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Abstract

Sixteen provenances representing six *Leucaena* species and one unknown *Leucaena* hybrid were assessed for growth and biomass production, and drought and psyllid resistance at the University Experimental Station, Dodangolla, Sri Lanka during 1995/96. There was considerable variation for all characters both within and between species. Wood production was highest (2.64 kg/tree) in *L. trichandra* 35/88, while highest leaf production (0.97 kg/tree) was recorded in *L. diversifolia* 82/92. Although psyllids were not a major problem during the experiment, *L. leucocephala* 32/88, *L. diversifolia* 46/87 and *L. trichandra* 4/91 were the most susceptible but *L. trichandra* 53/88 and *L. esculenta* 47/87 suffered no damage. Based on assessment of all characters, *L. diversifolia* 83/92 was the best overall performer. *L. leucocephala* 32/88 may be particularly useful for fuelwood production because of its large number of branches, although it is susceptible to the psyllid. *L. diversifolia* 82/92 and *L. leucocephala* 32/88 showed good regrowth in the dry season and should thus be useful in seasonally dry areas.

LEUCAENA leucocephala was introduced to Sri Lanka in the early 1970s. Since then it has become naturalised in both the dry and wet zones of the country. Farmers use *L. leucocephala* forage for feeding dairy cattle, buffalo and goats, and also use the wood as fuel for domestic cooking. In addition, *L. leucocephala* is used in agroforestry systems such as alley cropping and avenue cropping, as shade for annual and perennial crops, and as compost for vegetables and horticultural crops.

Presently, the major constraint to its widespread use is its high susceptibility to the *L. leucocephala* psyllid (*Heteropsylla cubana*) which is common in all *L. leucocephala* growing areas of the country (Gunasena et al. 1989). In Sri Lanka, *Leucaena* species trials for psyllid resistance and biomass productivity have been conducted since 1992, as a collaborative research program between the Oxford Forestry Institute and the Faculty of Agriculture, University of Peradeniya.

This paper presents the results of a trial of 16 provenances, from a range of *Leucaena* species. The objectives were to select psyllid resistant species having high biomass productivity, coppicing ability and leaf nutrient composition. A secondary objective was to identify species with good growth during the dry season, as a possible source of livestock fodder.

Materials and Methods

The trial was conducted at the University Experimental station, Dodangolla, in the mid-country intermediate zone of Sri Lanka (7°15′N, 80°45′E, altitude 367 m). The mean annual rainfall is 1563 mm, with major dry periods from February to March and June to September. The average temperature is 31 °C.

The 16 *Leucaena* provenances and their countries of origin are given in Table 1. A randomised complete block design was used with 3 replicates. Each plot had 16 trees, at a spacing of 1.5 × 1.5 m. The experiment was established in February 1994.

Measurements

Diameter at Breast Height (dbh), plant height and branch number were measured on three occasions

[1] University of Peradeniya, Peradeniya, Sri Lanka

Table 1. Provenances used in the trial, their origin, and some growth characteristics.

Species	Provenance	Origin	DBH 11/95 (cm)	Height 11/95 (m)	No. branches 11/95
L. diversifolia	45/87	Mexico	1.7cd[1]	5.1abc	20.5ab
	46/87	Mexico	3.1ab	5.0abc	20.8ab
	82/92	Guatemala	3.4a	6.2a	21.3ab
	83/92	Mexico	3.4a	5.2ab	24.2ab
L. esculenta	47/87	Mexico	1.7cd	3.1bcd	11.8b
L. leucocephala subsp. *glabrata*	32/88	Haiti	3.1ab	4.4abcd	31.5a
L. pallida	78/92	Mexico	2.0bcd	4.3abcd	16.4b
	79/92	Mexico	3.0ab	3.9abcd	22.1ab
L. pulverulenta	83/87	Mexico	3.1ab	2.3d	12.9b
	84/87	USA	1.2d	2.8bcd	15.6b
L. trichandra	35/88	Honduras	2.6abc	2.8cd	14.6b
	53/88	Guatemala	1.1d	3.3bcd	19.5ab
	3/91	Honduras	1.5cd	3.4bcd	23.3ab
	4/91	Honduras	2.0bcd	2.8cd	17.0b
	138/92	Guatemala	1.9bcd	3.5bcd	19.4ab
Leucaena sp. (unknown hybrid)	52/87	Mexico	2.4abc	4.5abcd	17.8b

[1] Means within a column followed by the same letter are not significantly different ($p>0.05$).

between February and November 1995. Dry weight production of leaf and wood was recorded in January 1996, two years after planting. Regrowth stem length was measured after the dry season following this harvest (January to April).

Psyllid damage was assessed on two trees in each plot on five occasions, using the 9-point scale recommended by NFTA (Wheeler 1988)

Results and Discussion

The trees grew vigorously during the experimental period, with the best attaining a height of more than 6 m in two years (Table 1). After one year, the four *L. diversifolia* provenances (45/87, 46/87, 82/92 and 83/92) and the *Leucaena* hybrid (52/87) were the tallest of the entries. After two years, the four *L. diversifolia* provenances were tallest. The shortest growth was within the *L. trichandra* provenances. The *L. diversifolia* provenances 82/92 and 83/92 also had the greatest dbh after 2 years growth, with the *L. trichandra* provenances again being smaller.

The *L. leucocephala* provenance 32/88 had the highest number of branches, followed by the *L. diversifolia* provenances, with the *L. trichandra* group generally being less branched. It would be expected that higher branch numbers should produce good wood yields. Accessions with high branch numbers should also be particularly useful for fuelwood production.

The highest wood production (Table 2) was recorded by *L. trichandra* 35/88, followed by *L. pulverulenta* 83/87 and *L. diversifolia* 83/92. There was considerable variation within species, as evidenced by the poor performance of *L. trichandra* 3/91 and 4/91, and *L. pulverulenta* 84/87. Leaf production was generally well related to wood production, with *L. diversifolia* 82/92, *L. trichandra* 35/88 and *L. pulverulenta* 83/87 having the highest levels (Table 2).

At the end of the 12-week regrowth period during the dry season, the tallest regrowth (over 1 m) was observed in *L. leucocephala* 32/88, *L. diversifolia* 82/92, 83/92 and 45/87, and *L. pallida* 78/92 and 79/92. The provenances with the best branching at this time were *L. leucocephala* 32/88, *L. pallida* 78/92, *L. trichandra* 35/88 and *L. diversifolia* 83/92. The provenances with good regrowth during this period should be suitable for areas with pronounced dry seasons to provide seasonal supplies of fodder.

Although psyllids were present throughout the experiment, damage was never severe. However, differences were observed between provenances in the number of adults, nymphs and eggs in the various sampling periods. The mean damage rating, based on the two periods with most psyllid damage, is shown in Table 2. The most susceptible provenances were *L. diversifolia* 46/87 and *L. leucocephala* 32/88. *L. trichandra* 53/88 and *L. esculenta* 47/87 suffered no damage. There was considerable variation within the *L. diversifolia* and *L. trichandra* groups.

Table 2. Wood and leaf production in January, 1996 and psyllid damage of 16 *Leucaena* provenances.

Species	Provenance	DW wood kg/tree	DW leaf kg/tree	Psyllid damage[1]
L. diversifolia	45/87	0.5b[2]	0.3	1.8
	46/87	1.6ab	0.3	2.5
	82/92	1.4ab	0.1	1.9
	83/92	1.9ab	0.5	1.6
L. esculenta	47/87	0.4b	0.2	1.0
L. leucocephala subsp. *glabrata*	32/88	1.7ab	0.6	2.2
L. pallida	78/92	0.8b	0.2	1.5
	79/92	1.4ab	0.5	1.3
L. pulverulenta	83/87	2.0ab	0.9	1.2
	84/87	0.3b	0.1	2.2
L. trichandra	35/88	2.6a	0.9	1.3
	53/88	1.0b	0.4	1.0
	3/91	0.54b	0.2	1.2
	4/91	0.8b	0.4	2.6
	138/92	1.2ab	0.6	1.3
Leucaena sp. (unknown hybrid)	52/87	1. 7ab	0.3	2.8

[1] Average rating from two worst sampling dates.
[2] Means within a column followed by the same letter are not significantly different ($p>0.05$).

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Germplasm Evaluation of New Leucaenas in Papua New Guinea

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Abstract

Twenty-eight accessions of *Leucaena* and 2 species of *Calliandra* were evaluated for dry matter (DM) yield, psyllid resistance and tolerance of regular coppicing at 3 contrasting sites in Papua New Guinea. Mean DM yields were very high at Lae, (a hot, high rainfall environment), moderately high at Erap, (a seasonally dry humid tropical environment), and low at Aiyura, (a highland tropical environment constrained primarily by low temperatures). Psyllid pressure at all sites was low. The *L. pallida* K748 × *L. leucocephala* K636 F1 hybrid accession (KX2 F1) displayed broad adaptation for DM yield and was the highest yielding accession at Lae and Erap. *L. macrophylla* OFI 47/85 displayed moderate adaptation to the wet, low solar radiation Lae wet season environment, but no specific adaptation was apparent to low soil moisture conditions experienced during the Erap dry seasons. *L. trichandra* OFI 53/88, and to a lesser extent, *L. diversifolia* PNG 4 and KX2 F1 were high yielding accessions at Aiyura. *L. trichandra* OFI 53/88 and *L. diversifolia* PNG 4 were only moderate yielding at lowland sites, but were considered to be specifically adapted to the low temperature environments.

LEUCAENA leucocephala was first introduced to Papua New Guinea (PNG) as a shade tree for coffee and cocoa and has since become naturalised in the coastal lowlands, where it has gained acceptance as a useful multi-purpose tree species. Its utilisation by smallholder farmers has been primarily for fuelwood and pole timber and as a shade tree for new settlements in semi-arid savanna areas.

L. leucocephala is increasingly being utilised as a high quality fodder for grazing in the Markham Valley in PNG. Slow uptake by graziers has been attributed to the invasion of the leucaena psyllid (*Heteropsylla cubana*) in the mid-1980s, just as the DHP toxicity problem had been solved (Galgal et al. 1994). By the end of 1986, most of the naturalised *L. leucocephala* had been severely defoliated or killed by the psyllid. The experience with psyllids lead the Department of Agriculture and Livestock's Research Division in 1989/90 to investigate a broader range of leguminous shrubs and trees, including several lesser-known *Leucaena* species, in its Multi-Purpose Tree Species evaluation program (Kanua and Sitapai 1992). Promising accessions at both highland and lowland sites included *L. diversifolia* PNG4 and a *Leucaena* hybrid (named 'mexicana').

In Papua New Guinea, evaluation of the diversity within the *Leucaena* genus was initiated in 1995 as a component of an Australian Centre for International Agricultural Research (ACIAR) program New Leucaenas for Southeast Asian, Pacific and Australian Agriculture. The program sought to identify agronomic adaptation for forage yield under regular cutting to low temperatures (cold and frost) and acid soils, and resistance to the psyllid insect. In PNG, sites were specifically selected to investigate low temperature adaptation at Aiyura in the eastern highlands, and yield potential at Lae and Erap in the hot, humid lowlands. Results of the PNG evaluation are presented in this paper.

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Materials and Methods

Site descriptions

Three sites were selected to cover the range of agro-climatic zones in PNG (Figure 1). Lae and Erap are humid tropical lowland sites, but, whereas Lae has high annual rainfall and no distinct dry season, Erap has moderate annual rainfall and is seasonally dry.

Aiyura is a highland tropical site with relatively low temperatures year-round and a short dry season. Only minor seasonal variations in maximum and minimum temperatures are experienced within sites (Figure 1). Soils at Lae and Erap are free-draining, fertile alluvials of near neutral pH, whereas the Aiyura site has a mildly acidic, fertile organic soil (Table 1).

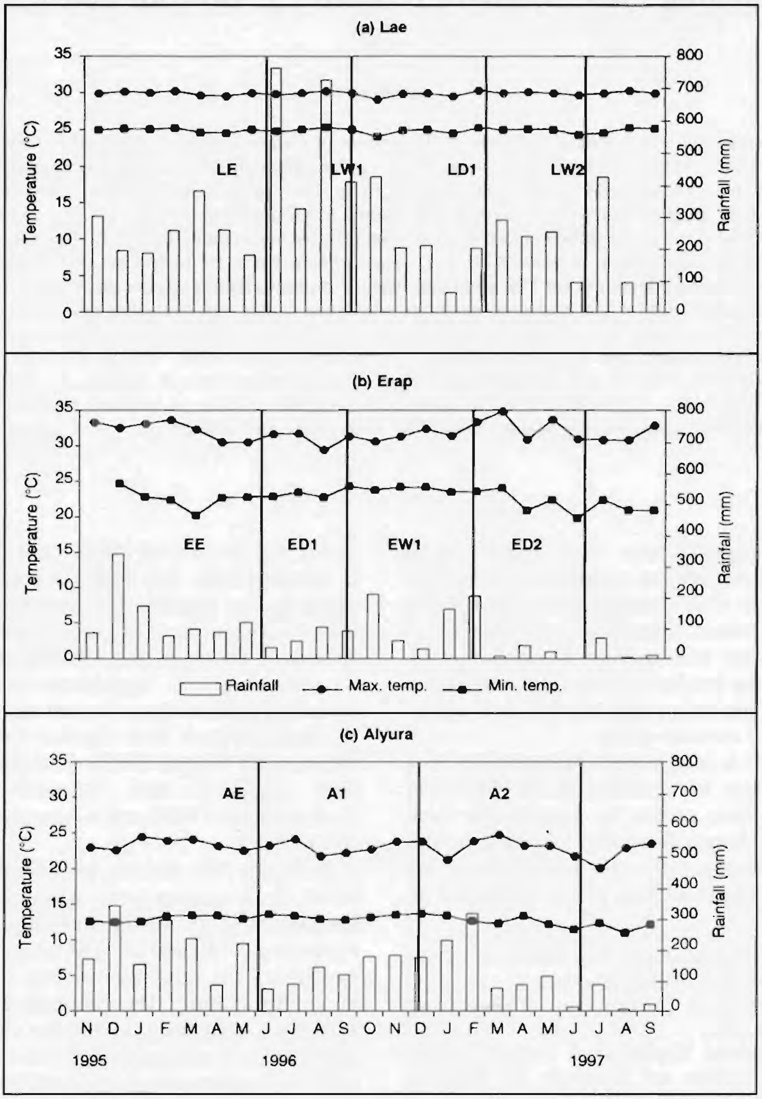

Figure 1. Monthly maximum and minimum temperature and rainfall for Lae, Erap and Aiyura over the experimental period. The experimental period was subdivided into environmental periods used for data analyses. These were: LE, LW1, LD1 and LW2 for the establishment period, the first wet season, the first dry season and the second wet season at Lae; EE, ED1, EW1 and ED2 for the establishment period, the first dry season, the first wet season and the second dry season at Erap; AE, A1 and A2 for the establishment period and subsequent periods at Aiyura.

Table 1. Latitude, altitude, annual rainfall and soil chemical characteristics for *Leucaena* evaluation sites in Papua New Guinea.

Site	Latitude	Altitude (m.a.s.l.)	Rainfall (mm/year)	Soil pH (1:5 in H_2O)	Avail P (mg/kg)	Cation ex. cap. (meq/100 g soil)
Lae	6°35'S	30	4000	6.4	>200	23.2
Erap	6°45'S	100	1200	6.7	>200	31.4
Aiyura	6°15'S	1700	2000	5.6	47	7.9

Experimental design and management

At all sites a randomised complete block design was used with 3 replicates as blocks, and one plot of each accession (treatments) per replicate. Treatments consisted of 28 accessions of *Leucaena* and 2 species of *Calliandra* (Table 2) planted as seedlings in line plots 5 m long, with 10 plants at 50 cm spacings within the rows. Rows were spaced 3 m apart. Seedlings were inoculated with an effective strain of *Rhizobium*, CB3060, (Mullen et al. 1998) prior to transplanting in November 1995. Weed growth was controlled over the experimental period.

Measurements and data analysis

Initial assessment of DM yield was carried out in June 1996, at 7 months after field planting. For each plot, the middle 6 trees were cut at 50 cm above ground, separated into edible (leaf and green stem) and non-edible fractions, and dehydrated to determine yield. Subsequent harvests were taken at three monthly intervals for the lowland sites (Lae and Erap) and at six monthly intervals at Aiyura. Harvesting continued over a 13-month period, and harvests were scheduled to correspond with the change of the seasons (wet/dry).

Psyllid damage was assessed on a monthly basis over the experimental period, using a damage score rating of 1 to 9. A score of 1 = no damage observed, 4 = tips and young leaves badly curled, yellowish and covered with sap, 5 = up to 25% leaflet loss form young shoots and 9 = blackened stems with total leaf loss (Wheeler 1988).

Accession yield data for each site and for each season were determined. Analysis of variance was performed for each site to identify statistical significance among accessions.

Results and Discussion

Sites and environments

Maximum and minimum temperatures over the experimental period at Lae and Erap were consistent with long-term averages, but below average temperatures were recorded at Aiyura during the final harvest period (Figure 1). Rainfall was well below average at Erap and Aiyura from March to September 1997.

Mean yields of accessions at each site are presented in Table 2. Average DM yield of accessions was high at Lae (13.0 t/ha/year), moderate at Erap (9.3 t/ha/year) and very low at Aiyura (2.1 t/ha/year). Accession yields were consistent throughout the year at Lae, but at Erap yields dropped by 60% in the first dry season and 90% in the second dry season compared with wet season yields. Final period yields were also very low at Aiyura due to below average rainfall and temperatures.

At Aiyura, the low temperatures experienced throughout the evaluation and low rainfall in the final period clearly limited growth of *Leucaena* and *Calliandra* accessions. However, substantial differences in the relative yields of accessions at Aiyura in comparison to the lowland environments at Lae and Erap was evident (Table 1).

Yields at Lae may have been limited by low solar radiation due to extended periods of overcast weather. Sunlight hours at Lae averaged only 5.5 hours/day during the experimental period; however, solar radiation was not measured. Severe decline in yield occurred during the dry seasons at Erap; however, no adaptation to these periods of acute moisture stress was apparent within the test accessions.

Accession yield adaptation

The *L. pallida* K748 × *L. leucocephala* K636 F1 hybrid (KX2 F1) was the highest yielding accession at the lowland sites, outyielding the next best accessions at Lae and Erap by 47% and 70% respectively. This agrees with results from the MET evaluation reported by Mullen, Shelton et al. (these Proceedings) and the foundation collection evaluations in the Philippines (Gabunada and Stür, these Proceedings) and in Australia (Mullen and Shelton, these Proceedings). Commercial quantities of propagules (seed or cuttings) of the KX2 F1 hybrid are currently not available. Large-scale seed production and/or vegetative propagation techniques are required so that the forage quality for ruminants and multi-purpose utility for smallholder agriculture of this agronomically excellent accession can be determined.

Table 2. Total DM yields from transplanting to final harvest at Lae, Erap and Aiyura, and mean psyllid damage rating (PDR) for *Calliandra* and *Leucaena* accessions evaluated in Papua New Guinea. Accessions are ranked by DM yield at Lae.

Genotype	Accession	GxE biplot ID	Lae DM yield (t/ha/year)	Erap DM yield (t/ha/year)	Aiyura DM yield (t/ha/year)	Mean PDR
L. pallida × *L. leucocephala*	K748 × K636 F1	20	38.7	29.8	9.7	1.1
L. macrophylla subsp. *istmensis*	OFI 47/85	18	26.4	9.7	0.2	1.4
L. esculenta	OFI 47/87	10	20.8	16.9	0.8	1.3
L. collinsii subsp. *collinsii*	OFI 52/88	1	20.1	17.5	0.6	1.2
L. salvadorensis	OFI 36/88	23	20.1	14.4	0.0	1.5
L. leucocephala subsp. *glabrata*	PNG K636	28	19.8	13.5	0.4	1.7
L. pallida × *L. leucocephala*	K376 × K8 F5	19	19.8	9.1	5.6	1.4
L. pallida	CQ3439	21	19.6	16.0	2.8	1.2
L. pallida	OFI 79/92	11	18.6	12.4	0.7	1.4
L. ? (unknown hybrid)	OFI 52/87	12	17.4	9.3	1.2	1.3
L. diversifolia × *L. leucocephala*	K156 × K8 F2	3	16.9	13.7	0.2	1.8
L. leucocephala subsp. *glabrata*	K636	16	16.2	11.4	0.2	1.9
L. lanceolata var. *lanceolata*	OFI 43/85	14	15.3	8.0	0.0	1.7
L. leucocephala subsp. *glabrata*	cv. Cunningham	17	12.6	9.3	0.0	2.3
L. diversifolia	OFI 83/92	7	11.9	6.9	2.8	1.1
L. ? (unknown hybrid)	Mexicana	26	11.8	6.7	0.8	1.4
L. collinsii subsp. *zacapana*	OFI 56/88	2	11.3	5.3	0.2	2.0
C. houstoniana	PNG2	27	10.8	8.0	7.6	1.0
L. trichandra	OFI 53/88	5	9.0	10.7	15.2	1.0
L. trichodes	OFI 61/88	25	8.8	9.5	0.0	1.8
L. magnifica	OFI 19/84	24	7.8	6.3	0.4	1.4
L. diversifolia	PNG4	29	6.4	5.4	10.1	1.2
L. pulverulenta	OFI 83/87	22	5.6	4.9	0.0	1.6
L. lempirana	OFI 6/91	15	5.0	2.8	—	1.4
L. diversifolia	OFI 82/92	6	4.7	4.3	0.6	1.6
L. diversifolia	K156	8	4.5	4.4	0.1	1.2
C. calothyrsus	PNG5	30	3.7	2.6	2.3	1.0
L. trichandra	CPI46568	4	2.8	4.4	—	1.0
L. diversifolia	OFI 4/91	9	2.5	3.1	0.8	1.3
L. involucrata	OFI 87/92	13	2.0	1.7	0.0	1.9
LSD ($P<0.05$)			5.1	6.4	5.5	

In addition to the KX2 F1 hybrid *L. macrophylla* OFI47/85 was high yielding at Lae but was only moderate yielding at Erap. This accession was also highly productive in an evaluation trial in Honduras (Stewart et al. 1991). It has wood of medium density (Pottinger et al., these Proceedings), but its forage quality requires clarification. Despite high DM digestibility and low condensed tannin content from in vitro studies (Dalzell et al. these Proceedings), Faint et al. (these Proceedings) reported *L. macrophylla* OFI47/85 to be less palatable than other *Leucaena* accessions.

Other high yielding accessions in the lowland sites were *L. collinsii* subsp. *collinsii* OFI 52/88, *L. pallida* CQ3439 and *L. esculenta* OFI 47/87, but these produced only half the yield of the KX2 F1 hybrid. Lowest yielding accessions were *L. diversifolia* OFI 4/91, *L. involucrata*, OFI 87/92 and *L. trichandra* CPI46568.

In the highlands, *L. trichandra* OFI 53/88 was the highest yielding accession, outyielding the KX2 F1 and *L. diversifolia* PNG 4 by approximately 50% and displaying excellent specific adaptation to the cool, highland-tropical environment. Initial in vitro tests indicate that this accession has high DM digestibility, but also a high CT content (Dalzell et al., these Proceedings). Comparative feeding studies with this accession are currently being conducted (M. Komolong) to determine its forage quality. Wood quality evaluations indicate that *L. trichandra* (OFI 53/88) will be a useful fuelwood, with a wood density of 0.72 g/cm^3 (compared to *L. leucocephala* K636 0.61g/cm^3).

The KX2 F1 hybrid, *L. diversifolia* PNG4 and *C. houstoniana* were moderately well adapted to the highland environment. Little is known about the wood and forage qualities of these accessions. *C. houstoniana* was a highly branched shrub with negligible wood component, a form better suited to a forage crop or a hedgerow for alley cropping. The *Leucaena* accessions were more arboreal and could be managed for either wood or forage production. Twenty accessions produced less than 2 t/ha/year yield, and 6 accessions failed to produce measurable yields in the cool highland environment.

Plant mortality

Plant mortality was negligible at Lae, with only *L. diversifolia* PNG4 experiencing significant mortality (30%). At Erap, *L. trichandra* OFI 4/91 and OFI 53/88, *L. diversifolia* PNG4, and *L. involucrata* OFI 87/92 experienced substantial mortality (30–50%), whereas at Aiyura *L. involucrata* OFI 87/92, *L. trichodes* OFI 61/88, *L. macrophylla* OFI 47/85 and the 'mexicana' hybrid experienced highest mortality (30–60%). Plant death for other accessions was negligible.

Psyllid pressure and accession resistance

Mean psyllid damage ratings at the 3 PNG sites were low. However, at Lae and Aiyura, psyllid pressure was periodically high (>4), whereas at Erap psyllid pressure remained low over the experimental period (<3). Lae and Aiyura experience only minor annual variation in climatic variables (Figure 1) and no explanations for the fluctuations in psyllid pressure were apparent.

Mean psyllid damage ratings for *Leucaena* accessions are presented in Table 1. *L. leucocephala* cv. Cunningham and *L. collinsii* subsp. *zacapana* OFI 56/88 were the most psyllid susceptible accessions, whereas *L. trichandra* accessions CPI46568 and OFI 53/88 were most tolerant.

Although psyllid pressure was generally low at the PNG sites, accession resistance to psyllids was reasonably well correlated with previous reports ($r^2 = 0.56$) (Mullen and Shelton 1997). However, long periods of high psyllid pressure are required to effectively determine the psyllid resistance of *Leucaena* accessions (Bray 1994) and therefore detailed analysis is not appropriate in this paper (for more information see Mullen, Gabunada et al., these Proceedings).

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Leucaena Germplasm Evaluation in North Sumatra

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Abstract

The genus *Leucaena* contains many vigorous tree species which are potentially higher yielding than currently available cultivars. An experiment was designed to find accessions of *Leucaena* adapted to mildly acidic soils and having tolerance to the *Leucaena* psyllid. Twenty eight accessions of *Leucaena* and two of other genera (*Calliandra calothyrsus* and *Gliricidia sepium*) were grown at Sei Putih, Indonesia in a randomised block design with three replications. Seedlings were transplanted in November 1995 and regrowth and yield was measured above a height of 50 cm every 12 weeks from August 1996. Monthly measurements of psyllid damage commenced in October 1996. Six accessions of *Leucaena* provided higher yields than *Gliricidia* and *Calliandra* giving yields >200 g/m row/month. The most productive accession was *L. pallida* CQ 3439, followed by *L. leucocephala* cv. Tarramba (K636). Three other high yielding accessions (*L. collinsii* 52/88, *L. esculenta* and *L. trichandra 53/88*) were totally free from psyllid damage.

ANNUAL meat consumption in North Sumatra is only 5.7 kg per capita (DISNAK SUMUT 1994) or 74% of the national standard (Soehadji 1993). Karo-karo et al. (1993) reported that only 45% of North Sumatra's demand for small ruminants is met by local supply. This shortfall in supply is a reflection of low animal population and productivity in the region where most ruminants are raised by smallholders. In addition, Middle East countries, Malaysia and Singapore need to import more than 3 million head of small ruminants per year (Soehadji 1993). Thus there is significant unmet demand from both local and international markets and there is a need to increase both population and productivity of ruminants within this region.

Many different feeding systems are used by smallholders in the Southeast Asian region including total or partial pen-feeding, tethering, free grazing and shepherding (Horne and Ibrahim 1996). However, the feed base of ruminants produced by smallholders is commonly characterised by high fibre and low protein contents (Mullen 1996). Protein and energy supplementation using agro-industrial by-products has been successful in overcoming nutritional limitations of low quality diets (Horne et al. 1995), but may prove too expensive for smallholders.

Shrub and tree legumes have made a significant contribution to animal production in the tropics (Stobbs and Johnson 1975; Jones 1979) and their utilisation for ruminant production is popular in smallholder farming systems of Southeast Asia (Mullen 1996). Forage tree legumes have the potential to increase the dry matter digestibility and voluntary intake of low quality diets by supplying a valuable protein source.

Leucaena leucocephala (leucaena) is a vigorous tree legume with potentially high forage yields and good nutritional quality. It is easy to manage and is highly persistent once established; it is suited to deeper soils in a wide range of climates, especially neutral or alkaline soils, but it requires weed control during establishment. Leucaena does not grow well on acidic soils (Hill 1971; Brewbaker 1986) and this, along with the psyllid pest, are the major limitations for its expanded use in the humid tropics. This experiment was designed as part of an integrated research program aimed at finding suitable species of *Leucaena* adapted to acidic soils in the humid tropics and having tolerance to the *Leucaena* psyllid. Nineteen trial sites in seven countries were chosen to evaluate genotypic and environmental interactions of a representative range of *Leucaena* accessions as part of a comprehensive investigation of yield and adaptation in the *Leucaena* genus (Shelton 1997).

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Methodology

Site description

The trial was located at Sei Putih in North Sumatra, Indonesia. The site was chosen to represent acidic soils common to the humid tropics. Sei Putih is 50 km southeast of Medan, North Sumatra, Indonesia located at approximately 3°30'N and 99°00'E, about 70 m above sea level. The mean annual rainfall is 1910 mm with 82% falling in the months June to December. The soil at this site is classified as a tropudult. The experiment was established in a flat area previously occupied by native grasses. Soil samples were collected from the surface horizon (0–15 cm) for chemical analysis.

Design, treatments and management

Twenty eight accessions of *Leucaena* and two other shrub legumes (*Calliandra calothyrsus* and *Gliricidia sepium*) were grown (Table 2). Pre-scarified seed was soaked for 24 hours in fresh water and placed on moist cotton wool for two days until germination. The germinated seeds were planted into 150 × 30 mm black polybags containing about 0.5 kg of soil collected from the experimental site. After three months (28 November 1995), the seedlings were transplanted into the field in a randomised block design with three replications. Each block consisted of 30 accessions with individual plots comprising one row of 10 plants with an inter-row spacing of 3 m and an intra-row spacing of 0.5 m. The soil surrounding each plant was inoculated with *Rhizobium* strain 3060 at the time of transplanting. Plots were irrigated at transplanting. Throughout the experiment, the site was kept clean of weeds by both chemical and manual control as required. No fertiliser was applied.

Measurements

The first cutting was made on 26 August 1996, nine months after transplanting. Yield was measured by harvesting the four central plants in each plot above a height of 50 cm. Samples were then separated into edible and non-edible components, with each component subsampled for dry matter determination. Four further harvests were made at 12-week intervals. Monthly measurements of psyllid damage were made between October 1996 and September 1997 using the University of Hawaii damage rating scale (Wheeler 1988) where a rating of 1 indicates no damage and a rating of 9 indicates blackened stems with total leaf loss.

Results and Discussion

Soil properties

The soil characteristics of Sei Putih site are presented in Table 1; the soil is relatively fertile although mildly acid and marginal in available K. In addition, Ca, Mg and Mn concentrations are close to critical. All other nutrients are in adequate supply.

Table 1. Soil properties from the experimental site at Sei Putih, Indonesia

Soil properties	Actual	Critical levels	Notes
pH (H_2O)	5.5	< 5.5	marginal
P (mg/kg)	49	<19	
K (meq/100g)	0.2	<0.2	marginal
S (mg/kg)	76	<5	
Ca (meq/100 g)	2.7	<2.5	close to marginal
Mg (meq/100 g)	0.5	< 0.4	close to marginal
Zn (mg/kg)	12.2	< 0.5	
Fe (mg/kg)	34	> 500	
Mn (mg/kg)	99	> 100	close to critical
CEC (meq/100 g)	4		low
Al Sat. (%)	7	> 20	

Rainfall

Although the rainfall during the month of transplanting (November 1995) was much higher than average (Figure 1), the rainfall for the experimental

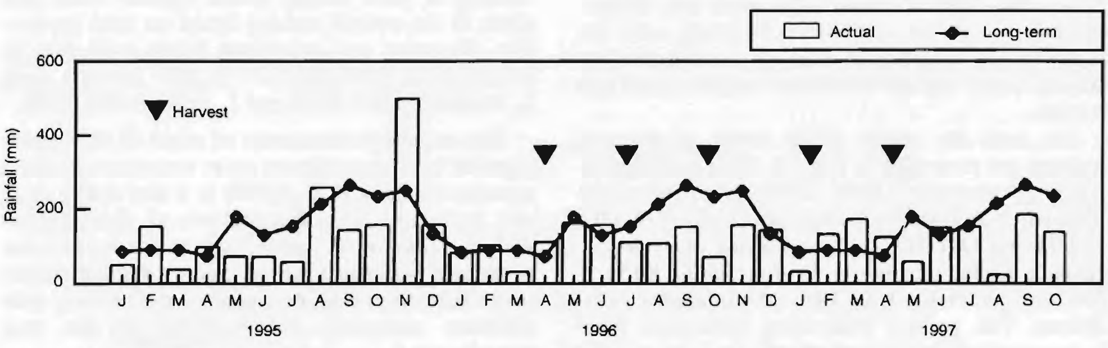

Figure 1. Actual and long-term rainfall distribution during the experimental period at Sei Putih.

Table 2. Dry matter yields and psyllid damage ratings for 28 accessions of *Leucaena*, *Calliandra calothyrsus* and *Gliricidia sepium* at Sei Putih.

Accession	Average DM yield (g/m row/month)	Average psyllid damage rating*
L. collinsii subsp. *collinsii* OFI 52/88	183	1.0
L. collinsii subsp. *zacapana* OFI 56/88	77	2.0
L. diversifolia OFI 82/92	112	1.2
L. diversifolia OFI 83/92	146	1.0
L. diversifolia K156	100	1.1
L. diversifolia OFI 4/91	156	1.3
L. esculenta OFI 47/87	151	1.0
L. lanceolata subsp. *lanceolata* OFI 43/85	156	1.3
L. lempirana OFI 5/91	116	1.5
L. leucocephala cv Cunningham	97	2.1
L. leucocephala K636 (OFI 94/92)	217	1.9
L. leucocephala K636 (cv Tarramba)	247	1.8
L. macrophylla subsp. *istmensis* OFI 47/85	154	1.1
L. magnifica OFI 19/84	69	1.1
L. multicapitula OFI 81/87	87	1.7
L. pallida OFI 137/94	228	1.0
L. pallida OFI 52/87	214	1.4
L. pallida CQ3439	261	1.1
L. pallida OFI 79/92	167	1.0
L. pulverulenta OFI 83/87	80	1.4
L. salvadorensis OFI 38/88	147	1.3
L. trichandra CPI 46568	142	1.3
L. trichandra OFI 53/88	190	1.0
L. trichodes OFI 61/88	81	1.3
L. diversifolia × *L. leucocephala hybrid* KX3 F4 (OFI 3/95)	166	1.7
L. diversifolia × *L. leucocephala hybrid* KX3 F2	193	1.6
L. diversifolia × *L. leucocephala hybrid* KX3 F4	228	1.7
L. pallida × *L. leucocephala hybrid* KX2 F5 (OFI 2/95)	136	1.2
C. calothyrsus (local)	201	
G. sepium (local)	113	

* Scale of Wheeler (1988) 1 = no damage 9 = death of young shoots.

period was below the long-term average. In particular, during the period from July to December 1996 less than half the average rainfall was received.

Dry matter (DM) yields

DM yields during the establishment period (November 1995 to June 1996) were low. Subsequently, yields varied between harvests, with the highest yield occurring at Harvest 4 during the dry season. There was no correlation between yield and rainfall.

The total dry matter (DM) yields of the tree legumes are presented in Table 2. The seven highest yielding accessions (DM >200 g/m/row/month) included 3 accessions of *L. pallida* (CQ 3439, OFI 137/94 and OFI 52/87), 2 accessions of *L. leucocephala* K636, the hybrid *L. diversifolia* K156 × *L. leucocephala* K8 KX3 F4, and *Calliandra calothyrsus.* The poorest performing accessions were *L. leucocephala* (cv. Cunningham), *L. multicapitula, L. trichodes, L. pulverulenta, L. collinsii* subsp. *zacapana* and *L. magnifica.*

The rankings of the entries for edible DM yield for each harvest were examined (data not presented). It was apparent that in the last 2 harvest periods, ranking of yield among entries became stable and close to the overall ranking based on total production. However, two accessions which were slow to establish but performed well in later harvests were *L. trichandra* OFI 53/88 and *L. collinsii* OFI 52/88.

The relative performances of some of the species reported in this experiment are at variance with those reported by Bray et al. (1997) in a trial at the same site. In their work, *L. leucocephala* cv. Cunningham and *C. calothyrsus* performed much better, but *L. pallida* performed worse. Some of these differences may be due to intra-specific differences, with different accessions being tested in the two experiments.

Psyllid infestation and damage

A high level of psyllid damage was recorded on only one occasion (December 1996), and there was no correlation between rainfall and the level of psyllid damage throughout the experimental period. However, further study may be necessary to fully elucidate the pattern of psyllid damage.

The accessions most damaged by psyllids were *L. leucocephala* cv. Cunningham, *L. collinsii* subsp. *zacapana* and the two accessions of *L. leucocephala* K636. However, the K636 accessions were in the top five yielders indicating that the level of psyllid infestation was not critical. This agrees with observations from previous trials (Bray et al. 1997). The most productive accession (*L. pallida* CQ 3439) was almost free from psyllid infestation. Three other accessions, *L. collinsii* 52/88, *L. esculenta* 47/87 and *L. trichandra* 53/88, were totally free from psyllid damage. These accessions also provided an acceptable production of edible forage (Table 2).

Conclusions

A number of conclusions are possible from this trial:

- Good growth of many *Leucaena* accessions was recorded at this relatively fertile, mildly acid and marginally fertile site with most providing much higher yields than the commonly available *L. leucocephala* cv. Cunningham.
- The seven highest yielding entries were three *L. pallida* accessions, two *L. leucocephala* accessions (K636), a KX3 hybrid and an accession of *Calliandra calothyrsus*. The value of these accessions for animal production now needs to be quantified.
- The highest psyllid damage occurred on the four accessions of the two most susceptible species (*L. leucocephala* and *L. collinsii* subsp. *zacapana*) and was in the damage scale range of 4 to 6; however, the overall level of psyllid damage was not critical as some of these accessions yielded well. There was no correlation between psyllid damage and rainfall.
- Further monitoring of psyllid damage is necessary to ascertain the pattern of psyllid infestation at this site through the year and its relationship to environmental factors.

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Development of Acid/Psyllid Tolerant *Leucaena* Hybrids for Ruminant Production

C.C. Wong[1], C.P. Chen[2] and E.M. Hutton[3]

Abstract

The cultivation of *Leucaena leucocephala* for high quality fodder production on acid soils is always a problem without generous application of lime. Breeding for acid soil tolerance *Leucaena* was undertaken in CIAT, Cali, Columbia as early as 1981. In 1988, initial F2 and F3 hybrids from crosses between *Leucaena leucocephala* and diploid and tetraploid *L. diversifolia* were made available for evaluation of acid soil tolerance and psyllid resistance in Malaysia. Over the years, screening and selection of the hybrids at four regional MARDI stations with acid soils of pH 3.5–5 resulted in the identification of two best performing hybrids 40-1-18 and 62-6-8 for release in early 1998. These two hybrids are superior to the ML1 cultivar in edible dry matter, vigour, and psyllid tolerance under acid soil environments.

FORAGE agronomists in MARDI have worked intensively with *Leucaena leucocephala* for acidic soils for more than two decades. Several *L. leucocephala* accessions such as ML1 and ML2 have proven their superiority over all other nitrogen-fixing trees for beef and dairy cattle and small ruminant production. Small plot experiments conducted by MARDI researchers on some of the promising accessions of *L. leucocephala* have produced dry matter yields averaging more than 20 metric tons per hectare per year.

In view of the persistent and pressing psyllid problem on *L. leucocephala* and the extensiveness of the acid-soils in Malaysia and in neighbouring countries of the Southeast Asian and Pacific Region, there is an urgent need for incorporation of psyllid resistance/tolerance into the acid-soil tolerant *Leucaena* to overcome both the pest and edaphic problems. This approach offers a long-term solution to the problem at a lower cost than chemical amelioration of soil and chemical control of psyllid (Sanchez and Salinas 1981).

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A project was then initiated to develop key lines for adaptation to acidic soils in order to produce dual purpose *Leucaena* high in forage and wood production. The sites identified were at Serdang, Bukit Tangga, Jeram Pasu and Kuala Linggi which all have acidic soils of pH <5.5.

This paper reports some of the results of the screening and selection of the hybrids from the F2 to the F6 generation.

Materials and Methods

The methodology involved screening of the hybrid lines by documenting and initial screening of the acid-soil tolerant and psyllid-tolerant key lines (developed by Dr. E.M. Hutton at EMBRAPA in Brazil) on acidic Malaysian soils. Initial evaluation and selection of the interspecific hybrids between *L. leucocephala* and *L. diversifolia* was conducted at Serdang and subsequently at the different eco-climatic environments in Malaysia (Hutton 1990; Hutton and Chen 1993; Chen et al. 1995).

Fifty-nine groups of hybrid selections including the parental materials were planted in 1986/1987 at MARDI Research Station in Serdang. This led to the subsequent selection of 66 F2 lines for planting between October 1989 and April 1990 at four MARDI Research Stations: Kuala Linggi, Malacca (acid sulphate soil); Serdang, Selangor inland sedentary soil, acidic in nature; Jeram Pasu, Kelantan (granite wash); Bukit Tangga, Kedah.

Seeds of F3 generation were made available for the December–April 1991 planting season from the F2 planting at Serdang and Jeram Pasu. A minimum of 100 plants of each line were planted in double hedgerow arrangement of 1 m × 0.5 m × 1.5 m. A common basal fertiliser rate was applied. It comprised 50 kg each of triple superphosphate and muriate of potash and 5 kg each of copper sulphate and zinc sulphate and 500 g ammonium molybdate. The maintenance fertiliser rate was 10 kg P and 25 kg K per hectare per year.

Standard data from the screening at the various sites were recorded. These included soil chemical analysis, foliar mineral composition and tannin contents (young and old leaves), dry matter digestibility, dry matter yield, stem diameter at 50 cm, flowering, plant height at different stages of growth, growth vigour rating and psyllid damage. This methodology of screening and selection was repeated for F3 to F6 generations. Each selection took a period of several years to complete. Only the top 25% of the hybrid plants were selected for further screening and selection.

Final evaluation of selections was carried out at Serdang station, using cv. ML1 as a standard.

Results and Discussion

Initial hybrid assessment and selection

In the F3 hybrids assessment, great variations in plant growth between and within lines were recorded (Table 1). The promising acid tolerant lines of 11 × 25 and 11 × 31 had greater height and stem diameter than Cunningham. Among the lines, height and stem diameter were well correlated. The relative growth advantage of the hybrids over the acid-intolerant Cunningham was greater at Kuala Linggi (81% Al saturation) than at Serdang (68% Al saturation). At Kuala Linggi, Cunningham had poor growth and yellow leaves but at Serdang, Cunningham remained healthy. Intensive selection based on plant height, stem diameter, and plant vigour was carried out on individual plants within the lines late in February 1992.

At Kuala Linggi, the best hybrids were 62-6-8, 62-6-3, 62-12-1, 30-1-12, 45-4-11, 53-1-4, and 40-1-14. At Serdang, the best performing hybrids were 62-6-8 and 40-1-18. At Jeram Pasu, best hybrids were 62-6-8, 45-4-11, 39-1-12, and 40-1-18. Hybrid 53-1-4 had good growth vigour as well as all the *L. diversifolia* lines.

Psyllid reactions of hybrids and parents

In both F3 and F4 assessments, Cunningham was badly affected by psyllids with a damage rating of 4.2 reflecting considerable leaflet drop. The *L. leucocephala* 11 parent was also badly affected. Both *L. diversifolia* parents were psyllid tolerant with damage ratings <2, indicating some yellowing and no leaflet drop. Five of 11 × 25 lines (including 62-6) had a high percentage of tolerant trees as indicated by 62/6. In the F5 generation several psyllid-tolerant hybrids were identified (Table 2). Line 40-1-18 was the most tolerant hybrid. Psyllid tolerance appeared to be related to lower ratings for psyllid numbers.

Three hybrids (40-1-18, 62-6-3 and 62-6-8) were selected for final evaluation.

Table 1. Growth comparison of *Leucaena* F3 hybrids and Cunningham (control) in the acid soils at Kuala Linggi and Serdang Station.

Site	Hybrid	Line No.	Mean height (cm)	Mean stem diameter (cm)
Kuala Linggi	Cunningham (control)		114.8d	0.98
	11 × 25	62-6	265.3a	2.04
	11 × 25	62-12	228.5b	1.68
	11 × 31	30-1	221.0b	1.65
	11 × 25	39-2	119.6c	1.56
Serdang	Cunningham (control)		162.0d	1.19
	11 × 25	62-6	193.4c	1.28
	11 × 25	62-12	225.7b	1.80
	11 × 31	30-1	242.4a	2.02
	11 × 25	39-2	218.2b	1.82

Means with different letters differ significantly at $P<0.05$.

Table 2. Mean ratings for psyllid number (0-3) and damage (0-5) on young leaflets of F5 hybrids, parents and Cunningham, each with 80-84 trees, during a severe psyllid attack at Kuala Linggi Station in July 1991.

Entry	Psyllid No.	Psyllid damage mean
Cunningham (control)	2.2	4.2
L. leucocephala 11	2.2	3.6
L. diversifolia 25	—	1.5
L. diversi.folia 30	1.4	1.8
Hybrid 11 × 25 (62/6)	1.9	2.2
Hybrid 11 × 25 (51/1)	2.2	4.6
Hybrid 11 × 31 (30/1)	1.4	1.9
Hybrid 11 × 31 (40/1)	1.0	1.3

Dry matter yield

Cumulative dry matter yields of the 3 hybrids and the ML1 control over four harvests are shown in Figures 1 and 2. Without lime application, hybrid 40-1-18 was significantly (P<0. 05) higher in yield than the others entries. However, with lime application of 500kg/ha, hybrid 62-6-8 was a better yielder than hybrid 40-1-18. Both the hybrids 40-1-18 and 62-6-8 were significantly (P<0.5) higher than the control in dry matter yield (Figures 1 and 2), and have been selected for release in 1998.

Acknowledgments

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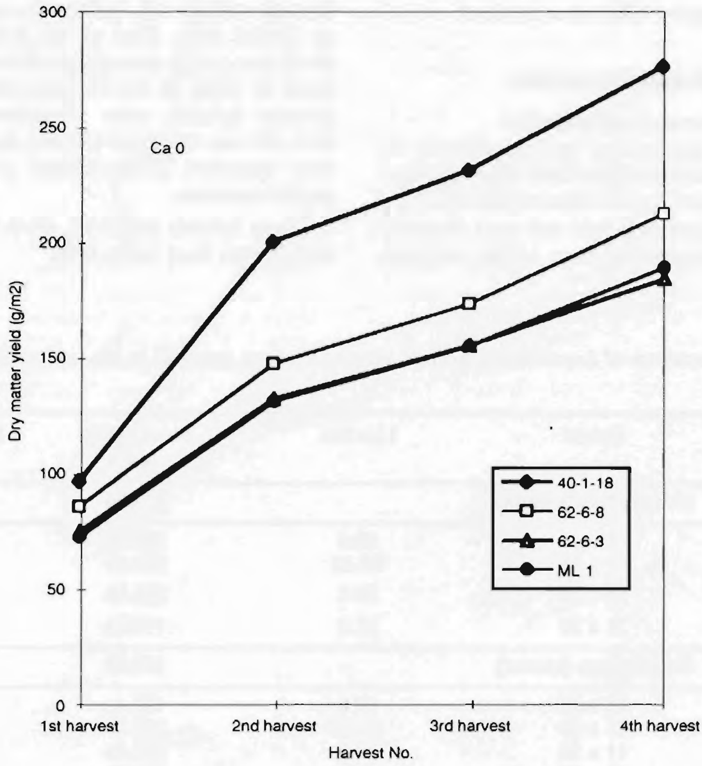

Figure 1. Cumulative dry matter production (g/m^2) of selected *Leucaena* hybrids and ML1 (control) over four harvests, without liming, at Serdang Station.

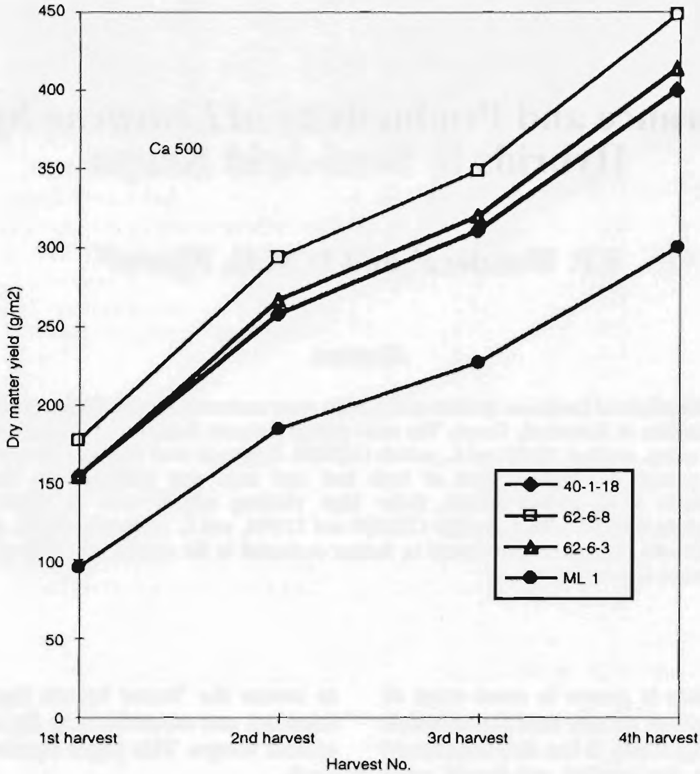

Figure 2. Cumulative dry matter production (g/m^2) of selected *Leucaena* hybrids and ML1 (control) over four harvests with liming at 500 kg/ha at establishment, at Serdang Station.

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Psyllid Tolerance and Productivity of *Leucaena* Species and Hybrids in Semi-Arid Kenya

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Abstract

Thirty accessions of *Leucaena* species and hybrids were evaluated for psyllid tolerance and dry matter production at Katumani, Kenya. The most psyllid resistant lines were *L. trichandra* 53/88, *L. collinsii* subsp. *collinsii* 52/88 and *L. pallida* CQ3439. Averaged over five harvests covering an 18-month period, the highest yield of both leaf and stem was produced by the hybrid *L. leucocephala* × *L. pallida* UQ45. Other high yielding entries were *L. diversifolia* × *L. leucocephala* KX3 F4 5/95, *L. pallida* CQ3439 and 137/94, and *L. trichandra* 53/88. *L. pallida* and *L. trichandra* are speceis that should be further evaluated in the search for highly productive psyllid resistant *Leucaena*.

LEUCAENA leucocephala is grown in some areas of semi-arid Kenya as a high quality feed for livestock (Tessema and Emojong 1984). It has also been found to grow naturally in the coastal sub-humid zone (Mureithi et al. 1994). The cultivars Peru, Cunningham and K8 were identified as some of the most suitable browse species in the semi-arid eastern Kenya (Wandera et al. 1991). The expansion and utility of these cultivars is, however, threatened by the leucaena psyllid (*Heteropsylla cubana*) which has been observed to cause widespread damage to the currently planted cultivars. However the damage caused has not been quantified in any part of the country. Nevertheless, in Australia, a reduction in yield of edible dry material by 52% and yield of stem by 79% has been reported to be caused by the psyllid (Bray and Woodroffe 1991). One of the options for addressing the psyllid problem is to explore possible psyllid tolerance that may exist within the wide range of *Leucaena* accessions and hybrids that are now available.

A collaborative project between Kenya Agricultural Research Institute (KARI), University of Queensland and Oxford Forestry Institute was initiated in 1995, under the Australian Centre for International Agricultural Research (ACIAR) project 9433, to screen the 'lesser known leucaenas' for psyllid tolerance and adaptability to the semi-arid tropics of eastern Kenya. This paper reports the results of that work.

Materials and Methods

Site

The experiment was carried out at the National Dryland Farming Research Centre, Katumani, 70 km SE of Nairobi (1°58'S, 38°28'E, 1600 m asl). The field where the experiment was established had been under *Cenchrus ciliaris* and *Chloris gayana* pasture for about 10 years unfertilised. Analysis of the soil from the site indicated that it is a sandy clay loam with pH 6.4 (1:6, soil:water); organic C 1.1%; and soil nutrients (mg/kg) nitrate N 4.2; P 24 (Colwell); S 6; Zn 2.1; Fe 24; exchangeable cations (meq/100g) K 1.26; Ca 3.92; Mg 1.45; Na 0.02. The site has a mean annual rainfall of 717 mm, bimodally distributed with the 'long rains' occurring from March to May and the 'short rains' from October to December. Mean maximum temperature is 24.9 °C while mean minimum is 13.1 °C.

Treatments and design

The accessions that were screened in this experiment are shown in Table 1.

Seedlings were raised in polybags for 10 weeks before transplanting in the field on 5 April 1996 into

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a well prepared field which had been ploughed to a depth of 45 cm and harrowed once.

The design was a randomised complete block, with 5 m single-row plots in 3 replications. The spacing between plants was 0.5 m with 3 m between rows.

At planting, 40 kg/ha of P_2O_5 as triple superphosphate was mixed with the soil in a 0.5 m wide band along the rows on both sides. Plants were watered twice to supplement the low rainfall during the establishment period. The experimental area was kept weed-free by hand weeding. A chain link fence was used to exclude livestock and wildlife, and furadan was applied around the stem at 20 kg/ha to control termites.

Psyllid damage

Psyllid damage was monitored monthly using the damage scale of Wheeler (1988) (rating of 1–9; 1 = no damage observed and rating 9 = blackened stem with total leaf loss). Only damage ratings in months when the site mean was greater than 2.5 were used to calculate the average for each accession.

Dry matter production

The six central plants from within each plot were sampled for dry matter production, at a cutting height of 50 cm. In plots where the number of plants was less than six, all the plants were sampled. The side branches below the cutting height were gathered vertically and cut at the main stem cutting height. The leaf and edible stem up to 6 mm in diameter was separated from the non-edible wood materials and both leaf and stem were dried in an oven at 70 °C for 48 hr and 5 days respectively. The dried samples were then weighed. There were six harvests, at intervals of between 2 and 4 months, commencing 6 months after transplanting.

Table 1. *Leucaena* accessions evaluated at Katumani site, Machakos Kenya, their psyllid resistance and mean dry matter production.

Species	Psyllid damage rating[1]	Mean dry matter production (g/plant)	
		Leaf	Stem
L. collinsii subsp. *collinsii* 52/88	1.3	74.7	29.5
L. collinsii subsp. *zacapana* 56/88	5.4	6.0	2.2
L. diversifolia 82/92	2.6	38.6	9.1
L. diversifolia 83/92	1.8	65.8	20.6
L. diversifolia K156	3.9	60.0	25.7
L. esculenta 47/87	1.5	60.8	16.9
L. lanceolata var. *lanceolata* 43/85	5.1	19.3	4.0
L. lempirana 6/91	4.5	10.2	2.6
L. leucocephala subsp. *glabrata* cv Cunningham	5.4	38.9	5.2
L. leucocephala subsp. *glabrata* cv Peru	6.1	41.1	13.1
L. leucocephala subsp. *glabrata* cv Tarramba	4.0	71.5	15.3
L. leucocephala subsp. *glabrata* K636	4.7	61.4	17.1
L. leucocephala subsp. *glabrata* K8	5.2	54.5	12.1
L. macrophylla subsp. *istmensis* 47/85	3.7	54.0	17.6
L. magnifica 19/84	3.6	39.9	15.6
L. multicapitula 81/87	6.1	4.1	1.0
L. pallida 137/94	1.7	108.1	47.8
L. pallida 79/92	1.8	89.3	41.2
L. pallida CQ 3439	1.3	118.7	57.5
L. pulverulenta 83/87	3.7	29.5	2.9
L. salvadorensis 36/88	4.8	29.3	5.7
L. trichandra 4/91	3.4	48.9	20.2
L. trichandra 53/88	1.2	98.6	55.5
L. trichodes 61/88	5.7	31.1	10.7
L. diversifolia × *L. leucocephala* KX3 F4 5/95	2.0	116.8	31.7
L. leucocephala × *L. diversifolia* UQ6	3.5	69.9	22.2
L. leucocephala K584 × *L. pallida* K748 UQ45	1.7	209.4	96.5
L. leucocephala K636 × *L. pallida* K748 (KX2 F1)	1.5	96.7	48.1
L. leucocephala × *L. pallida* KX2 F5 2/92	2.6	67.6	24.2
L. unknown hybrid 52/87	2.3	41.5	20.2
LSD (0.05)		24.3	10.6

[1] Wheeler (1988).

Results

Throughout the period, rainfall was below the long term average, except during the warm/wet season of October–December 1997, when rainfall received was above average (Figure 1).

Psyllid damage

The highest psyllid damage occurred during the dry season, with the month of July having the highest psyllid pressure (Figure 2). Generally, the pressure was maintained at a high level for the experimental period of two years. Table 1 shows the mean psyllid rating for each accession. Of the 30 accessions tested, 10 showed high resistance to psyllids with *L. trichandra* 53/88, *L. collinsii* 52/88 and *L. pallida* CQ 3439 exhibiting the least damage. The seven highly susceptible accessions were *L. lanceolata* 43/85, *L. leucocephala* cvv. K8, Cunningham and Peru, *L. collinsii* subsp. *zacapana* 56/88, *L. trichodes* 61/88 and *L. multicapitula* 81/87.

Dry matter production

The weight of stem and leaf for all entries averaged across all seasons is given in Table 1. *L. leucocephala* × *L. pallida* UQ45 produced the highest amount of edible dry matter (leaf) across all seasons. Data for individual seasons are not presented, but during the warm/wet season the top accessions were *L. leucocephala* × *L. pallida* UQ45, *L. pallida* CQ 3439, the KX3 F4 hybrid 5/95, *L. pallida* 137/94 and *L. trichandra* 53/88. However, in the warm/dry season the top five accessions were *L. leucocephala* × *L. pallida* UQ45, *L. pallida* 137/94, *L. pulverulenta* 83/87, *L. diversifolia* K156 and *L. leucocephala* × *L pallida* KX2 F1. The cool/dry season was dominated by the *L. leucocephala* × *L. pallida* hybrids, KX3 F4, and *L. leucocephala* K636.

Across all seasons *L. leucocephala* × *L. pallida* UQ45 and *L. trichandra* 53/88 consistently yielded high stem dry matter. In the warm/wet season these two accessions together with *L. pallida* CQ3439 were the top yielders. The warm/dry season was dominated by *L. leucocephala* × *L. pallida* UQ45, *L. trichandra* 53/88, *L. pallida* 137/94 and *L. pallida* 79/92, while, during the cool/dry season, *L. leucocephala* × *L. pallida* UQ45, *L. trichandra* 53/88, *L. leucocephala* × *pallida* KX2 F1 and *L. magnifica* 19/84 were the top performers.

Discussion

During the rainy season, psyllid populations seemed to be reduced by adults and larvae being washed physically off the plants. This reduced population lowered the damage rating during the wet seasons. The population buildup in the dry season follows general insect trends in the area as temperature increases (Dr Songa (Mrs), pers. comm.). However, this does not explain the very high psyllid damage in July, which falls within a designated cool/dry season. The high level of psyllid pressure that was maintained over the two years of experimentation may indicate that populations of natural predators (if they exist) are still low in Kenya and/or the site climatic factors are conducive to psyllid multiplication.

Considerable variation exists between species and to a limited extent, within species, for psyllid tolerance in semi-arid areas. Generally, *L. diversifolia*, *L. pallida* accessions and hybrids of *L. leucocephala* and *L. pallida* rated highly resistant while the *L. leucocephala*, *L. trichodes* and *L. multicapitula* accessions were highly susceptible. Within species variation was exhibited by *L. diversifolia* with 82/92 and 83/92 being moderately resistant, but K156 being quite susceptible. Within *L. collinsii*, subspecies *collinsii* was highly resistant while subspecies *zacapana* was highly susceptible. Clearly, the opportunity exists for selection of psyllid resistant lines for further testing.

Dry matter (DM) production followed the same pattern as psyllid resistance, with the highly resistant accessions yielding more than the susceptible ones. The commercial cultivars Cunningham, Peru and K8, identified earlier as suitable for the semi-arid Kenya by Wandera et al. (1991) were highly susceptible to psyllids and had only moderate edible DM production. While slow establishment of some leucaenas was mainly due to low rainfall, the psyllid attack must have strongly contributed to low vigour.

Leucaena in the semi-arid areas is planted as a multipurpose shrub with fodder and fuelwood as some of the products that are targeted. Thus combining the psyllid resistance, growth and edible DM production attributes, the top five accessions were *L. leucocephala* × *pallida* UQ45, *L. pallida* CQ 3439 and 137/94, *L. trichandra* 53/88 and the KX3 F4 hybrid 5/95, in that order.

The prominence of *L. pallida* in this list suggests that this is a species to which future attention must be directed in terms of screening for psyllid tolerance. The other promising species was *L. trichandra*. However, *L. pallida* may be the more promising species since animals are reported to consume it even more than *L. leucocephala* (Prof. Umunna, personal communication from ILRI, Addis Abbaba).

These preliminary results suggest that the psyllid menace can be managed by selecting the tolerant accessions from the available germplasm. It appears that *L. leucocephala* × *L. pallida* UQ45 was the most productive in leaf and stem production while *L. trichandra* 53/88 was most tolerant under current

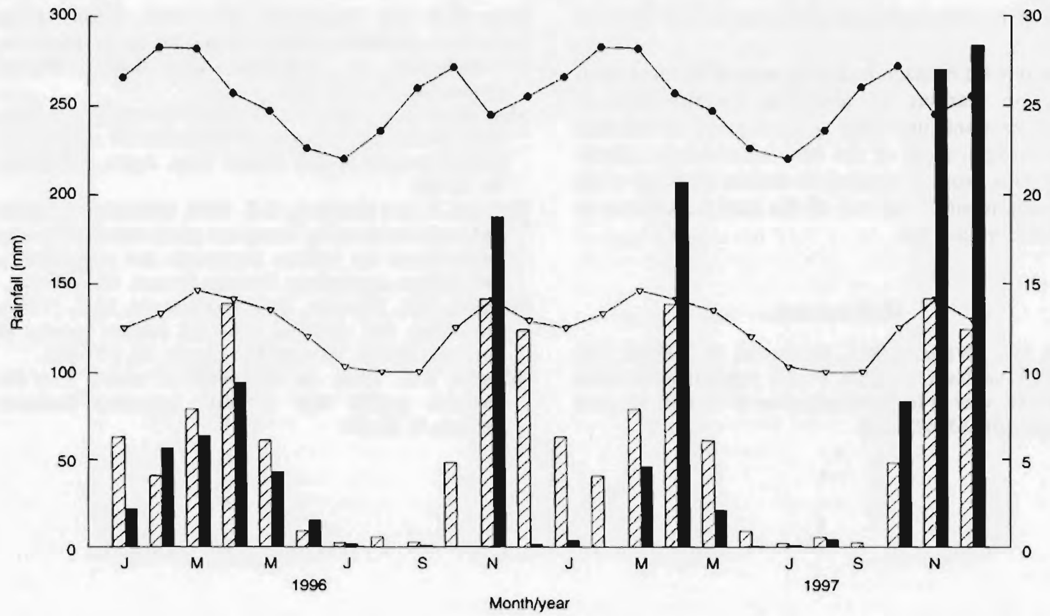

Figure 1. Monthly rainfall totals (long term average ■ and rainfall during the experimentation period ▨), mean maximum ● and mean minimum ▽ temperature at Katumani eastern Kenya.

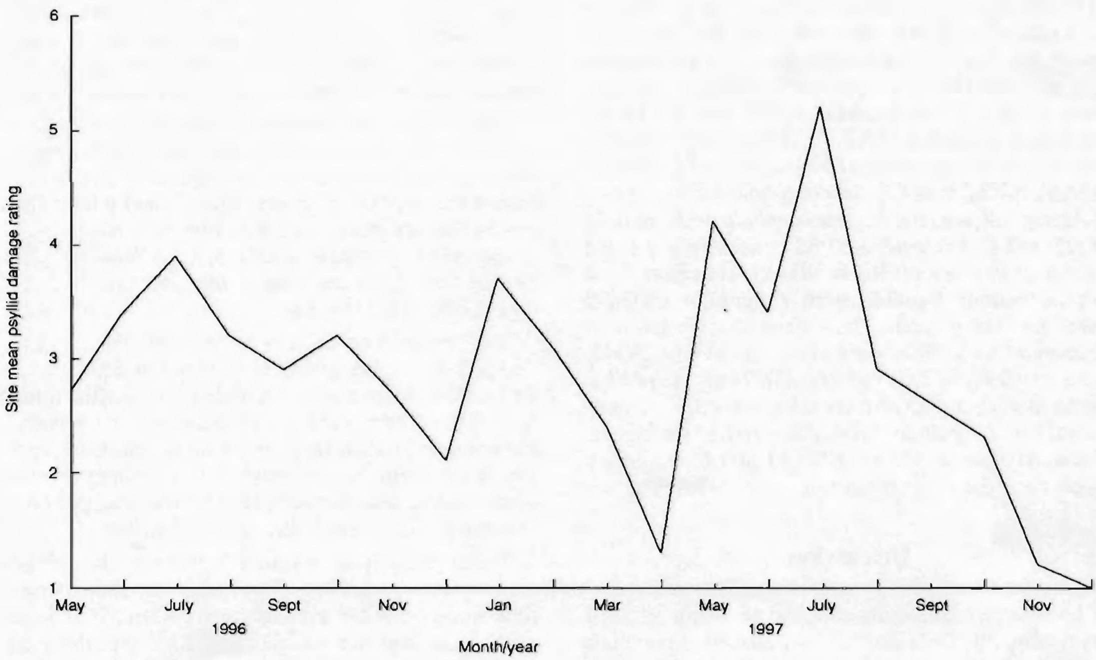

Figure 2. Mean monthly psyllid damage rating for thirty *Leucaena* accessions at Katumani site, eastern Kenya.

levels of psyllid challenge in the semi-arid areas of Kenya.

The psyllid menace had discouraged farmers from taking up planting of leucaena. Identification of psyllid resistant lines may see a renewal of interest. Seed multiplication of the best accession(s) identified in this work is needed to enable on-farm trials and assessment of impact of the new accessions to livestock production.

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Phytotoxicity of Insecticides and Wetting Agents to the *Leucaena* Genus

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Abstract

The phytotoxicity of common insecticide formulations and wetting agents to a range of *Leucaena* species was evaluated in 2 glasshouse experiments. When applied separately, wetting agents and emulsifiable concentrate (EC) insecticides were phytotoxic, as evidenced by growth supression. In contrast, soluble concentrate and wettable powder insecticides were not phytotoxic but failed to wet the leaf surface in the absence of a wetting agent. Growth reduction due to insecticides varied among the *Leucaena* accessions evaluated, with *L. lanceolata* var. *lanceolata* being least affected and *L. trichandra* being most affected. Of the insecticides evaluated, the EC formulation of chlorpyrifos caused lowest mean phytotoxicity and lowest variation in phytotoxicity among *Leucaena* accessions. Visual symptoms of phytotoxicity were a poor indicator of the degree of growth supression. Research and commercial ramifications are discussed.

INSECTICIDES have commonly been used to control insect pests in *Leucaena leucocephala* grown for both research and commercial purposes. However, dimethoate, one of the most commonly used insecticides, is known to be phytotoxic to many crop and tree species (Anon. 1992), and anecdotal reports have suggested it is phytotoxic to *L. leucocephala* (B.F. Mullen, unpublished data).

Phytotoxicity of insecticide formulations may be caused by insecticide active ingredients, the active ingredient carriers or wetting agents (surfactants). The severity of phytotoxic effects of insecticide active ingredients is dependent on the toxicity and application rate of the insecticide and the sensitivity of the crop plant. Most insecticides are phytotoxic to at least some crop plants (Anon. 1992). Phytotoxic effects range from reductions in photosynthetic rate and stomatal conductance, to damage to plasma membranes, tissue necrosis and leaf abscission (Men et al. 1994).

Two glasshouse experiments were conducted to identify insecticide treatments capable of controlling psyllids, and other insect pests, on a broad range of *Leucaena* species, without affecting DM yield. Experiment 1 tested the effect of wetting agents alone and in combination with two contrasting insecticide formulations, viz., a wettable powder (WP) and an emulsifiable concentrate (EC), on growth of six accessions of *Leucaena*. Experiment 2 aimed to confirm the phytotoxic effect of the wetting agents from Experiment 1, and to test the effect of a range of insecticides applied without wetting agents on DM yield of *Leucaena*. This paper summarises the results of these experiments.

Materials and Methods

Two controlled experiments were conducted at The University of Queensland, Brisbane, between January and April 1997. A sterilised, quarantine glasshouse with an airlock was used to provide insect-free conditions. For all experiments, well-established *L. leucocephala* plants grown in 200 mm pots were pruned to bare, single stems, 30 cm high with 1 plant/pot, and allowed to regrow for 5 weeks prior to imposition of spray treatments. Treatments were arranged in randomised complete block designs with 3 blocks (1 pot per treatment). Pots were re-randomised weekly.

Insecticide treatments were applied weekly, over a six-week period. Recommended rates of insecticides and wetting agents (Table 1) were sprayed to run-off. Control treatments were sprayed with water. Plastic

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Table 1. Trade names, active ingredients and their application rates, formulations and recorded phytotoxicities for insecticides used in Experiments 1 and 2.

Active ingredient (A.I.)	Trade name	Formulation		Rate of A.I. applied (g/L)	Phytotoxicity at recommended rates[2]
		A.I. concentration (g/kg)	Type[1]/carrier		
Dimethoate	Rogor	400	EC/xylene	0.4	Crops, ornamentals
Imidicloprid	Confidor	350	WP/water	0.05	Unknown
Tau-fluvalinate	Mavrik	240	SC/water	0.96	None recorded
Chlorpyrifos	Lorsban	500	EC/xylene	2.0	Ornamentals, sorghum
Prothiofos	Tokuthion	500	EC/xylene	1.0	None recorded
Alcohol alkoxylate	BS1000	1000		1.0	Unknown
Alkyl phenol ethoxylate	Agral 60	600		1.2	Sensitive crops

[1] WP = wettable powder, EC = emulsifiable concentrate, SC = aqueous concentrate.
[2] Source: Anon. (1992) and Worthing and Hance (1991).

barriers were used to prevent over-spray from accumulating in the potting media.

Clinical phytotoxicity symptoms were recorded for Experiment 1 by rating damage to the youngest fully expanded leaves one week after application of insecticide. Ratings were: 1 = no phytotoxic symptoms; 2 = mild chlorosis; 3 = chlorosis, mild necrosis; 4 = moderate — severe necrosis; and 5 = leaflet abscission.

Following the 6 week spraying period, plants were harvested to bare stems, 30 cm high. Harvested material was separated into leaf and stem and dehydrated at 70 °C for 48 hrs. Phytotoxicity of treatments was assessed by comparing dry matter (DM) production of the sprayed treatments with DM production of control treatments. To compare the effects of insecticide treatments on the six *Leucaena* accession treatments, data were converted to percentages of unsprayed controls and analysed by ANOVA. Regression analysis was used to examine relationships between visual phytotoxicity ratings and reduction in DM yield in Experiment 1.

Experiment 1

Six accessions of *Leucaena* (Table 3) were sprayed, over a 5-week period, with two insecticide treatments alone and in combination with two wetting agents (Table 2). Insecticide treatments were dimethoate (EC formulation), reported to be phytotoxic to a range of crop species (Anon. 1992), and imidicloprid (WP formulation), not known to be phytotoxic. Wetting agents were Agral 60, a commonly-used wetting agent known to be phytotoxic to sensitive crops, and BS1000, a biodegradable product of unknown phytotoxicity (Table 1).

Experiment 2

Six accessions of *Leucaena* (Table 3) were subjected to seven spraying treatments, viz., two wetting agents applied alone, and five insecticides applied without wetting agent over a 5-week period. Four of the insecticide treatments (imidicloprid, tau-fluvalinate, chlorpyrifos and prothiofos) were selected for their low phytotoxicity to crop (Table 1). Dimethoate was included due to its common use for psyllid control in *L. leucocephala*.

Results

Experiment 1

With the exception of the imidicloprid treatment, all spraying treatments caused significant reductions to mean DM yield of *Leucaena* (Table 2). Imidicloprid failed to thoroughly wet the leaves of *Leucaena* when applied without a wetting agent, but in combination with wetting agents, thorough wetting and significant reductions in DM yield occurred. Dimethoate + Agral and dimethoate + BS1000 were the most phytotoxic treatments, causing mean yield reductions of 40% and 35% respectively. Wetting agents applied without insecticides were moderately phytotoxic, reducing yields by an average 24%. Dimethoate applied without wetting agents was less phytotoxic than when applied with wetting agents, but all treatment combinations that included dimethoate significantly reduced DM yields. For all spraying treatments VSRs were a poor indicator of yield reduction (Table 2).

Accessions of *Leucaena* differed significantly in their mean DM responses to spraying treatments (Table 3). The DM production of *L. lanceolata*

Table 2. Mean treatment DM yields and DM yields as percentages of control treatments for Experiments 1 and 2, and visual symptom ratings (VSR) and correlation between VSR and yield loss for Experiment 1.

Insecticide treatment	Experiment 1				Experiment 2	
	Mean DM yield (g)	Mean DM yield as percentage of control (%)	Mean visual symptoms rating (VSR)	VSR as predictor of yield loss (r^2)	Mean DM yield (g)	Mean DM yield as percentage of control (%)
Control	14.3	100	1.0	—	9.7	100
Imidicloprid	12.9	84	1.0	0.16*	9.6	95
BS1000	11.6	78	1.9	0.24*	7.4	73
Agral 60	10.9	4	1.9	0.09	6.4	58
Imidicloprid +BS1000	11.4	74	2.0	0.34**	—	—
Dimethoate	11.5	73	2.0	0.10	7.9	75
Imidicloprid +Agral	10.5	68	1.8	0.08	—	—
Dimethoate +BS1000	10.0	65	2.8	0.06	—	—
Dimethoate +Agral	9.5	60	2.8	0.27**	—	—
Tau-fluvalinate	—	—	—	—	9.4	94
Chlorpyrifos	—	—	—	—	9.3	87
prothiofos	—	—	—	—	7.6	74
LSD 5%	2.6	17.1	0.31	0.15	1.72	15.6

* Significant correlation (P<0.05) and ** (P<0.01)

Table 3. Mean effects of insecticides on DM production for Experiments 1 and 2, and visual symptoms ratings (VSR) and correlation of VSR with % DM yield reduction of 6 *Leucaena* accessions for Experiment 1.

Species/subspecies/variety	Accession	Experiment 1				Experiment 2	
		Mean DM yield of accessions (g)	Mean DM yield as % of control (%)	Mean visual symptom rating (VSR)	VSR as predictor of yield loss (r^2)	Mean DM yield of accessions (g)	Mean DM yield as % of control (%)
L. lanceolata var. *lanceolata*	OFI 43/85	16.0	95	2.0	0.38**	10.7	84
L. leucocephala subsp. *glabrata*	K636	13.1	88	1.8	0.34**	10.1	87
L. pallida	CQ3439	12.3	79	1.9	0.55**	10.6	86
L. leucocephala subsp. *glabrata*	Cunningham	9.4	76	2.2	0.58**	7.1	78
L. magnifica	OFI 19/84	11.9	61	2.1	0.66**	9.3	79
L. trichandra	OFI 53/88	2.7	33	1.5	0.54**	2.5	62
LSD 5%		1.4	14.8	0.26	0.11	1.49	14.5

** Significant correlation (P<0.01)

OFI 43/85 and *L. leucocephala* K636 was not significantly affected by spraying treatments whereas mean DM production of *L. trichandra* OFI 53/88 was reduced by 67%. Growth differences were apparent between accessions of *Leucaena*, with *L. lanceolata* OFI 43/85 and *L. trichandra* OFI 53/88 being the highest and lowest yielding accessions respectively.

Visual symptom ratings correlated poorly with percentage yield reduction when all accessions were combined ($r^2 = 0.24$). However, when accessions were analysed individually correlations were significant for all six accessions (Table 3).

There were significant interactions between the *Leucaena* accessions and the spraying treatments. *L. trichandra* OFI 53/88 and *L. pallida* CQ3439 expressed the greatest variability whereas *L. lanceolata* OFI 43/85 and *L. leucocephala* K636 were least variable (data not presented). Wetting agents severely reduced DM yields of *L. trichandra* OFI 53/88 and *L. magnifica* OFI 19/84, but were less phytotoxic to other accessions. Dimethoate and imidicloprid, applied without wetting agents were severely phytotoxic only to *L. trichandra* OFI 53/88. In combination with wetting agents, however, dimethoate severely reduced DM yields of

L. leucocephala cv. Cunningham, *L. pallida* CQ3439, *L. magnifica* OFI 19/84 and *L. trichandra* OFI 53/88. In combination with wetting agents, imidicloprid reduced DM yields of *L. magnifica* OFI 19/84 and *L. trichandra* OFI 53/88 and to a lesser extent *L. leucocephala* cv. Cunningham and *L. pallida* CQ3439.

Experiment 2

Insecticide treatments imidicloprid, tau-fluvalinate and chlorpyrifos did not significantly reduce the mean DM yield of *Leucaena* accessions, but of these treatments only chlorpyrifos thoroughly wet the leaves in the absence of a wetting agent (Table 2). Wetting agents Agral 60 and BS1000 were the most phytotoxic of all treatments, reducing mean DM yields by 42% and 27% respectively. Insecticide treatments, dimethoate and prothiofos, significantly reduced yields by approximately 26%.

L. trichandra OFI 53/88 was the most severely affected by spraying treatments, experiencing a mean yield reduction of 38% (Table 3). *Leucaena lanceolata* OFI 43/85, *L. pallida* CQ3439, *L. leucocephala* K636, *L. magnifica* OFI 19/84 and *L. leucocephala* cv. Cunningham were less affected, experiencing mean yield reductions of approximately 17%.

Individual accessions of *Leucaena* varied greatly in their DM response to Agral 60, BS1000, dimethoate and prothiofos. Less variability was apparent with imidicloprid, tau-fluvalinate and chlorpyrifos. Of the accessions evaluated, *L. leucocephala* K636, *L. pallida* CQ3439 and *L. magnifica* OFI 19/84 expressed the least variability in response to spraying treatments whereas *L. trichandra* OFI 53/88 expressed high variability.

Discussion

The experiments highlighted the sensitivity of a wide range of *Leucaena* accessions to common insecticides and the strong interactions between *Leucaena* species and insecticide treatments. In addition, the phytotoxic effects of wetting agents on DM production of *Leucaena*, whether applied alone or in combination with insecticides, was identified. The severity of yield reductions caused by spraying treatments varied between experiments, although the ranking of accessions of *Leucaena* in terms of phytotoxic response was constant.

Wetting agents and insecticides

All EC formulations, applied with or without a wetting agent, appeared to thoroughly wet the foliage of all *Leucaena* accessions. In comparison, imidicloprid and tau-fluvalinate, WP and SC formulations respectively, rapidly ran off the leaves of all accessions of *Leucaena* when applied without a wetting agent. The low phytotoxicity of these treatments may be related to this poor wetting ability, and therefore lack of penetration of active ingredient into the leaf tissue.

Considerable variation was noted among the EC formulation treatments, despite the fact that all used xylene as a carrier. This result indicated that xylene was not the principal cause of phytotoxicity in these treatments. Chlorpyrifos caused minimal phytotoxicity to most accessions of *Leucaena*. Chlorpyrifos is a contact insecticide with some fumigant action and a dermal LD50 of 2000 mg/kg (Worthing and Hance 1991).

Accessions of *Leucaena*

There was considerable variation in the phytotoxic response of *Leucaena* accessions to insecticide treatments. *L. lanceolata* and *L. pallida* accessions were least affected, whereas *L. trichandra* was most affected. Unfortunately, *L. trichandra* plants were smaller and more variable in size than plants of other experimental accessions due to their slow seedling growth and general lack of vigour as potted plants. Field grown plants of OFI 53/88 are comparatively robust and vigorous (Mullen, Shelton et al., these Proceedings). These factors may have exacerbated the phytotoxic effects of spraying treatments to this accession.

In a related experiment, intraspecific variation in phytotoxicity was evident in *L leucocephala*, *L. collinsii* and *L. pallida* (Mullen and Dalzell, unpublished data).

Visual symptoms

Ratings of visual symptoms (VSRs) of phytotoxicity gave a poor indication of expected yield supression for most species of *Leucaena*, and at best, observation of clinical phytotoxicity symptoms following insecticide application indicated that yield loss may occur. In addition, the degree of yield supression as indicated by VSRs varied between species. The relatively poor VSR correlations with yield reduction indicate that the plants' ability to recover from mild phytotoxicity is highly variable, both within and between *Leucaena* species.

Implications for commercial production of *L. leucocephala*

While insecticide application to forages is generally uneconomic, seed crops of *L. leucocephala* are regularly sprayed to control bruchid beetles and psyllids. In these experiments, *L. leucocephala* K636 and cv. Cunningham were highly variable in their phytotoxic responses to insecticide treatments, experiencing mean yield reductions of 13% and 23% respectively. However, the experiments were conducted in a glasshouse over the summer period and do not necessarily mimic the paddock situation. The high glasshouse temperatures and relative humidities (up to 38 °C and >90% respectively) may have exacerbated the phytotoxicity of wetting agents and insecticides.

In a field experiment Palmer et al. (1989) reported only a 9% yield reduction in dimethoate sprayed compared with unsprayed cv. Cunningham growing in a near psyllid-free environment. Field experiments with K636 sprayed with insecticide have not been conducted, but a significant phytotoxic effect is unlikely. Under field conditions, the phytotoxic effects of these insecticides to *L. leucocephala* may be minor in comparison to the reduction in forage production due to the psyllid insect, and in seed yield and quality due to the bruchid beetle.

Conclusions

The experiments highlighted the sensitivity of a broad range of *Leucaena* accessions to common insecticides. Wetting agents were also found to significantly reduce the DM yields of *Leucaena* accessions both solely and in combination with EC, SC and WP insecticide formulations.

Accessions of *Leucaena* were highly variable in their phytotoxic responses. This result has implications for experiments involving several accessions of *Leucaena*, reliant on these insecticide treatments, to control psyllid and other insect pests, for unchecked growth. Of the insecticides tested and likely to be effective when applied without a wetting agent, chlorpyrifos was least phytotoxic to most accessions.

Commercial plantings of *L. leucocephala* may not be measurably affected by application of these common insecticides.

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Adaptation of New Species of *Leucaena* in Costa Rica, Central America — Preliminary Results

P. J. Argel[1] and G. Pérez[1]

Abstract

In a trial of 17 *Leucaena* species and hybrids in Costa Rica, considerable variation was recorded for plant height and vigour, foliar retention during the dry period, plant mortality and dry matter (DM) yields. Most *Leucaena* species showed strong apical dominance as their habit of growth. *L. trichandra* 53/88, *L. collinsii* subsp. *collinsii* 52/88, *Leucaena* hybrid 52/87, *L. pallida* 14/96 and *L. leucocephala* subsp. *glabrata* 34/92 (K636) were among the best yielders, while *L. lempirana* 6/91, *L. collinsii* subsp. *zacapana* 56/88, *L. trichodes* 61/88 and *L. multicapitula* 81/87 produced low DM yields reflecting their poor adaptation to the climatic and soil conditions of the trial area. Only mild attacks of the psyllid insect were recorded.

THERE are 22 species of *Leucaena*, all native to the New World; however, the most researched and utilised species worldwide continues to be *L. leucocephala* (Lam) de Wit. It is known for its high forage production and quality, but also for its low cold and drought tolerances, poor growth on acid soils, heavy pod production, low wood durability and susceptibility to psyllid damage (Hughes 1993). The other species of *Leucaena* are little known although indigenous people, particularly of Mexico and Central America, have utilised them for centuries as sources of food, firewood, timber for construction and feed for domestic animals.

In 1996, CIAT agreed to collaborate with the Oxford Forestry Institute (OFI) to evaluate the adaptation and potential use of new species of *Leucaena* in the tropics of Latin America. OFI provided experimental seeds of 18 new lines of *Leucaena*, inoculum, and the experimental methodology for evaluation. During 1997, seed was distributed to collaborators in Costa Rica, Mexico, Honduras, Nicaragua, Belize, Panamá, Colombia, Venezuela and Brazil. The trials were coordinated from a regional CIAT office located at the headquarters of the Instituto Interamericano de Cooperación para la Agricultura (IICA) in San José, Costa Rica.

Preliminary results of the first trial established in Costa Rica are presented.

Materials and Methods

The experimental site was located in the Escuela Centro Americana de Ganadería (ECAG) (9° 58′ N, 84° 23′ W, 200 m.a.s.l.) in Atenas, Costa Rica. It is classified as sub-humid tropical forest with 23.7 °C mean temperature and 1600 mm of annual rainfall distributed from May to November. The soils are inceptisols of medium fertility with the following characteristics: pH 5.9 (H_2O); 7.6% OM; 3.6 ppm of P; 9.5, 6.0 and 0.24 meq/100 g respectively of Ca, Mg and K; the Al content is negligible.

Seed of 18 species of *Leucaena* were scarified with sandpaper, inoculated with *Rhizobium* and planted directly in the field placing two seeds per site. Plants were later thinned to one per site for a total of 10 plants per plot spaced at 0.50 m between plants. Controls were provided by one line selected by CIAT of *L. leucocephala* (CIAT 17263), one introduction of *Calliandra calothyrsus* from Australia (CPI 115690) and the shrub *Cratylia argentea* (CIAT 18668). Each species was replicated four times.

Measurements of plant height, stem diameter, foliar retention and plant mortality were taken 3.5 months after planting at the end of the dry season. Plant height was measured again 9.8 months after planting, before a uniformity cut was made at

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0.50 m height. At this age, the foliar retention of the different accessions was ranked using a scale suggested by OFI. (Foliar retention scale: 1 = less than 20% foliar retention; 2 = 20% – 40%; 3 = 40% – 60%; 4 = 60% – 80% and 5 >80% foliar retention).

Evaluation cuts at 0.5 m height to estimate dry matter production were carried out on 8 week regrowth during the rainy season; the material harvested was separated into edible component (leaves and thin stems) and woody parts. Samples were dried for 48 hours in a forced air oven.

Psyllid damage was scored at monthly intervals on a nine point scale (1 = no damage; 2 = young leaves moderately curled; 3 = tips and young leaves curled and yellow; 4 = tips and young leaves severely curled, yellow and covered with sap; 5 = loss of up to 25% of young leaves; 6 = loss of up to 50% of young leaves; 7 = loss of up to 75% of young leaves; 8 = loss of up to 100% of young leaves and darkening of older leaves, and 9 = stained stems and total loss of foliage).

Results and Discussion

Considerable variation in growth was observed between *Leucaena* species as indicated by plant height, stem diameter, foliar retention and plant mortality at the end of the 6 months dry period (Argel and Pérez 1997). Most *Leucaena* species showed strong apical dominance, with the exception of *L. pallida* 79/92, *L. leucocephala* CIAT 17263 and *Leucaena* hybrid 1/95.

Plant height varied from 0.5 m to more than 1.5 m 9.8 months after planting, with ten lines reaching more than 1 m height (Table 1). The best growth was recorded in *L. collinsii* subsp. *collinsii* 52/88, which was more than three times taller than the poorest species (*L. multicapitula* 81/87). Other outstanding lines up to this date were *L. salvadorensis* 17/86, *L. trichandra* 53/88, *L. diversifolia* 83/92, *L. leucocephala* subsp. *glabrata* 34/92 (K636) and *L. macrophylla* 47/85. These observations are in agreement with those reported by Karachi and Lefofe (1997) in a different environment at Morale, Botswana; however, none of these accessions has shown any adaptation to acidic ultisols (pH = 4.7) with Al saturation of 49% (Castillo et al. 1997).

Foliar retention and plant survival are very important in environments such as Atenas which have 6 months dry season. *L. magnifica* 19/84, *L. leucocephala* subsp. *glabrata* 34/92 (K636), *L. macrophylla* 47/85 and *Leucaena* hybrid 1/95 have over 60% foliar retention and nil or very little plant mortality under the conditions of the trial. On the other hand, *L. multicapitula* 81/87, an introduction from Los Santos (Panamá) and the check *Calliandra calothyrsus* had high plant mortality.

Table 1. Plant height, foliar retention and plant mortality of *Leucaena* and other species planted for evaluation in Atenas, Costa Rica. (Adapted from Argel and Pérez 1997).

Entry	Identification	Plant height at 9.8 months (m)	Foliar retention	Plant mortality after the dry season
L. collinsii subsp. *zacapana*	56/88	1.1	3.4	0
L. collinsii subsp. *collinsii*	52/88	1.5	3.5	0
L. diversifolia	83/92	1.2	2.8	0
L. trichandra	53/88	1.2	3.1	0
L. esculenta	47/87	0.8	1.9	0
Leucaena hybrid (unknown parents)	52/87	1.1	1.9	1
L. pallida	79/92	1.0	2.9	0
L. leucocephala × *L. pallida* (F5) (K376 × K8)	1/95	0.9	4.0	0
L. lanceolata	43/85	1.0	3.5	0
L. lempirana	6/91	1.1	3.1	0
L. leucocephala subsp. *glabrata*	34/92 (K636)	1.2	4.4	0
L. macrophylla	47/85	1.2	4.1	1
L. multicapitula	81/87	0.5	2.5	14
L. pallida	14/96	1.1	3.1	1
L. pulverulenta	83/87	0.6	3.4	0
L. salvadorensis	17/86	1.4	3.9	1
L. magnifica	19/84	0.9	4.0	1
L. trichodes	61/88	0.7	2.5	6
L. leucocephala	CIAT 17263	0.8	3.8	0
Calliandra calothyrsus	CPI 115690	0.9	2.9	11
Cratylia argentea	CIAT 18668	1.5	4.5	0

Total plant dry matter yield also varied significantly both within and between species of *Leucaena* (Table 2). *L. trichandra* 53/88, *L. collinsii* 52/88, *Leucaena* hybrid 52/87 and *L. pallida* 14/96 were among the best yielders; *L. diversifolia* 83/92 and *L. collinsii* subsp. *zacapana* 56/88 yielded significantly less ($P<0.05$). Other poor yielding species included the checks *Calliandra calothyrsus* and *L. leucocephala* CIAT 17263, *L. lempirana* 6/91, *L. trichodes* 61/88 and *L. multicapitula* 81/87. Nevertheless, all lines produced a high proportion of edible forage.

The shrub *Cratylia argentea* was placed between the best *Leucaena* species in terms of DM yields and foliar retention during the dry season (Table 1 and 2). This plant developed a form of 'climbing branches' that made it difficult to determine a clear pattern of growth; under cutting, it produced multiple branches that replaced the main stem.

The psyllid insect was present throughout the trial but plant damage has been mild up to date. Table 2 shows that the lower yielding species of *Leucaena* have been slightly more affected by psyllids, resulting in curled young leaves and tips; with a maximum leaf loss of 25%. *L. trichandra* 53/88, *L. pallida* 14/96 and *L. pulverulenta* 47/87 showed less susceptibility to the psyllid insect. This insect has natural enemies in the area that probably make an effective biological control; however, it could become a problem if the area planted with *Leucaena* continues to expand (Schultze-Kraft 1994).

Mild attacks of the fungus *Camptomeris leucaenae* have been recorded, particularly in old leaves of *Leucaena* species. This fungal infestation is particularly severe in *L. leucocephala*, but it has been reported that the species *L. diversifolia*, *L. esculenta*, *L. lanceolata*, *L. macrophylla* and *L. trichodes* are not affected (Moreno et al. 1988).

This trial will continue for another growing season.

Preliminary Conclusions

Considerable variation has been recorded between *Leucaena* species in terms of plant height and vigour, foliar retention during the dry period, plant mortality and DM yields.

Most *Leucaena* species showed strong apical dominance as their habit of growth.

L. trichandra 53/88, *L. collinsii* subsp. *collinsii* 52/88, *Leucaena* hybrid 52/87, *L. pallida* 14/96 and *L. leucocephala* subsp. *glabrata* 34/92 (K636) were among the best yielders, while *L. lempirana* 6/91, *L. collinsii* subsp. *zacapana* 56/88, *L. trichodes* 61/88 and *L. multicapitula* 81/87 produced poor DM

Table 2. Psyllid damage and dry matter (DM) yields of *Leucaena* and other species established in Atenas, Costa Rica. DM is the mean of 2 evaluation cuts after 8 weeks of regrowth during the wet season, and psyllid damage is the mean of 4 ratings at monthly intervals. For total DM, means followed by similar letters are not significantly different ($P>0.05$).

Entry	Identification	Psyllid damage	DM yield (g/plant)		
			Total	Edible	% Edible
L. trichandra	53/88	1.1	111 a	90	81
Cratylia argentea	CIAT18668	1.0	106 ab	98	92
L. collinsii subsp. *collinsii*	52/88	2.1	90 abc	75	83
Leucaena hybrid (unknown parents)	52/87	1.8	84 bcd	65	77
L. pallida	14/96	1.2	83 bcd	72	87
L. leucocephala subsp. *glabrata*	34/92 (K636)	3.5	81 bcde	67	83
L. pallida	79/92	1.5	73 bcdef	63	86
L. diversifolia	83/92	1.6	68 cdef	55	81
L. leucocephala × *L. pallida* (F5) K376 × K8)	1/95	2.4	64 cdef	61	95
L. esculenta	47/87	1.0	64 cdef	59	92
L. salvadorensis	17/86	3.9	58 defg	51	88
L. macrophylla	47/85	2.3	54 efgh	46	85
L. lanceolata	43/85	3.1	49 fgh	48	98
L. pulverulenta	83/87	2.1	48 fgh	48	100
Calliandra calothyrsus	CPI 115690	1.0	47 fgh	43	91
L. leucocephala	CIAT 17263	2.6	47 fgh	44	94
L. magnifica	19/84	3.1	33 ghi	29	88
L. lempirana	6/91	3.7	31 ghi	29	94
L. collinsii subsp. *zacapana*	56/88	4.0	28 hi	27	96
L. trichodes	61/88	3.6	13 i	13	100
L. multicapitula	81/87	4.1	7 i	7	100

yields reflecting their poor adaptation to the climatic and soil conditions of the trial area. Only mild attacks of the psyllid insect were recorded.

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Yield, Nutritive Value and Psyllid Resistance of Seven Accessions of *Leucaena* in Mexico

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Abstract

An experiment to compare the agronomic performance, nutritive value and resistance to *Leucaena* psyllid of seven accessions of *Leucaena* was carried out in southeast Mexico during the growing season of 1994. The seven accessions tested were three lines of *Leucaena leucocephala* (cv. Cunningham, a local strain, and an intraspecific hybrid), *L. diversifolia* K156, a *L. diversifolia* × *L. leucocephala* hybrid, a *L. pallida* × *L. leucocephala* hybrid, and a *L. pallida* mixture. The three *L. leucocephala* accessions had the highest dry matter production, and also the highest crude protein content and rumen digestibility of dry matter and protein. They also suffered more psyllid damage than the other entries. *L. diversifolia* K156 and the *L. pallida* mixture had the least psyllid damage. It is concluded that, although the *L. leucocephala* entries had the best agronomic performance despite having the greatest psyllid damage, it is still important to evaluate psyllid resistant accessions for the Yucatan peninsula.

LEUCAENA leucocephala is a leguminous shrub with high potential to improve animal production systems. However, in the past decade, it has been severely attacked by the psyllid *Heteropsylla cubana*, particularly outside its native environment. Currently, there is a plant improvement program, organised by the University of Hawaii and the Oxford Forestry Institute, aimed at producing psyllid-resistant genetic material with favourable agronomic characteristics. The present study was undertaken to evaluate some of this genetic material in an environment where *L. leucocephala* is native.

Materials and Methods

The study was carried out at the University of Yucatan in south-east Mexico. The region is sub-humid tropical (MAR 960 mm/yr) and has a rainy season of about six months, a dry season of about the same length, a relative humidity of 80%, and an average annual temperature range between 24 and 27 °C. Main soil types are of calcareous origin, with a depth from 0 to 60 cm, well drained, low in organic matter and nutrients and neutral pH.

The evaluated genetic materials included a range of hybrids, mixtures and species. *L. leucocephala* commonly found in the local forest was included as control (Table 1).

Seed was soaked in hot water (80 °C for 3 min) before sowing in pots. Two months later, seedlings about 40 cm high were transplanted in the field. Each entry was planted in 8.0 × 2.5 m plots, containing four rows 2.0 m apart with 0.5 m between plants. Evaluations were made on the two central rows only. A randomised block design with five replications was used. Blocks were located in rocky (lithosol) and deep red (luvisol) soils. Weeds were manually controlled.

Dry matter yield (DMY) was determined twice, on July 12 and August 23, by cutting plants to a height of 0.5 m. All cut materials were weighed in the field, and samples of about 1000 to 1500 g were obtained to determine the edible material (leaves and fine green stems, less than 7 mm diameter). Plant height, diameter at the base of the plant, and number of branches were measured before plants were cut.

Leucaena psyllid damage evaluation

Fifteen days before the first evaluation a psyllid population assessment was undertaken. A sample of immature leaves (unopened leaflets) 7 cm long was taken from two randomly selected plants from each

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Table 1. *Leucaena* germplasm evaluated in the experiment.

Accession/Entry	Text reference
L. diversifolia K156	K156
L. diversifolia × *L. leucocephala* K156 × K500, K156 × K636, and K156 × K8 (F2)	D × L hybrid
L. pallida × *L. leucocephala* (F4 of K376 × K8)	P × L hybrid
L. pallida (mixture of K376, CQ3439 and K784 × K806)	*L. pallida* mixture
L. leucocephala K584 × K636 (F2)	LxL hybrid
L. leucocephala cv. Cunningham	Cunningham
L. leucocephala (local collection)	Local

plot. This sample was frozen to kill the nymphs and to preserve the sample. The number of nymphs was later determined using a stereoscope and the number of pinnae in the 7 cm length counted.

Visual assessment of *Leucaena* psyllid damage was made on two occasions (May 20 and June 20). The psyllid damage rating (PDR) scale proposed by Wheeler (1988) was used. In this rating, scores ranged from 1, no damage, to 9, blackened stems with total leaf loss.

Rumen digestibility was assessed with the nylon bag technique (Orskov et al. 1980). The material incubated consisted of immature and mature leaves. Before incubation, samples were dried and ground to 3 mm. Five bulls with rumen cannulas were used, and were fed *Pennisetum purpureum*, *L. leucocephala* and minerals. Samples were rumen incubated for 12 h. Crude protein (CP) was determined before and after incubation by the Kjeldahl method (AOAC 1980).

Three weeks before the first evaluation cut samples of immature unopened leaves and mature leaves were taken from five plants selected at random from each of the entries in each replication. Total phenols were determined by the technique of Price and Butter (1977).

Data were analysed by analysis of variance. Duncan's Multiple Range Test was applied when the variance analysis was significant ($P<0.05$).

Results and Discussion

Morphological characters

There were no significant differences among entries for the morphological data of the first harvest. At the second harvest, the three *L. leucocephala* entries were tallest (Table 2). Stem diameters were not significantly different at this harvest. The *L. pallida* hybrid was the most branched (Table 2).

Dry matter yield

There were significant DMY differences only for the second harvest and for cumulative DMY (Table 2). Cunningham, Local, and the *L. pallida* mixture all yielded better than K156 and the interspecific hybrids. The differences were more pronounced for edible DM than total DM.

Since this experiment had only been in progress for a short time, not a great deal of reliance can be placed on these DM results. *L. diversifolia* has often not yielded well in cutting trials (Glover 1988; Wheeler 1988) the relatively poor performance of K156 and the interspecific hybrids is probably due to a lack of adaptation of the parental species to the Yucatan area.

Psyllid damage

There were no significant differences in psyllid nymph numbers. However, when data were expressed as density of nymphs (number/pinna) K156 had the lowest density, and Cunningham and the PxL hybrid the highest (Table 2). These figures did not correlate well with psyllid damage (Table 2) indicating that higher density of nymphs did not always result in greater psyllid damage. The *L. leucocephala* entries were most severely damaged. Although K156 and the *L. pallida* mixture had nymphs on their pinnae, they did not suffer any damage. The relative damage scores agree well with other reports for similar species (Sorensson and Brewbaker 1986; Glover 1987; Piggin and Mella 1987; Bray and Woodroffe 1989).

Chemical characteristics

There were significant differences among entries for CP content in immature leaves (Table 3), but not in mature leaves. The *L. leucocephala* entries had the highest CP levels. Although the CP levels reported here are generally higher than usually reported (NAS 1984; Brewbaker and Hutton 1979), they support the observations of Lahane et al. (1987) that *L. diversifolia* and *L. pallida* derivatives generally have lower CP values.

Dry matter and CP rumen digestibility were significantly ($P<0.001$) different among the entries both in immature and mature leaves. Again, the highest values were recorded for the *L. leucocephala* entries

Table 2. Plant height and number of branches at the second cut, cumulative dry matter (DM) yields over two harvests, and psyllid data for the seven accessions.

Entry	Plant height (cm)	Number of Branches	Edible DM (kg/ha)	Total DM (kg/ha)	Density of nymphs (no./pinna)	Psyllid damage score
K156	98.7 bc	10.3 c	1140 b	1470 b	0.3 a	1.0 a
D × L hybrid	119.1 abc	15.2 b	1414 b	1770 ab	1.3 c	2.2 b
P × L hybrid	95.2 c	13.4 b	1066 b	1178 c	1.7 d	1.9 b
L. pallida mixture	100.5bc	21.6 a	1891 a	2256 a	0.6 b	1.0a
L. leucocephala hybrid	132.1 a	10.5 c	1518 ab	1971 ab	1.2 c	5.0 cd
Cunningham	122.8 ab	13.5 b	1714 a	1991 ab	1.6 d	5.4 d
Local	136.4 a	14.7 b	2153 a	2509 a	1.3 c	4.6 c

Data within a column followed by the same letter are not significantly different (P>0.05)

Table 3. Crude protein content (%), rumen digestibility (%) of dry matter (DM) and crude protein (CP), for the seven accessions.

Entry	Immature leaves			Mature leaves	
	CP	DM dig.	CP dig.	DM dig.	CP dig.
K156	27.8 e	32.6 d	39.3 d	57.2 a	31.7 c
DxL hybrid	30.2 d	40.2 cd	49.1 cd	41.6 b	27.5 bc
PxL hybrid	30.7 cd	47.8 bc	59.0 ab	49.8 ab	36.6 ab
L. pallida mixture	27.3 e	47.8 bc	54.9 bc	46.5 ab	36.4 ab
L. leucocephala hybrid	32.1 bc	63.6 a	67.9 a	55.4 a	41.8 a
Cunningham	34.8 a	63.5 a	71.4 a	57.2 a	47.2 a
Local	33.3 b	59.9 ab	63.0 ab	52.7 a	36.8 ab
Mean	30.9				

Data within a column followed by the same letter are not significantly different (P>0.05)

and this difference was maintained, to a lesser extent in the mature leaves. This difference between the mature and immature leaves reflects the accumulation of cell wall fibres in the mature leaves, which also could affect the digestibility of other nutrients (Schneider and Flatt 1975).

Total phenols were highest in the non-*L. leucocephala* entries, with K156 having the highest values (Table 4). Young leaves had higher total phenols than old leaves. Since there were no differences among accessions for psyllid nymph numbers, this could suggest that nymph number is to some extent independent of the concentration of total phenols, and that nymphs find some protection from the sun and predators in the unopened pinnae.

Conclusions

The three entries of *L. leucocephala* had better agronomic and quality attributes than the other species and hybrids evaluated, despite having more psyllid damage. Because of the short term duration of this experiment, and the relatively low psyllid pressure, it is important to continue the evaluation of psyllid resistant material with good agronomic qualities for the Yucatan peninsula.

Table 4. Total phenols (g gallic acid/kg MS) in immature and mature leaves of the seven accessions.

Entry	Immature leaves	Mature leaves
K156	46.9 a	38.4 a
D × L hybrid	39.9 ab	18.3 b
P × L hybrid	43.4 ab	18.3 b
L. pallida mixture	35.9 abc	10.1 c
L. leucocephala hybrid	31.7 bcd	8.9 c
Cunningham	21.7 d	7.0 c
Local	26.0 cd	8.3 c
Mean	35.1	15.6

Data within a column followed by the same letter are not significantly different (P>0.05)

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Evaluation of *Leucaena* Germplasm on Clay Soils in Central and Southern Inland Queensland

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Abstract

Leucaena evaluation sites were established at Brigalow and Brian Pastures Research Stations in September 1995. Twenty-seven *Leucaena* accessions from 14 species and hybrids were planted in neutral cracking clay soil at Brian Pastures Research Station and 25 accessions in alkaline cracking clay soil at Brigalow Research Station to evaluate cold and psyllid tolerance, edible yield and persistence. Performance in the first season after establishment indicated a wide variation between accessions in growth form, leafiness, yield and frost resistance. The hybrid *L. pallida* K748 × *L. leucocephala* K636 was the most outstanding line at both sites, being high yielding and reasonably frost and psyllid tolerant. No other lines were better in edible yield than the commercial *L. leucocephala* cultivars Cunningham and Tarramba.

LEUCAENA *leucocephala* (leucaena) has been used commercially in tropical Australia as a grazing legume for more than 40 years. Some 50 000 ha have been planted, most of this in central Queensland (Middleton et al. 1995). Leucaena is used in a free-grazing system where it is grown in rows 5–12 m apart with an adapted grass such as buffel (*Cenchrus ciliaris*), rhodes grass (*Chloris gayana*) or green panic (*Panicum maximum*) grown in the inter-rows. It is the only rain-grown tropical pasture capable of consistently finishing beef animals to meet the major export weight for age carcase specifications. Its potential to improve animal production was recently demonstrated in central Queensland (Esdale and Middleton 1997).

In Queensland, most leucaena is grown on brigalow and downs (cracking clay) soil because of their relative high fertility. Average annual rainfall in these areas is 600–800 mm. On the higher rainfall coastal areas, the soils are generally shallow, low fertility, duplex soils unsuited to leucaena.

L. leucocephala is the only species that has been extensively tested in tropical Australia and only two commercial cultivars (Cunningham and Peru) are widely used. A new cultivar (Tarramba) was released for commercial use in late 1997.

The wider use of leucaena has been limited by psyllids and poor soil in coastal areas and marginal rainfall, slow establishment and winter frost in inland areas. Better leucaenas would require tolerance to psyllids, frost, and drought as well as being able to compete with grass and weeds. In addition any new cultivars must be highly palatable and manageable (avoiding tall, robust trees) so as not to become environmental threats.

Materials and Methods

Sites

The sites were Brigalow Research Station (BRS, Lat 24 51′ S; Long 149 48′ E; AAR 709 mm) and Brian Pastures Research Station (BP, Lat 25° 39′ S; Long 151° 45′ E; AAR 708 mm) and represent the main leucaena growing areas of Queensland. Soils are alkaline cracking clays (BRS) and neutral alluvial clay (BP), relatively fertile, well drained, and of medium to high fertility.

Accessions

Twenty-seven *Leucaena* accessions from 14 species and 3 hybrids, including the three *L. leucocephala* cultivars, as well as representatives of the diversity among the lesser known *Leucaena* spp., were selected for the trial (Table 1).

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Design and Layout

Three replications of the accessions were set out in a 5 × 5 lattice (BRS) and a randomised block (BP). Each plot consisted of 10 seedlings planted 50 cm apart in the centre of a 1.5 m rotavated strip in a native grass pasture. Rows were 5 m apart. Planting was carried out on 5–6 September 1995 (BRS) and 13 September 1995 (BP). Trickle irrigation was applied to ensure establishment.

Weed control (mechanical and chemical) was carried out on about 1.5 m either side of the rows.

Measurements

After establishment, plots were sampled for dry matter yield about three times per year. Edible material was considered to be leaf plus green stems up to 6 mm diameter. Psyllid and frost damage were rated periodically on a 1–8 scale where 1 was no damage and 8 was total leaf loss. Primary stem branching and stem diameter were also measured.

Results and Discussion

Persistence

At BRS, some lines were badly frosted just after planting but survived.

At the BRS site, 14 lines have given a survival rate of 80% or better. Poor survival (less than 50%) occurred with *L. involucrata*, *L. trichandra* OFI 4/91, *L. pallida* OFI 52/87, *L. lempirana*, and *L. salvadorensis*. Persistence was better at BP (all but 6 lines gave better than 80% persistence), probably due to a lighter textured, better drained soil and more supplementary irrigation during establishment. *L involucrata* (40% survival) and *L. lempirana* (60% survival) had the poorest persistence.

Psyllid damage

Psyllids caused no damage at the BRS site. At BP, psyllid pressure was highest in the periods November 1995 to January 1996, April to May 1996, November 1996 and July 1997. The mean damage rating over these periods is shown in Table 1. The

Table 1. Frost and psyllid damage and edible dry matter yield of 27 *Leucaena* accessions at Brigalow (BRS) and Brian Pastures (BP) Research Stations.

Species/Accession	Frost-BRS 3-yr mean[1]	Psyllids-BP 3-yr mean[2]	Relative edible DM yld[3]-BRS	Relative edible DM yld[3]-BP
L. collinsii ssp. *collinsii* OFI 52/88	4.7	1.0	12.7	24.1
L. collinsii ssp. *zacapana* OFI 56/88	5.1	4.5	8.3	5.3
L. diversifolia OFI 82/92	2.3	1.4	5.8	15.9
L. diversifolia OFI 83/92	2.8	1.3	20.0	21.7
L. diversifolia CPI 33820	not planted	1.0	not planted	6.4
L. diversifolia K156	2.1	2.2	27.3	16.0
L. diversifolia K156 × *L. leucocephala* K8 (F2)	3.3	2.8	29.8	25.6
L. esculenta OFI 47/87	6.7	1.1	10.5	33.8
L. involucrata OFI 87/92	3.4	3.8	4.1	2.9
L. lanceolata var. *lanceolata* 43/85	6.6	4.1	17.3	27.2
L. lempirana OFI 5/91	4.8	3.2	3.0	8.1
L. leucocephala ssp. *glabrata* cv. Cunningham	3.0	3.9	66.5	38.9
L. leucocephala ssp. *glabrata* cv. Peru	3.4	not planted	32.2	not planted
L. leucocephala ssp. *glabrata* cv. Tarramba	3.2	3.1	48.6	43.8
L. macrophylla ssp. *istmensis* OFI 47/85	6.8	2.8	8.9	15.6
L. magnifica OFI 19/84	5.5	3.1	4.2	12.1
L. pallida CQ3439 (CSIRO composite)	3.2	1.3	19.1	41.4
L. pallida OFI 52/87	4.9	1.4	30.2	36.7
L. pallida K376 × *L. leucocephala* K8 (F5)	3.7	1.7	32.4	56.2
L. pallida K748 × *L. leucocephala* K636 (F1)	2.7	1.1	100.0	100.0
L. pallida OFI 79/92	3.8	1.2	49.9	37.0
L. pulverulenta OFI 83/87	1.8	2.6	11.4	17.3
L. salvadorensis OFI 36/88	7.2	2.6	7.9	22.2
L. trichandra CPI 46568	not planted	1.0	not planted	15.6
L. trichandra OFI 4/91	3.8	1.6	8.2	7.7
L. trichandra OFI 53/88	4.0	1.0	28.3	31.2
L. trichodes OFI 61/88	7.1	3.9	3.0	9.5

[1] Mean frost damage rating at BRS over 1995, 1996 and 1997 winters. 1 = no leaf damage, 8 =100% leaf killed
[2] Psyllid damage at BP at peak damage period (mean of 1995, 1996 and 1997). 1 = no psyllids, 8 = 100% leaf killed.
[3] Edible dry matter yield (summer) expressed as a percentage of the highest yielding accession.

most consistently susceptible lines were *L. collinsii* OFI 56/88, *L. lanceolata* OFI 43/85, *L. leucocephala* cv. Cunningham, and *L trichodes* OFI 61/88. Some other lines showed occasional moderately severe damage. Cunningham was generally more severely damaged than Tarramba. Compared to the *L. leucocephala* cultivars the hybrid *L. pallida* K748 × *L. leucocephala* K636, other *L. pallida* lines and hybrids, *L. trichandra, L. diversifolia* and *L. esculenta* showed only minor damage.

Frost damage

Frost occurred at both sites in all years. However, at BP in 1996 frequent heavy frost killed all top growth of all lines. The plants had been sampled to 50 cm in late autumn and there was not much regrowth present at time of frosting. In 1997, a mild winter and taller plants resulted in little damage on any line.

At BRS, frosts occurred just after establishment (Sept 7–8, 1995) with a terrestrial minimum temperature to –4 °C; Aug 20–31, 1996 (minimum to –6 °C); Aug 26–30, 1997 (minimum to –7 °C). Over the three winters, there were five lines consistently badly frosted (Table 1). These were *L. salvadorensis* OFI 36/88, *L. trichodes* OFI 61/88 *L. macrophylla* OFI 47/85, *L. esculenta* OFI 47/87 and *L. lanceolata* OFI 43/85. Two other lines, *L. magnifica* OFI 19/84 and *L. collinsii* OFI 52/88, were badly frosted in two of the three winters. The most frost tolerant accessions were *L. diversifolia* K156 and *L. pulverulenta* OFI 83/87. All the commercial *L. leucocephala* lines had reasonable frost tolerance with no real difference between them. The hybrid *L. pallida* K748 × *L. leucocephala* K636 also had good frost tolerance.

Branching habit

There was a big range in both primary branching and stem diameter between lines (data not shown). At both sites, branch numbers were greater and stem thickness smaller in cv. Cunningham than in cv. Tarramba and the high-yielding *L. pallida* × *L. leucocephala* hybrid.

Edible yield

The hybrid *L. pallida* K748 × *L. leucocephala* K636 clearly outyielded all other lines at all times of the year at both sites. This occurred despite a relatively high proportion of inedible stem. Other lines that yielded as highly as the commercial cultivars Cunningham and Tarramba were *L. pallida* OFI 79/92 (BRS) and *L. pallida* K376 × *L. leucocephala* K8 (BP).

Yields of other lines were variable. At BP *L. trichandra* OFI 53/88 and *L. salvadorensis* OFI 36/88 yielded well initially but rapidly declined. This may be a consequence of the cutting regime imposed. Others accessions such as *L. collinsii* OFI 52/88 and *L. esculenta* OFI 47/87 at BP and *L. pallida* OF 52/87 and 79/92 at BRS gave relatively high yields in the late summer but relatively low yields in the early growing season. All these lines appear relatively frost susceptible.

At BP, Tarramba gave a slightly higher edible yield than Cunningham. The reverse happened at BRS supporting the view that Tarramba possesses better psyllid tolerance.

Conclusions

The results to date indicated there were major differences in performance characters (yield, branching habit, frost and psyllid susceptibility) among the accessions. In general, the yield rankings were consistent between sites. The hybrid *L. pallida* K748 × *L. leucocephala* K636 was outstanding in performance at both sites, possessing rapid growth, high yield, good frost tolerance and moderate stem branching at both sites. This accession tended to grow very tall and its stems were relatively thick. Under grazing it would need to be managed to keep it within grazing height.

Of all the others, none were superior in edible yield to the *L. leucocephala* cultivars Tarramba at BP and Cunningham at BRS. Basal branching of Cunningham was the best of all lines at BRS and it had a high percentage of edible material compared to other lines. While Tarramba had a high total yield, a higher proportion was inedible stem. In terms of commercial potential, which includes a readily available source of seed, the *L. leucocephala* cultivars remain the best choice in the low psyllid environments of Central Queensland. Once established they possess reasonable frost tolerance.

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Evaluation of *Leucaena* Species in the Dry Tropics of N.E. Australia for Yield and Psyllid Tolerance

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Abstract

Twenty-six accessions from 15 *Leucaena* species, including three hybrids, were grown in rows 3 m apart on a Kandosol (red earth) in the dry tropical environment of NE Queensland, Australia. Plants were cut to 50 cm, 3–4 times a year. Stem and edible material were separated, dried and weighed. Psyllid damage was also estimated on a 1–9 scale. The objective was to identify material that could replace the psyllid-susceptible cultivars of *L. leucocephala*, Cunningham and Peru, in this environment. The outstanding accession was the psyllid tolerant *L. pallida* K748 × *L. leucocephala* K636 F_1 hybrid (UQ118). It was taller and outyielded all other accessions at every harvest. Other psyllid-tolerant accessions were: *L. trichandra* OFI 53/88, CPI 46568; *L. diversifolia* CPI 33820; *L. pallida* CSIRO composite; and *L. esculenta* OFI 47/87. Despite high psyllid tolerance, none of these five lines was ranked in the top nine for yield. *L. pallida* OFI 52/87 (believed to be a hybrid) ranked 3 in terms of total yield, but 9 in terms of edible yield due to a low leaf:stem (L:S) ratio. The cultivars Cunningham and Tarramba ranked 2 and 4 with similar total DM yields, though Cunningham produced more edible DM, had a higher L:S ratio and a higher leaf density. Tarramba was less damaged by psyllids and, as a result, had less variable yields across harvests. Other high yielding accessions were *L. salvadorensis* 36/88, the *L. leucocephala* × *L. diversifolia* hybrid UQ5, *L. macrophylla* OFI 47/85, *L. lanceolata* OFI 43/85 and the *L. leucocephala* × *L. pallida* F_5 hybrid. No clear-cut replacement for Cunningham and Peru has been identified. Seed of the F_1 hybrid UQ118 cannot be produced commercially and it could be more difficult to manage under grazing in this environment due to high stem production. High yielding species/hybrids other than *L. leucocephala* may have lower nutritive value.

LEUCAENA leucocephala cvs Peru and Cunningham have proved to be persistent, palatable and productive legumes when grown on the deeper, well drained soils of coastal and sub-coastal Queensland (Jones and Bunch 1995; Foster and Blight 1983; Quirk et al. 1988; Wildin 1994). Steer gains on Cunningham leucaena, following rumen infusion of the DHP-degrading bacteria *Synergistes jonesii*, have attained 275 kg/head in a year (Jones and Megarrity 1986). This high animal production is associated with high leaf production, high digestibility, ready accessibility and possibly the protection of protein from digestion in the rumen by the presence of condensed tannins (Norton et al. 1995).

The advent of the psyllid insect (*Heteropsylla cubana*) in 1986 seriously reduced yields in cutting experiments by up to 50% or more (Palmer et al. 1989; Bray and Woodroffe 1991). Although attacks have not been serious every year, psyllids are still an additional risk to a crop that is expensive to establish. Graziers are therefore reluctant to continue investment in establishing more leucaena except in the drier, more inland areas less prone to psyllid challenge. This situation generated a need for psyllid-tolerant material that could replace cvs Cunningham and Peru but still retain their yield and animal production potential.

The experiment reported here was part of a much wider evaluation of *Leucaena* germplasm in the ACIAR Project 9433.

Materials and Methods

The site

The site, a well drained Kandosol (Isbell 1996) on the Lansdown CSIRO Pasture Research Station,

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50 km south of Townsville (19°40'S, 146°51'E) was used for the experiment. It is a grey brown sandy loam grading to a medium clay at 0.5 m and to water worn gravel at 0.9 m. The surface soil is hard setting when dry. It had a pH (1:5 water) of 6.3, and an organic carbon content of 1.0%. Nutrients in mg/kg were P (Colwell) 13; S 3; Cu 0.2; and Zn 1.2. Other nutrients in meq/100g were: Ca 2.05; K 0.35; Na 0.19. The cation exchange capacity (CEC) was 3.23 meq/100g. Electrical conductivity was a low 0.04 dS/m.

Climate

Lansdown has a sub-humid tropical marine climate with a mean annual rainfall of 861mm, 86% of which falls in the wet season from October–March. On average, there are only 49 wet days a year. Rainfall variability is high with coefficients of variation for summer and winter rainfall of 23 and 39% respectively (Cook and Russell 1983). Mean average temperature is 23 °C. Frosts are rare.

Accessions

A total of 26 accessions were used. These are listed in Table 1.

Plants, grown in soil-filled plastic tubes, were 10–20 cm tall when planted 0.5 m apart in rows 3 m apart. There were 10 plants in a single row per plot giving a density of 6667 plants/ha. A randomised block design with three replicates was used.

Accessions 1–23 were planted on July 28, 1995; accession 24 on October 12, 1995; and accessions 25 and 26 on December 20, 1995. Those planted in December 1995 suffered from drought stress and were not considered comparable to the others for yield assessment. Data from these two entries were not included in the statistical analysis for yield.

The six plants in the centre of the plot were used for yield estimates and height measurements. Two plants at each end of the plot were border plants that were cut and removed at each harvest period. All 10 plants were used to assess survival in each plot.

Establishment fertiliser applied along the rows was 67 kg single superphosphate/ha. Trickle irrigation along the rows was used to establish the seedlings in a season of below average rainfall and intermittently to help late planted lines in 1996. No irrigation was given after October 1996.

Height and diameter of seedlings at 10 cm above ground level was measured on November 20, 1995. The first full harvest was made 207 days after planting on February 2, 1996 and further harvests on May 20 (88 days) and October 23 1996 (156 days). In 1997, there were 4 harvests: on January 8 (77 days), March 8 (59 days), May 5 (76 days) and September 24 (124 days), and in 1998 one harvest on January 22 (121 days). At each harvest, plants were cut to 50 cm above ground level, weighed fresh and subsampled (about 1–2 kg fresh weight). This was divided into edible (all leaf plus flowers and young soft stem <6 mm diameter) and stem. Each fraction was dried for 3 days at 100 °C in a dehydrator to obtain dry weights. The heights of shoots above the 50 cm stumps were also measured. The weight of the edible fraction was divided by the mean height above 50 cm to give a leaf density measure. A leaf:stem ratio was also calculated by dividing the edible dry weight by the stem dry weight for each plot.

Psyllid damage to leaf and young stem was assessed at intervals of about one month on a scale of 1 (no damage) to 9 (total loss of young leaf and blackened stem) (Wheeler 1988). Only the data for dates when psyllids were present have been analysed; these were for scores recorded on May 22, July 16, August 20, September 16, October 24 1996, and May 20 and September 25 1997.

Results

Psyllid damage

Serious damage occurred to susceptible lines in the cool months of July to September 1996, and May to September 1997, with large differences between accessions (Table 1). Damage during the warmer months was minor. The most tolerant lines were *L. trichandra* OFI 53/88, CPI 46568; *L. diversifolia* CPI 33820; *L. esculenta* OFI 47/87; *L pallida* CSIRO composite, OFI 79/92, and the *L. pallida* × *L. leucocephala* hybrid UQ118. At these times, the two *L leucocephala* cultivars were severely affected, with cv. Cunningham the most susceptible accession, having scores 1 to 2 units higher than cv. Tarramba (Table 1). Overall, eight lines had damage scores <2, six lines had scores of 2 to 3, five lines scores of 3–4 and seven lines >4. Of the *L. diversifolia* accessions, K156 was more severely damaged than the other accessions, and in general they and the hybrid (21) had more damage than did the *L. pallida* and *L. pallida* hybrids (20, 22). *L. collinsii* var. *zacapana* (2) sustained far greater psyllid damage than *L. collinsii* var. *collinsii* (1).

Seedling growth

For early growth measured on November 20, 1995, most accessions grew taller than cv. Cunningham (719 mm), accessions 2, 3, 4, 5, 6, 8, 12, 15, 16, 18, 21, 22, 23 significantly so ($P<0.05$). The tallest growing accessions were *L. pallida* 52/87 and the F_1 hybrid *L. pallida* × *L. leucocephala* UQ118 at 1348 mm and 1276 mm respectively. Only these two accessions had significantly greater ($P<0.05$) stem diameters at 11.3 mm and 12.2 mm respectively compared with 10.1 mm for cv. Cunningham.

Plant height in mm (y) was linearly related to stem diameter in mm (x) by the equation: y = 23.5 + 103 × (r^2 = 0.732).

Dry matter yields

Highly significant (P<0.0001) differences were measured for accessions, harvests and the interaction of accession × harvest. Cumulative plant DM yield for the sum of the eight harvests ranged from 25.8 t/ha to 3.2 t/ha, or from 10.4 to 1.3 t/ha/yr.

Only one accession, 22, the F_1 *L. pallida* × *L. leucocephala* KX2 hybrid gave a significantly (P<0.01) higher yield than the standard cultivars of *L. leucocephala* Cunningham and Tarramba (Table 1). This hybrid was exceptional in that it gave the highest DM yield at all eight harvests. The ranking of the other accessions varied with harvest (Table 2) resulting in a highly significant accession × harvest interaction (P<0.0001).

The cause of the interactions was not fully clear. However, at least two factors appeared to be implicated: psyllid challenge and drought. For

Table 1. Total yield, edible yield, stem yield, height, leaf:stem ratio, leaf density and psyllid damage scores of 26 leucaena accessions. Values are means of 8 harvests[1].

Accession	Total DM yield (kg/ha)	Edible DM yield (kg/ha)	Stem DM yield (kg/ha)	Height[2] (mm)	L:S ratio	'Leaf density' (g/cm) ht	Psyllid score[3] (1–9)
1. *L. collinsii* 52/88	1384	642	742	1374	0.98	4.12	1.8
2. *L. collinsii* 56/88	983	373	610	1345	1.05	2.67	4.3
3. *L. diversifolia* 82/92	705	353	352	1283	1.34	2.70	2.7
4. *L. diversifolia* 83/92	1163	576	587	1319	1.23	4.38	2.4
5. *L. diversifolia* 4/91	1151	525	625	1374	1.07	3.55	3.0
6. *L. trichandra* 53/88	1509	759	750	1315	1.14	5.18	1.0
7. *L. esculenta* 47/87	1265	760	505	1122	1.75	5.84	1.4
8. *L. pallida* 52/87	2113	793	1320	1681	0.77	4.04	2.4
9. *L. pallida* 79/92	1587	761	826	1370	1.09	4.93	1.8
10. *L. involucrata* 87/92	741	376	365	1135	1.79	3.00	4.7
11. *L. lanceolata* 43/85	1758	807	952	1401	1.71	5.37	4.3
12. *L. lempirana* 5/91	400	189	209	1113	1.35	1.79	4.3
13. *L. macrophylla* 47/85	2036	954	1083	1766	1.15	4.89	3.4
14. *L. pulverulenta* 83/87	449	325	120	637	3.22	4.72	3.8
15. *L. salvadorensis* 36/88	2080	874	1207	1573	0.92	5.13	3.7
16. *L. magnifica* 19/84	1178	510	667	1523	0.84	3.14	2.5
17. *L. trichodes* 61/88	649	347	301	1046	1.65	3.07	3.7
18. *L. leucocephala* K636 cv. Tarramba UQ197	**2089**	**947**	**1141**	**1842**	**1.23**	**4.84**	**4.0**
19. *L. leucocephala* cv. Cunningham UQ8	**2121**	**1117**	**1005**	**1469**	**1.56**	**6.67**	**5.4**
20. *L. leucocephala* × *L. pallida* KX2 F5	1643	834	809	1438	1.14	5.30	3.0
21. *L. leucocephala* × *L. diversifolia* UQ5	1845	875	969	1676	1.31	4.67	4.4
22. *L. pallida* × *L. leucocephala* UQ118	3223	1363	1861	2342	0.83	5.39	1.3
23. *L. diversifolia* K156 UQ1	941	453	488	1274	1.47	3.33	4.4
24. *L. pallida* CSIRO Composite CQ3439	1192	597	596	1240	1.14	4.14	1.2
25. *L. diversifolia* CPI 33820	803	449	355	1065	1.51	3.88	1.4
26. *L. trichandra* CPI 46568	540	310	230	1011	1.59		

[1] Only 5 harvests for numbers 25 and 26.
[2] Above the 500 mm stump.
[3] Means of 7 occasions when psyllid damage occurred.

Table 2. Total DM yield rankings (1 = highest, 24 = lowerst) over 8 harvests for 24 accessions of *Leucaena*. Accession numbers in the body of the table are those given in Table 1. Enties in bold type (**18** and **19**) are Tarramba and Cunningham.

	Harvest								
Rank	1 21.2.96	2 22.5.96	3 23.10.96	4 8.1.97	5 8.3.97	6 23.5.97	7 24.9.97	8 21.1.98	Overall rank (8 harvests)
1	22	22	22	22	22	22	22	22	22
2	8	21	16	**19**	**19**	**18**	**18**	13	19
3	21	8	6	13	8	8	20	15	8
4	**18**	15	13	8	11	15	6	**19**	**18**
5	15	13	4	15	13	24	16	**18**	15
6	6	**19**	15	11	**18**	13	4	11	13
7	**19**	**18**	24	**18**	21	9	15	8	21
8	11	9	20	9	15	20	13	9	11
9	5	11	**18**	24	20	**19**	3	20	20
10	13	6	1	1	9	11	21	24	9
11	9	20	5	20	1	21	**19**	1	6
12	4	4	21	7	7	6	5	21	1
13	20	1	11	21	2	7	1	2	7
14	7	7	3	5	6	1	24	6	24
15	23	5	17	6	23	16	14	7	16
16	16	23	8	16	16	4	7	16	4
17	2	16	**19**	4	10	5	11	4	5
18	1	2	7	23	5	2	9	10	2
19	3	24	9	2	24	3	23	5	23
20	10	17	23	10	17	10	8	23	10
21	17	3	12	17	4	23	2	3	3
22	24	10	14	3	3	17	12	14	17
23	12	14	10	14	14	14	17	17	14
24	14	12	2	12	12	12	10	12	12

Cunningham, total yield ranking ranged from 2 to 17. The low rankings in October 1996 and in September 1997 followed heavy psyllid attacks. High rankings in January and March 1997 and January 1998 occurred when psyllids were absent.

Overall, the yields of Cunningham and Tarramba were similar. However, rankings varied at the different harvests, with those of Tarramba being higher than Cunningham whenever psyllid challenge was high. The reverse was generally the case when psyllids were absent, thus Tarramba gave a more stable ranking across harvests.

For psyllid-tolerant material, the fluctuation in yield ranking is less easy to explain. For accession 8, *L. pallida* OFI 52/87, which was reasonably psyllid-tolerant, rankings ranged between 2 and 20, with low rankings in October 1996 and in September 1997 when both moisture stress and psyllid challenge were high. Accession 15, *L. salvadorensis*, was more stable across harvests, rankings only ranging from 3 to 8 with an overall rank of 5 (Table 2). The seventh ranked accession, 21, *L. leucocephala* × *L. diversifolia* UQ5, yielded highly in the first two harvests, but gave only average yields in harvests 3, 4, 6 and 7 following psyllid attacks. At the different harvests, ranking ranged from 2 to 13 (Table 2).

Two of the larger leaved accessions, 13 and 11, performed reasonably well. Accession 13, *L. macrophylla*, ranked in the first 10 at all harvests with *L. lanceolata* (11) following a similar pattern except for harvests 3 and 7, where under heavy psyllid damage it ranked 13 and 17 (Table 2). Accession 20, *L. leucocephala* × *L. pallida* KX2 F_5 material, improved from a rank of 13 at harvest 1 to rank 3 at harvest 7. It performed well under psyllid challenge although it had only a moderate average psyllid score of 2.9 (Table 2).

Accessions with ranks above 10 had yields less than half of the highest yielding accession 22. They are not considered as useful in this seasonally dry environment.

Edible DM yield

Although the general pattern for edible DM yield was similar to that of total DM yield, the rankings for individual harvests, and for the mean of all harvests, changed (Table 1). At harvests 4 and 5, when psyllid challenge was low, Cunningham had the highest rank. Overall, however, accession 22 again had the highest yields, with Cunningham and Tarramba ranked 2 and 3. *L. pallida* 52/87 (8) dropped to rank 9 compared to rank 3 for total yield (Table 1). This was associated with a low L:S ratio. Conversely, *L. macrophylla* (13) and the *L. leucocephala* × *L. diversifolia* hybrid (21) with higher L:S ratios were elevated from rank 6 and 7 to rank 3 and 5 respectively (Table 1). However, the actual range in edible DM yield per harvest for the accessions ranked 4 to 12, varied by only 188 kg/ha or 2.5 × SE (Table 1).

Stem DM yield and height

Not unexpectedly, there was a general linear relation between stem yield (y) and height (x) for the accessions: $y = -685 + 0.987\,x$ ($r^2 = 0.853$). Both varied greatly by factors of 17 and 3.7 respectively (Table 1). Accession 22 was the tallest, followed by Tarramba (18), *L. macrophylla* (13), *L. leucocephala* × *L. diversifolia* (21), *L. pallida* (8), *L. salvadorensis* (15) and *L. magnifica* (16). Highest stem DM yields were recorded for accessions 22, 8, 15, 18, 21, 13, 19 and 11.

Leaf:stem ratio

These values varied widely from 0.77 in *L. pallida* (8) to 3.22 in the low yielding *L. pulverulenta* (14), with most accessions falling in the range of 1.0 to 1.5. Cunningham at 1.56 had a higher L:S ratio than Tarramba at 1.23 or UQ118 at 0.83.

Leaf density

Cunningham had the highest leaf density of 6.67 and *L. lempirana*, with very small leaves, the lowest, at 1.79. All nine accessions with the highest edible yield had leaf density measurements above 4.0 g/cm of height (Table 1).

Plant survival

Overall, plant survival was very good. Two accessions — *L. diversifolia* 4/91 and *L. involucrata* 87/92 had lower survival (77%) than the other accessions which exceeded 85% survival.

Discussion

Most of the accessions evaluated were either inherently low yielding or not well adapted to this site and did not attain the production of the control cv Cunningham. This was unexpected in view of the known susceptibility of cv. Cunningham to psyllids. The outstanding exception was the F_1 hybrid *L. pallida* × *L. leucocephala* UQ118. In total yield, it ranked first at every harvest, it had good psyllid-tolerance and was the tallest accession grown. Other research (Austin et al. 1997; Castillo et al. 1997) has highlighted the value of this particular hybrid in both hot and cool climates, particularly where psyllid challenge is high. Unfortunately, production of this F_1 hybrid appears not to be commercially viable, and, for Australian situations, vegetative propagation for seasonally dry tropical sites would be risky, even if technology to root cuttings is developed. A further problem under Australian conditions is its rapid stem growth that could require intensive grazing management or frequent mechanical slashing to control.

The other hybrids (20 and 21) together with the suspected hybrid (8) also performed well, although the *L. leucocephala* × *L. diversifolia* hybrid was damaged more by psyllids than the other hybrids.

L. trichandra, *L. diversifolia* and *L. pallida* all showed greater psyllid-tolerance than *L. leucocephala* as has been shown in other studies (Sorensson and Brewbaker 1986; Bray et al. 1990). Furthermore, within these species, there was also variation — the K156 *L. diversifolia* showing by far the most psyllid damage. Despite the good psyllid-tolerance of most of these accessions, their yield performance was poor and they cannot be recommended for planting in this environment.

L. salvadorensis, *L. macrophylla* and *L. lanceolata* gave above average yields despite the fact that they were not highly psyllid-tolerant. The latter two had good leaf:stem ratio and all had high leaf density making them attractive for forage.

L. collinsii, *L. lempirana*, *L. magnifica*, *L. pulverulenta*, *L. trichodes* were low yielding and not highly psyllid-tolerant. Of these, the most promising was *L. collinsii* 52/88 which had good psyllid-tolerance and moderate yield, but with a low L:S ratio.

Although Tarramba was more psyllid-tolerant than Cunningham, it produced less leaf overall, had a lower L:S ratio, and a lower leaf density. Its taller habit could demand more exacting grazing management or more slashing to keep it within reach of grazing animals under Australian conditions. In this environment, the *L. leucocephala* cultivars performed far better than in the cooler, moister and more psyllid-prone environments of Southeast Queensland where they gave lower yields than accessions of *L. pallida*, *L. diversifolia* and various *L. leucocephala* hybrids (Castillo et al. 1997). In this respect, their performance was more similar to that in Florida, where they out-performed *L. pallida* K376, *L. esculenta* K948 and also the KX1, KX2 and KX3 hybrids (Austin et al. 1995).

The high leaf yield of Cunningham, despite heavy psyllid attack, indicates that it is very well adapted to this seasonally dry tropical environment where it was selected. It also has high L:S ratio and high leaf density and should be considered as a useful parent for crossing with other species to produce adapted, psyllid-tolerant and nutritious hybrids.

It is important that in any selection for replacements to existing cultivars for Australian conditions, due consideration be given to the assessment of animal production potential. In this regard, the *L. leucocephala* accessions appear to have higher leaf digestibility (Norton et al. 1995; Castillo et al. 1997; Austin et al. 1995) and promote better liveweight gains (Jones et al. 1998).

Acknowledgments

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Evaluation of *Leucaena* Germplasm in Northern Western Australia

M.J. Bolam[1] and T. Triglone

Abstract

Twenty-two taxa belonging to the genus *Leucaena* were assessed for their agronomic potential under irrigation in northern Western Australia. Survival of seedlings, height, dry matter production and insect damage were recorded over a 27-month period. There was considerable variability in the survival of seedlings with some species being poorly adapted. Edible dry matter production was greatest for *Leucaena leucocephala* cv. Cunningham and cv. Tarramba, three interspecific hybrids, and *L. salvadorensis* 36/88. Further evaluation for potential production under grazing is needed. No psyllids were observed, but thrips had a variable effect on plant growth immediately after harvest.

THE ORD River Irrigation Area (ORIA) of northern Western Australia (WA) is currently the only *Leucaena* growing area in WA. *L. leucocephala* is grown exclusively to provide forage for cattle. The industry is based on producing cattle for live export to Southeast Asia, with a small number of animals slaughtered for the local meat trade.

At present, approximately 1400 ha is planted in the ORIA to cv. Cunningham. *L. leucocephala* is planted on beds with inter-row grasses, such as pangola (*Digitaria eriantha*), and flood irrigated. Producers use a rotational grazing system and stock at an average of six head per hectare (hd/ha). The potential liveweight gains are of the order of 200–250 kg/hd/yr.

L. leucocephala provides market advantages for growers by extending the season that cattle can be sold, by providing good growth rates, and allowing easy mustering for sale. Much of the *L. leucocephala* grown in the ORIA is part of the vertical integration of extensive grazing businesses in northern Australia. There is the potential for 2500–5000 ha of *L. leucocephala* to be planted in a new stage of the irrigation area currently being developed. There is also potential to produce prime quality table beef for local consumption.

Key limiting factors to realising the potential of *Leucaena* in the ORIA include the effects of the root rot fungus, *Pirex subvinosus,* and the price and availability of irrigation land.

Involvement in this Australian Centre for International Agricultural Research (ACIAR) funded trial provided an opportunity to examine lesser known species of *Leucaena* for their potential for edible dry matter (DM) production and to assess their susceptibility to insect damage in the ORIA.

Materials and Methods

The list of accessions planted at the trial site is presented in Table 2. The twenty-two entries were planted in randomised complete blocks with three replicates. Nine seedlings were planted per plot, 0.5 m apart on 1.8 m beds.

The site, which had been previously laser-levelled, was ploughed, scarified, bed-shaped, rotary hoed and bed-shaped again before planting. No fertiliser or no pre-emergent herbicides were applied. The soil at the site is described as Cununurra clay (self-mulching, brownish cracking clay with fine structure and high pH topsoil) and had been used for various irrigated crops for 10 years. Chemical analysis of the soil is presented in Table 1.

The experiment was pre-irrigated before planting on the 28/9/95 and watered every five days for four waterings then every 14 days, with adjustment for rainfall over the 27-month period. Fertiliser was applied (240 kg/ha triple superphosphate and zinc) in January 1996, after receipt of soil analysis results.

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Data collection took place on the following dates:

Girth and height measurements: 23/11/95, 29/1/96, 1/5/96.

Thrip damage assessment: 23/11/95, 15/7/96, 19/9/96.

Nutritive value: 20/2/96.

Plant form and habit: 1/5/96.

Dry matter production: 1/5/96, 5/9/96, 22/1/97, 15/5/97, 22/9/97, 10/1/98.

Table 1. Soil analysis at the germplasm evaluation site including an expected range of values from numerous sites and critical levels below which plant growth may be adversely affected.

	Plot site	Expected range	Critical level
pH	8.1	4–8	—
C	0.7	1–5	—
P	19	5–200	< 25
K	0.92	0–2	< 0.2
S	8	2–100	< 5
Ca	16.6	1–50	< 2.5
Mg	11.25	0–20	< 0.4
Zn	0.2	0–10	< 0.5
Fe	9	0–500	—
Mn	8	0–200	> 100
CEC	29.29	2–40	< 5
Al Sat	0.001	0–90	—
Ca/Mg	1.48	1–8	<1.5 >5

Results and Discussion

The establishment procedures used in this trial are typical of those used commercially in the ORIA and are discussed further by Pratchett and Triglone (1990). Long-term climatic data indicated that the growing environment of the ORIA was divided into three periods. Firstly, the dry season period (May–Sep.) where night-time temperature can limit production of edible DM; secondly, the early wet-season period (Oct.–Dec.) which has good growing conditions; and thirdly, the late wet season period (Jan.–Apr.), where overcast conditions and water-logging may affect plant production.

Psyllids were not observed during the trial period and, although recorded on occasion in the ORIA as causing damage to *L. leucocephala* they are not considered a problem. Thrips are a more significant problem, especially at establishment and after *L. leucocephala* has been cut, and therefore insect damage assessment focused on these insects.

At the initial assessment on 23/11/95 (8 weeks post-planting), few thrips were evident. On 15/7/96 (10 weeks after the first DM production assessment), a moderate thrip challenge was present and low damage scores were recorded for accessions *L. salvadorensis* 36/88 and *L. leucocephala* cv. Cunningham. High damage scores were recorded for accessions *L. lanceolata* var. *lanceolata* 43/85,

Table 2. Plant survival, height and total dry matter production of the 22 leucaena accessions.

Entry	Identification	Plants surviving 10/1/98 (%)	Plant height 1/5/96 (cm)	Total dry matter production (g/m of row/month)	
				Edible	Non-edible
L. leucocephala	cv. Cunningham	89	247	1333	1995
L. pallida × *L. leucocephala*	K748 × K636 F_1	79	298	1318	2505
L. leucocephala	cv Tarramba	89	264	1213	1873
L. leucocephala × *L. pallida*	K376 × K8 F_5	82	170	1047	1623
L. salvadorensis	36/88	82	208	975	1416
L. diversifolia × *L. leucocephala*	K156 × K8 F_2	86	187	925	1302
L. macrophylla subsp. *istmensis*	47/85	86	162	825	1108
L. lanceolata var. *lanceolata*	43/85	79	198	724	1019
L. pallida	52/87	82	247	682	1011
L. pallida	79/92	68	205	642	879
L. collinsii subsp. *zacapana*	56/88	82	203	556	885
L. collinsii subsp. *collinsii*	52/88	86	144	527	607
L. diversifolia	K156	64	172	495	638
L. diversifolia	83/92	79	145	404	562
L. involucrata	87/92	18	128	381	424
L. trichodes	61/88	50	135	262	353
L. magnifica	19/84	54	156	220	262
L. esculenta	47/87	32	123	199	153
L. trichandra	53/88	14	134	142	112
L. pulverulenta	83/87	7	47	113	82
L. diversifolia	82/92	57	114	94	100
L. trichandra	4/91	14	138	46	25

L. collinsii subsp. *zacapana* 56/88, *L. diversifolia* × *L. leucocephala* (K156 × K8 F_2), *L. trichandra* 53/88 and *L. pallida* × *L. leucocephala* (K748 × K636 F_1).

On 19/9/96 (two weeks after the second DM production assessment), a moderate thrip challenge was present and low scores were recorded for accessions *L. collinsii* subsp. *zacapana* 56/88, *L. trichodes* 61/88, *L. magnifica* 19/84, *L. trichandra* 53/88 and 4/91. High damage scores were recorded for *L. macrophylla* subsp. *istmensis* 47/85, *L. leucocephala* cv. Tarramba, *L. pallida* × *L. leucocephala* (K748 × K636 F_1), *L. leucocephala* cv. Cunningham and *L. leucocephala* × *L. pallida* (K376 × K8 F_5).

Plant survival

Plant survival after six dry matter harvests varied between 7% and 89% (Table 2) with only 12 of the accessions having more than 75% survival. Clearly, many of these species are not adapted to regular defoliation in the ORIA.

Plant height

The heights of the accessions measured before the first dry matter assessment are also shown in Table 2. Again, there was a considerable range observed.

Dry matter production

The total DM production measured for six harvests is presented in Table 2. Clearly, total DM production is related both to plant survival and to plant height.

Included in the varieties which produced the greatest amount of edible DM in this comparison are the varieties that are currently grown in the ORIA, *L. leucocephala* cv. Cunningham and cv. Tarramba. Tarramba was planted on an adjoining site two years previously for comparison of the potential DM yield and animal production with cv. Cunningham. In these larger plantings of leucaena, cv. Cunningham has had slightly higher DM yields than cv. Tarramba. However, animal production from the two cultivars has been similar (see Jones et al., these Proceedings). The results from the germplasm evaluation are consistent with the results from this larger grazing trial, in that the new cv. Tarramba does not produce more dry matter (edible or non-edible) in this environment.

Of importance to growers in the ORIA is the performance of other accessions, in particular the three interspecific hybrids and *L. salvadorensis* (36/88). These provide potential alternate genetic material to the current monoculture of cv. Cunningham.

The nutritive value of these alternate accessions is presented elsewhere in these Proceedings. The in vitro digestibilities of the higher yielding newer *Leucaena* species (62%–64%) are similar to cv. Cunningham and cv. Tarramba (65% and 61% respectively), although the NDF content of the *L. salvadorensis* (36/88) is higher (30% v 20% DM) and the *L. pallida* × *leucocephala* (K748 × K636 F_1) has a higher extractable condensed tannin content (4% v 0.5% DM). The palatability of these alternative cultivars will be an important factor in their suitability for animal production in any environment.

It is important to evaluate the branching behaviour of these new species, as more suitable varieties for grazing systems should possess weak apical dominance and produce numerous branches from the point of cutting. The tallest varieties are not necessarily the best for grazing.

Conclusion

L. leucocephala cv. Cunningham and cv. Tarramba were confirmed as varieties that are suitable for the production of edible DM in the environment of the ORIA. The three interspecific hybrids show significant potential to produce large quantities of edible DM but the potential for increased animal production above that achieved with cv. Cunningham or cv. Tarramba will need to be confirmed. This also applies to plant vigour and survival under grazing.

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The Growth of *Leucaena leucocephala* in Northern Vietnam

Tu Quang Hien[1] and Nguyen Thi Lien[2]

Abstract

Leucaena leucocephala was grown in Thai Nguyen Province in the northern mountainous region of Vietnam. In the first year, 57 t/ha of green matter was produced, equivalent to 7 t/ha of dry leaf; in the second and third years, 70 t/ha of green matter (8.5 t of dry leaf) was produced. This shows that leucaena can be grown in this area, provided that adequate lime and fertiliser are applied

LEUCAENA (*Leucaena leucocephala*) is popular in many regions of Vietnam, but not in the northern mountainous region where the climate and soils are different. The soils are more acidic and less fertile, and the winter temperatures are lower.

Before trying to introduce leucaena into the farming systems of the area, a trial was conducted to study the growth of leucaena in Thai Nguyen Province, which is located in the mountainous region. The future of leucaena in the area would be judged on its performance in the trial.

Materials and Methods

The experiment was carried out from 1991–1993 on the Practical Farm of the Agroforestry College, Thai Nguyen. The average maximum and minimum temperatures at this site are 28.7 °C and 15.6 °C, with annual rainfall of 2007 mm.

Soil analysis revealed these characteristics: pH (KCl) 5.6, total N 0.13%, total P_2O_5 0.08%, total K_2O 1.56%, organic matter 2.12% and clay content 35%.

Leucaena leucocephala was grown in plots of 20 m^2. Fertiliser was applied as follows: first year: manure 15 t/ha, N 40 kg/ha, P_2O_5 60 kg/ha, K_2O 40 kg/ha, lime 1.01 t/ha; second and third years: manure 5 t/ha, P_2O_5 40 kg/ha, K_2O 20 kg/ha and lime 0.2 t/ha.

The trial was established in March 1991. Plants were harvested on 11 occasions over 3 years at intervals varying from 2 to 5 months and dry matter (DM) production measured. Plant height was also measured before each harvest.

Leucaena was also grown in hedgerows with other crops on land with a 14–16° slope. In each hedgerow, there were two rows of leucaena, spaced 0.5 m apart. Crops such as upland rice, maize and legumes were grown between the hedgerows. The leucaena was pruned to 50 cm when it reached a height of 1 m, three to four times a year. The pruned material was used as green manure for the crops.

Results

The plant height at the first cut and the regrowth height at subsequent cuts are shown in Table 1. In the May to September period, which was cool and rainy, leucaena grew quickly at an average of 1 cm/day. In October and November, the rainfall was less and the temperature lower so that the growth slowed to about 0.6–0.7 cm/day. Between December and April, it was dry and cold, with rain falling only rarely, so that leucaena only grew at 0.35 cm/day.

These growth rates were reflected in the green and dry matter production (Table 1). Cutting in the rainy season produced 19–22 t/ha/cutting of green material (equivalent to 2.3–2.6 t/ha/cutting of dry matter) and cutting in the dry season (October to April) produced 13–17 t/ha/cutting of green material (1.6–2.0 t/ha/cutting DM).

Averaged over all cuttings, the green material contained 48% leaf. Leaf DM production was 6.97 t/ha in the first year, 8.55 t/ha in the second,

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Table 1. Plant height and biomass production of leucaena over three years.

Growth periods between harvests	Days between harvests	Plant height at harvest (cm)	Growth rate (cm/day)	Fresh weight (t/ha)	Leaf dry weight (t/ha)
First year					
15/3/91–15/7/91	122	108.9	0.89	19.62	2.36
16/7/91–15/9/91	62	60.8	0.98	21.15	2.55
16/9/91–30/11/91	76	53.2	0.70	17.04	2.05
Second and third years					
15/11–20/4	156	54.6	0.35	13.40	1.61
21/4–30/6	71	65.3	0.92	22.08	2.66
1/7–31/8	62	62.6	1.01	20.94	2.52
1/9–15/11	76	49.4	0.65	15.12	1.82

and 8.69 t/ha in the third. Although this is less than yields reported elsewhere (Hawaii 12 t/ha/yr, India 14 t/ha/yr and Thailand 12 t/ha/yr), it is considered to be satisfactory, considering the climate and soil.

When leucaena was grown as hedgerows, total green matter production was 4.86, 5.61 and 5.87 t/ha for the first second and third years. This means that the hedgerows not only provide protection from erosion, but could also supply 5–6 t/yr of green manure for agricultural crops or about 1 t/year of leucaena leaf meal for animal production.

The chemical composition of leucaena leaf is shown in Table 2, illustrating its high quality as a potential feed.

Table 2. Chemical composition of leucaena leaf.

Component	Green leaf	Leaf meal	Dry leaf
Dry Matter (%)	25.1	89.0	100
Crude protein (%)	6.3	21.0	24.1
Lipids (%)	0.6	2.1	2.3
Cellulose (%)	4.1	14.8	16.7
Carbohydrate (%)	12.6	45.2	50.3

Conclusion

Leucaena grown in Thai Nguyen can produce about 8.5 t/ha/yr of leaf DM, with a high crude protein content. It can be grown to produce leaf meal for animal feed, but the application of lime and other fertilisers is needed to achieve these yields.

Nodulation

Assessment of Growth, Nodulation and Nitrogen Fixation of Lesser-Known *Leucaena* Species Inoculated with Different *Rhizobium* Strains in Greenhouse Conditions

G. Lemkine[1] and D. Lesueur[1]*

Abstract

The symbiotic behaviour of lesser-known *Leucaena* species was studied in a greenhouse experiment where 14 *Leucaena* species were inoculated with seven *Rhizobium* strains isolated from *Leucaena diversifolia, L. leucocephala, Calliandra calothyrsus* and *Prosopis juliflora*. The *Rhizobium* strain LDK4 isolated from *L. diversifolia* gave the highest shoot and nodule dry weight and shoot total nitrogen content for the majority of the *Leucaena* species tested. There were significant strain × species interactions, suggesting that the significant differences in growth, nodulation and nitrogen fixation in *Leucaena* species are the results of the *Rhizobium* strain × host plant genotype interaction. The *Leucaena* species were sorted into three groups according to their growth and capacity to fix atmospheric nitrogen. The best species were *L. trichodes, L. macrophylla, L. leucocephala, L. shannonii* and *L. pallida*. However, all these results need to be confirmed by further experiments in field conditions.

LEUCAENA *leucocephala* has been the subject of many studies which demonstrated an exceptional capacity to produce high amounts of biomass and protein when plants are associated with *Rhizobium* (Sanginga et al. 1995). For this reason, it has been widely used in many tropical countries. However, the psyllid problem and low tolerance of acid soils limit its utilisation, and it has become necessary to explore the natural diversity within *Leucaena* in order to identify alternative species not limited by these factors.

It has been demonstrated that *L. collinsii* subsp. *collinsii* and *L. pallida* are resistant to the psyllid (Hughes 1993), and that *L. diversifolia*, *L. shannonii* and *L. macrophylla* exhibit some acid soil tolerance (Brewbaker 1987). Nevertheless, other characteristics also need to be investigated before these *Leucaena* species can be promoted for use. The behaviour of these species has to be evaluated in field conditions in terms of N_2 fixation and forage production. Both these parameters could potentially be improved by inoculation with appropriate *Rhizobium* strains.

In many tropical soils, the presence of inadequate or non-effective *Rhizobium* populations may limit both N_2 fixation and forage production (Singleton et al. 1992). There is limited information on the symbiotic characteristics of these lesser-known *Leucaena* species (Halliday and Somasegaran 1983).

The objectives of this study were: (1) to identify *Leucaena* species of greatest potential in terms of growth and symbiotic nitrogen fixation; (2) to select *Rhizobium* strains which could be used for the inoculation of plants in field conditions.

Methods

Seeds of 14 species of *Leucaena* (Table 1), mainly provided by the Oxford Forestry Institute, were scarified for 30 minutes in sulfuric acid. Eight-day-old seedlings were transplanted into 12 × 8 plastic pots filled with a sand-vermiculite mixture. N-free nutrient solution (Broughton and Dilworth 1971) and distilled water were alternately added. For each *Leucaena* species, six plants were inoculated with each of seven strains of *Rhizobium* (Table 2). The plants were

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Table 1. Accession and corresponding *Rhizobium* strain which produced the highest shoot and nodule dry weight, nitrogen fixed per plant and the ratio N_2 fixed/nodule dry weight.

Species	Accession code	Shoot dry weight (g/plant)	Nodule dry weight (g/plant)	N_2 fixed/plant (mg/plant)	N_2 fixed/nodule dry weight
L. magnifica	19/84	**LDK4**	**LDK4**	**LDK4**	TAL52
L. salvadorensis	36/88	CB3060	CCK13	CB3060	CB3060
L. trichodes	61/88	TAL582	PJ12	CCR10	TAL582
L. pulverulenta	83/87	TAL582	**LDK4**	TAL582	TAL582
L. multicapitula	81/87	**LDK4**	**LDK4**	**LDK4**	**CCK13**
L. macrophylla subsp. *nelsonii*	47/85	**LDK4**	PJ12	**LDK4**	**CCK13**
L. leucocephala	79/02348	**LDK4**	**LDK4**	**LDK4**	**CCK13**
L. lempirana	6/91	**LDK4**	**LDK4**	**LDK4**	**CCK13**
L. lanceolata	43/85	**LDK4**	**LDK4**	**LDK4**	**CCK13**
L. pallida	52/87	**LDK4**	CB3138	**LDK4**	**CCK13**
L. esculenta	47/87	CB3060	**LDK4**	CB3060	**CCK13**
L. trichandra	53/88	CCR10	**LDK4**	CCR10	**CCK13**
L. diversifolia	83/92	CB3060	**LDK4**	CB3060	TAL582
L. collinsii subsp. *collinsii*	52/88	**LDK4**	**LDK4**	**LDK4**	CCR10
Best strain		**LDK4** (57%)	**LDK4** (71%)	**LDK4** (57%)	**CCK13** (57%)

Table 2. The origin of the seven *Rhizobium* strains used.

Strain	Original host	Reference
CCK13	*Calliandra calothyrsus*	Lesueur et al. 1996
CCR10	*Calliandra calothyrsus*	Lesueur et al. 1996
LDK4	*Leucaena diversifolia*	
CB3060	*Leucaena diversifolia*	Halliday and Somasegaran 1984
TAL582	*Leucaena leucocephala*	Halliday and Somasegaran 1984
CB3138	*Leucaena leucocephala*	R.A. Date pers. comm.
PJ12	*Prosopis juliflora*	Diagne 1988

harvested 12 weeks after planting. Data were subjected to a three-way analysis of variance and means were compared with the Fisher multi-range test.

Results

Identification of the more effective *Rhizobium* strains

The highest values of shoot and nodule dry weight, and shoot total nitrogen content were obtained mainly with plants inoculated with strain LDK4. Among the seven *Rhizobium* strains tested, this strain was the most effective with the 14 *Leucaena* species (Table 1).

Although results obtained with strain CB3060 (also known as TAL 1145), which is usually used for the inoculation of *L. leucocephala* in field conditions, were significantly lower than those obtained with strain LDK4, strain CB3060 also produced a higher shoot total nitrogen content (data not shown) compared to the control and the other strains tested.

In terms of N_2 fixed/nodule dry weight, the highest values were obtained in plants inoculated with strain CCK13 isolated from *C. calothyrsus*. This parameter indicates the efficiency of nodules. The CCK13 strain formed very efficient nodules which were capable of fixing a high quantity of atmospheric nitrogen with eight of the 14 *Leucaena* species.

However, the disadvantage of this strain is that it forms a low number of nodules on the root system (average of 35 mg of nodule dry weight per plant compared to 69 mg per plant in the case of LDK4 strain; data not shown). Thus this strain is not really well adapted for inoculation of *Leucaena* in field conditions in soils where competition with indigenous *Rhizobium* strains could be important.

A preliminary experiment carried out in Sénégal showed that the growth of *L. leucocephala* seedlings cultivated in unsterilised soil in a village nursery and inoculated with the strain LDK4 was two or three times higher than growth of uninoculated plants cultivated in the same conditions (Sougoufara and Lesueur, unpubl. data). This indicates that the effectiveness of strain LDK4 in the nursery could also apply in field conditions.

Rhizobium strains × *Leucaena* species interaction

Statistical analysis showed highly significant effects for *Leucaena* species, *Rhizobium* strains and the species × strain interaction for all variables analysed.

This demonstrates that variation in growth, nodulation and nitrogen fixation among *Leucaena* species could be the result of the *Rhizobium* strain × *Leucaena* species interaction.

Performance of *Leucaena* species in symbiosis with *Rhizobium*

The results presented in Table 3 suggest that it may be possible to divide the 14 *Leucaena* taxa into three groups according to their growth, nodulation and nitrogen-fixing potential.

The first group of species (*L. trichodes, L. macrophylla* subsp. *nelsonii, L. leucocephala, L. magnifica* and *L. pallida*) produced high biomass, had good nodulation and formed very efficient nodules with *Rhizobium*.

The second group (*L. esculenta, L. lempirana, L. trichandra, L. diversifolia* and *L. collinsii* subsp. *collinsii*) is designated as intermediate.

The third group (*L. lanceolata, L. pulverulenta, L. salvadorensis* and *L. multicapitula*) demonstrated low potential in terms of shoot production and nitrogen fixation.

These results should be viewed in association with other agroforestry parameters such as forage quality (especially tannin content), seed production, behaviour with nematodes, and adaptability to limiting soil factors before species are chosen for field testing.

Field trials in tropical countries should use a combination of highly effective *Rhizobium* strains (LDK4 and CB3060) and concentrate on the better performing *Leucaena* species (first group of species) in order to identify the best symbiotic association for forage production.

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Table 3. Shoot and nodule dry weight, nitrogen fixed per plant and the ratio N_2 fixed/nodule dry weight of seedlings of *Leucaena* species inoculated with seven *Rhizobium* strains, averaged over all strains. For each variable, means in the same column followed by the same letter are not significantly different according to the Fisher test (P>0.05).

Species	Accession code	Shoot dry weight (g/plant)	Nodule dry weight (mg/plant)	N_2 fixed/plant (mg/plant)	N_2 fixed/nodule dry weight
L. magnifica	19/84	1.11f	40cd	220f	5.2g
L. salvadorensis	36/88	0.59ab	24a	88ab	3.1bc
L. trichodes	61/88	1.79h	58e	348g	5.5g
L. pulverulenta	83/87	0.45a	25a	55a	2.1a
L. multicapitula	81/87	0.65abc	36bcd	109abc	2.7ab
L. macrophylla subsp. *nelsonii*	47/85	1.12f	35bcd	189def	5.0fg
L. leucocephala	79/02348	1.48g	64e	200ef	3.1bc
L. lempirana	6/91	0.74bcd	30ab	137bcde	4.0de
L. lanceolata	43/85	1.03ef	33abc	124abcd	3.7cd
L. pallida	52/87	1.56gh	43d	220f	5.7g
L. esculenta	47/87	0.92def	36bcd	131bcde	3.6cd
L. trichandra	53/88	0.89cdef	40cd	155bcdef	4.3ef
L. diversifolia	83/92	0.83bcde	40cd	160cdef	3.5cd
L. collinsii subsp. *collinsii*	52/88	0.92def	44d	157bcdef	3.5bcd

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Cold tolerance

Selection and Agronomic Characterisation of *Leucaena* Genotypes for Cold Tolerance

M.C. Goldfarb and J.F. Casco

Abstract

Fifty-six accessions of *Leucaena* species and hybrids were evaluated in order to identify those with tolerance to low temperature and with desirable characteristics as a forage crop. Selection was done in two phases. In phase 1, 2800 seedlings (92 days old) were subjected to one of two temperature treatments (–8 °C and –3 °C) for 14 hours. Plants that had 50% of live leaves remaining after the cold treatment were selected for further evaluation. One plant was selected from the –8 °C treatment and 16 from the –3 °C. In phase 2, 17 plants from 11 different biotypes were planted in the field and agronomic characteristics were measured. Only one plant maintained live stem and meristematic tissue after a –8.8 °C freeze occurrence, but several selections showed good agronomic adaptation and greater chilling tolerance.

LEUCAENA *leucocephala* has great potential for animal production in the humid subtropical area of Argentina. At Corrientes, beef production of 150 kg/ha/year (Gándara and Casco 1993) has been obtained with a mixed pasture of *L. leucocephala* and pangola grass, which doubled the production of 45–70 kg/ha/year obtained on range pasture.

At Corrientes weather conditions (mainly temperature and rainfall) are favourable for the rapid growth of *L. leucocephala* during most of the year. However, frosts of different intensities limit the growth of *L. leucocephala* during winter, but plants are generally not killed. An improvement of *L. leucocephala* forage production during the winter period could lead to an increase of beef production under grazing.

The purpose of this study was to evaluate 56 biotypes of *Leucaena* species and hybrids in order to identify those with cold tolerance and with desirable agronomic characteristics as a forage crop.

Materials and Methods

Fifty-six *Leucaena* biotypes were planted in pots with 1.5 kg of soil in July 1990. Selection was carried out in two phases. In phase 1, 92 day old seedlings (n= 1400 per treatment) were exposed during a 14-hour period in a growth chamber to one of two temperature treatments –8 °C (T1) and –3 °C (T2). Humidity was held constant at 90%. A seedling was selected as cold tolerant if 50% of live leaves remained after the cold treatment was applied (Goldfarb 1992).

In phase 2, plants selected in phase 1 were transplanted with an average age of seven months to field conditions on a Molisol soil. Phenology and standing crop dry matter (SCDM) were measured over three years. SCDM cuts were carried out during the winter and summer of the first year of field evaluation and in the spring, summer and fall of the second year of field evaluation. SCDM yield was composed of leaves, stems up to 5 mm diameter and green pods.

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Results and Discussion

Phase 1

From the 2800 plants exposed to temperature stress, seventeen plants were selected from eleven different biotypes. Only one plant (plant 11, *L. leucocephala* × *L. diversifolia* SF 9043) survived T1. Sixteen plants were selected from T2 (Table 1).

Phase II

The significant variables measured in the field conditions and their results were:

Cold Tolerance: Plant 17, *L. leucocephala* K 72 SF 8073, was the most tolerant of field conditions during the winter of 1991, 1992 and 1993. During

Table 1. Details of the 17 plants selected for cold tolerance and their dry matter production in the field.

Plant	Origin		Dry matter production (g/plant)		
			1991/92	1992/93	1993/94
1	*L. leucocephala* × *L. diversifolia*	SF 9036	31	19	3
2	*L. leucocephala*	SF 9033	309	383	137
3	*L. pulverulenta*	SF 8696	121	131	54
4	*L. leucocephala* × *L. diversifolia*	SF 9071	171	101	51
5	*L. leucocephala* × *L. diversifolia*	SF 9067	410	793	207
6	*L. leucocephala* × *L. diversifolia*	SF 9071	126	136	36
7	*L. pulverulenta* Sel 22	SF 8696	220	164	52
8	*L. leucocephala* × *L. diversifolia*	SF 9071	250	271	90
9	*L. leucocephala* cv. Cunningham	SF 8612	268	287	83
10	*L. leucocephala* × *L. diversifolia*	SF 9031	298	419	146
11	*L. leucocephala* × *L. diversifolia*	SF 9043	155	191	56
12	*L. leucocephala* × *L. diversifolia*	SF 9050	28	55	10
13	*L. leucocephala* K72	SF 8073	259	299	93
14	*L. leucocephala* × *L. diversifolia*	SF 9050	122	71	16
15	*L. leucocephala* cv. Peru	SF 8635	158	380	106
16	*L. leucocephala* × *L. diversifolia*	SF 9069	153	250	87
17	*L. leucocephala* K72	SF 8073	234	207	70

1992 and 1993 (mild winters) this plant maintained between 40% and 70% of live leaves. In the winter of 1991, the most severe historical freeze occurred (–8.8 °C at soil level). At that stage, cold tolerance was assessed by observing stems and buds, since leaves were totally killed.

Height: Plant 2 was the highest (260 cm) and plant 12 the smallest (60 cm).

Diameter: Plant 17 showed the greatest diameter (3 cm) at 143 days after planting.

Seed production: Eight plants (Nos. 1, 2, 5, 10, 11, 12, 14 and 15) did not produce seed. Three plants were characterised by their high seed production from the first year of evaluation: plant 6 (79 g/plant), plant 3 (20 g/plant) and plant 16 (18 g/plant).

Dry matter yield: Dry matter yield of the 17 selected biotypes is presented in Table 1. Plant 5 was the most productive, with plants 2, 8, 9, 10, 11, 13 and 15 also growing well.

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Frost Tolerance of *Leucaena* spp. in Subtropical Australia

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Abstract

The frost tolerance of lesser-known *Leucaena* spp. was compared to that of commercial cultivars of *L. leucocephala* subsp. *glabrata* in subtropical Australia. Despite originating in high altitude environments, accessions of *L. diversifolia*, *L. pallida* and *L. trichandra* were not as frost tolerant as *L. leucocephala* subsp. *glabrata* cv. Cunningham and cv. Tarramba. The KX2 hybrid and *L. collinsii* subsp. *collinsii* were the least frost tolerant of the accessions evaluated.

LEUCAENA *leucocephala* plays an important role in animal production systems in the tropics as a forage protein supplement to low quality roughage diets during the dry/cool season. However, *L. leucocephala* has been reported to be poorly adapted to cool environments and susceptible to frost damage (Brewbaker 1982). Frost damage to *L. leucocephala* causes leaf shedding and stem death (dieback) resulting in a shortage of leucaena forage during winter, when leguminous browse is most needed to supplement ruminant diets. Cooksley et al. (1988) observed that only 20% of annual leaf production remained on *L. leucocephala* stands following frosting or very dry winter periods in subtropical southeast Queensland. However, these authors noted that leaf N was not lost from the grazing system but was retained through the increased productivity of inter-row pasture grasses.

Perceived susceptibility to frost damage is a major limitation to the adoption of *L. leucocephala* in high altitude tropical, and subtropical areas (Lesleighter and Shelton 1986). Many lesser-known *Leucaena* spp. originate from high altitude (1000–2500 m) environments (Hughes 1993; Bray et al. 1997) and may have frost tolerance (Brewbaker 1982). Stem survival and leaf retention could confer a considerable yield advantage over frost susceptible genotypes and provide high quality forage during the winter feed gap.

The frost tolerance in the establishment year of agronomically desirable lesser-known *Leucaena* spp. was evaluated in subtropical Australia and compared to that of commercial cultivars of *L. leucocephala* subsp. *glabrata*.

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Material and Methods

Site description

The experiment was conducted 25 km west of Dalby (27°12'S, 151°00'E), southeast Queensland, altitude 340 m. The site receives an average annual rainfall of 640 mm and experiences mean monthly maximum/minimum temperatures of 32/18 °C in January and 19/4 °C in July. Extreme minimum screen temperatures recorded for the Dalby district are –6 °C, –4 °C and –3 °C in June, July and August respectively, and the site receives an average of 30 frost days annually. An experimental site was selected where three common soil types were found within close proximity (100 m) of each other, in order to minimise microclimatic differences in frost intensity. These soil types were an alfisol (a hardsetting texture contrast soil), an entisol (a deep loamy sand) and a vertisol (a black earth). Weeds were removed by cultivation prior to planting.

Experimental design

The experimental design was a randomised complete block design (RCBD), with nine *Leucaena* accessions as treatments in three blocks. The blocks were spaced 4 m apart and treatments (individual trees of each accession) were spaced 2 m apart within blocks. The RCBD was replicated on each of the three soil types. The data of all 3 RCBD were analysed in a combined analysis of variance.

Plant material

Seven *Leucaena* accessions that were agronomically superior in frost-free areas of southeast Queensland and two commercial cultivars were selected for evaluation. The latitude and altitude (Bray et al. 1997) of the collection site of these accessions are presented in Table 1. Other species renown for frost tolerance, such as *L. greggii* and *L. retusa* (Hughes 1993), were excluded due to poor agronomic performance. Seedlings of all accessions were grown in plastic propagating tubes for 10 weeks in a glasshouse at the University of Queensland, St. Lucia, prior to field planting. The exception was the KX2 hybrid, which was sown in August 1995. These plants were pruned to 30 cm and regrown as above. All seedlings were inoculated with *Rhizobium* strain CB3060 three weeks before transplanting.

Establishment and management

The seedlings were transplanted on 28 September 1996, to avoid premature frosting, into a full profile of soil moisture. The plants were placed in 30 cm deep holes and then watered to promote soil-root contact and minimise the risk of dehydration. Wire tree-guards were placed around each seedling to protect them from wildlife predation and the experimental site was conventionally fenced to exclude livestock. Weeds were controlled during the experiment by inter-row cultivation and manual chipping.

Observations and measurements

The incidence and severity (minimum screen temperature) of frosts were recorded 2 km from the site. A frost damage rating (FDR) scale of 1–5 was developed to assess the proportion of defoliation caused by frost damage (1: no foliar damage; 2: 1%–25% defoliation; 3: 25%–50% defoliation; 4: 50%–75% defoliation; 5: 75%–100% defoliation). Stem death observations (>80% of stem dead) were made on all plants that experienced 100% defoliation. Frost damage ratings and plant survival were recorded on 30 August 1997 at the end of winter.

Results and Discussion

Frost incidence and severity

During the winter of 1997, only 10 frost days occurred at the trial site. However, these frosts were historically severe for the location reaching –3 °C, with an average screen temperature of –2 °C.

Frost tolerance

Frost damage ratings for the establishment year are presented in Table 2. Plants growing on the vertisol soil were more severely frosted (P<0.01) than those growing on the entisol and alfisol soils (Table 2). This difference between soil types could be attributed to microclimatic effects, despite their close proximity, and to different soil heat conductivity and heat radiance characteristics. There was no interaction between accessions and soil types in the response to frosting.

Both accessions of *L. leucocephala* subsp. *glabrata* were more frost tolerant, averaged over all soil types, than most other accessions (P<0.05). On the less frosted sites (entisol and alfisol), the commercial *L. leucocephala* cultivars retained more leaf than the other accessions. Under severe frost conditions (vertisol site), all *L. leucocephala* stems survived, even retaining >25% of their leaf, while

Table 1. *Leucaena* accessions evaluated and the latitude and altitude (m asl) of their collection site*.

Species	Accession ID.	Latitude	Altitude (m)
L. collinsii subsp. *collinsii*	OFI 52/88	16°36′ N	475
L. diversifolia	K784	18°52′ N	1175
L. leucocephala subsp. *glabrata*	cv. Cunningham	(Bred variety)	
L. leucocephala subsp. *glabrata*	cv. Tarramba	25°25′ N	1575
L. pallida	CQ3439	(Composite)	
L. pallida	K376	17°08′ N	1675
L. pallida × *L. leucocephala* subsp. *glabrata* (KX2)	(K748 × K806) × K636	(Hybrid)	
L. trichandra	CPI46568	—	—
L. trichandra	OFI 53/88	14°49′ N	1450
KX2 *L. pallida* parents	K748	—	—
	K806	18°37′ N	2000

* Bray et al. (1997)

Table 2. Frost damage ratings of *Leucaena* accessions during the first year of establishment.

Accession	Frost damage rating			
	Alfisol	Entisol	Vertisol	Accession mean
L. leucocephala cv. Cunningham	2.7	2.0	4.0	2.9 a#
L. leucocephala cv. Tarramba	2.0	2.0	4.7	2.9 a
L. diversifolia K784	2.7	2.5	5.0†	3.4 ab
L. trichandra OFI 53/88	2.7	2.8	5.0†	3.5 ab
L. trichandra CPI 46568	3.0	3.8	5.0†	3.9 bc
L. pallida CQ3439	3.3	3.7	5.0†	4.0 bc
L. pallida K376	3.5	3.7†	5.0†	4.1 bc
L. collinsii OFI 52/88	3.5	4.3	5.0†	4.3 c
KX2 hybrid	4.3†	4.0†	5.0†	4.4 c
Site mean	3.1 a*	3.2 a	4.9 b	

* Site means followed by different letters are significantly different (P<0.01).
\# Accession means followed by different letters are significantly different (P<0.05).
† Stem death observed.

100% of the stems of the other accessions were killed to ground level. Glumac et al. (1987) also observed significant frost tolerance of established hedgerows of *L. leucocephala* which suffered moderate defoliation (25%–75% of leaf) at –5 °C, stem dieback at temperatures below –7 °C and 80% rootstock survival after 169 h of continuous subzero temperatures, which reached –12 °C.

Despite originating from high altitude environments, the *L. diversifolia*, *L. pallida* and *L. trichandra* accessions evaluated were not frost tolerant (Table 2). These species shed large amounts of leaf on the mildly frosted soil types and the stems of all plants were killed on the vertisol site. Similarly, Williams (1987) observed that *L. diversifolia* was no more frost tolerant at –4 °C than *L. leucocephala* in Florida. *L. collinsii* subsp. *collinsii*, which originates from low altitudes, was also susceptible to frost damage in subtropical Queensland (Table 2).

The vigorous KX2 hybrid (Mullen, Shelton et al., these Proceedings) was the least frost tolerant accession evaluated (Table 2). The large stems (mean length 1.5 m and diameter 1.3 cm) of the hybrid were killed to ground level even on the mildly frosted alfisol site, even though one of the *L. pallida* parents (K806) originates from 2000 m asl.

Gutteridge and Sorrenson (1992) reported that a KX3 (*L. diversifolia* × *L. leucocephala*) hybrid was extremely frost resistant to temperatures of approximately –10 °C, suffering minimal vegetative damage. Differences between the frost tolerance of the KX2 and this KX3 hybrid could be attributed to genetic differences between the *L. diversifolia* (CPI 33820) and *L. pallida* (K806xK748) parents.

Conversely, Williams (1987) found that the frost resistance of a different KX3 hybrid was no better than *L. leucocephala*, highlighting the genetic diversity of frost tolerance within *Leucaena* interspecific hybrids.

The data presented here only represent the frost tolerance of seedlings (9-months-old). Stem survival and leaf retention of mature hedgerows of *Leucaena* spp. may be considerably different.

However the frost tolerance exhibited by *L. leucocephala* seedlings would be of considerable advantage in improving the success of establishment in subtropical, frost prone areas. This is important in the context of the high failure rate of commercial leucaena plantings and the negative effects such failures have on *L. leucocephala* adoption (Lesleighter and Shelton 1986).

It is also significant that the data has shown the feasibility of large-scale plantings of leucaena in frost prone areas such as the Darling Downs in southern Queensland. While leaf loss may occur in winter, there is clearly an opportunity to promote the use of leucaena as a summer forage.

Plant survival

There was no significant difference in accession mortality, as all *Leucaena* spp. survived frost damage on all sites, with the exception of a single *L. collinsii* subsp. *collinsii* plant on the heavily frosted vertisol site.

Plants suffering stem death recovered by reshooting from the stem base. Rate of regrowth in spring will be an important characteristic for selecting *Leucaena* accessions for frost prone environments.

Conclusion

None of the *Leucaena* accessions tested was resistant to frost. *L. leucocephala* subsp. *glabrata* was the most frost tolerant of the taxa evaluated, with stems surviving severe frost and retaining >25% leaf. The stems (<1.5 m) of all other accessions were killed to ground level by severe frost.

All *Leucaena* spp. survived the frost, reshooting vigorously from the stem base. *L. diversifolia*, *L. pallida*, *L. trichandra* and the KX2 hybrid are genetically diverse taxa and require further more comprehensive screening for frost tolerance.

Further research should investigate the effects of frost frequency, duration, severity and frost interactions with stage of plant development and plant density, on the leaf retention and stem survival of *L. leucocephala* subsp. *glabrata*.

Acknowledgments

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Soil improvement

Improvement of Soil Properties under Long-Term *Leucaena leucocephala*

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Abstract

This paper briefly discusses improvements in soil physical, chemical and biological properties brought about by long-term (9, 12, and 21-year) growth of *Leucaena leucocephala*. Soil properties such as bulk density, infiltration rate, pH, and contents of nitrogen, potassium, organic matter, zinc, iron and boron were improved in soil under *L. leucocephala*. Respiration rate, microbial biomass C, N, and P, and earthworm populations were also higher in soil under *L. leucocephala*.

THE maintenance of soil fertility, and therefore of crop productivity, is crucial to the development of sustainable agriculture. Modern agricultural systems depend heavily on large inputs of chemical fertilisers for maintenance of crop productivity. However, environmentally friendly systems based on the use of nitrogen-fixing trees such as *Leucaena leucocephala* have been reported to bring about favourable changes to soil properties by promoting soil conservation, reducing soil degradation and achieving sustainable production (Ingram 1990).

This is an important step towards sustainable agriculture that can maintain productivity over a long period of time without depleting renewable resources. *L. leucocephala* was used for shade and soil improvement in Java as early as 1900 (Dijkman 1950). It can grow in humid, subhumid or even in the marginal semi-arid zones. According to Young (1991), the exceptional ability of *L. leucocephala* in improving soil fertility is due to its high biomass production, high nitrogen fixation, and substantial amounts of nitrogen, phosphorus, potassium and calcium in the leaves.

In Mauritius, *L. leucocephala* was introduced in 1967 (Osman 1979). Research on *L. leucocephala* as firewood and fodder, as well as spacing and variety trials, started as early as 1970 at the University of Mauritius. This paper briefly discusses the changes in the physical, chemical and biological properties of soil under long-term (9, 12 and 21-year) *L. leucocephala* on the University farm.

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Materials and Methods

L. leucocephala trees were grown on a low humic latosol (USDA: tropectic haplustox; FAO: humic nitosol) in a humid climate. The soils examined were under 0 (adjoining open field), 9, 12, and 21 years of experimental *L. leucocephala* in which the prunings were removed from the plots. The land was flat and well drained and no crops were cultivated between the rows of *L. leucocephala*.

Soil analyses were conducted following the techniques of Anderson and Ingram (1993). Ammonium and nitrate ions were determined by selective ion electrodes. Micronutrient determinations were performed in accordance with methods outlined in Sillaanpaa (1990).

Results and Discussion

Table 1 illustrates the physical properties of the soil under *L. leucocephala* and in the open field. The bulk densities were lower (818, 826, and 812 kg/m^3) under *L. leucocephala* compared to the open field (916 kg/m^3). This difference was probably due to the higher percentage of organic matter in the *L. leucocephala* soil (Table 2). However, the particle density was lower in the open field than under *L. leucocephala*.

The porosities of the soils were slightly different, the reason being that in the open field the soil has been continually cultivated through ploughing,

Table 1. Physical properties of soil under *L. leucocephala* and in an open field. (Where significant differences exist, means within a column followed by the same letter are not significantly different at P = 0.05).

Site / Years under *L. leucocephala*	Bulk density kg/m³	Particle density kg/m³	Porosity %	Infiltration rate cm/min	Penetrometer resistance kg/cm²	Particle size Sand (%)	Silt (%)	Clay (%)
0	916 a	2552 b	64.1 b	0.60 d	3.15 a	41.8	26.6	31.6
9	818 bc	2663 a	69.2 a	0.88 c	2.69 b	41.9	25.8	32.3
12	826 b	2698 a	68.7 a	1.50 b	2.52 c	42.1	26.2	31.7
21	812 c	2668 a	69.5 a	1.66 a	2.34 d	40.9	26.7	32.4

Table 2. Soil nutrient status under *L. leucocephala* and in an open field. (Where significant differences exist, means within a column followed by the same letter are not significantly different at P = 0.05).

Years under *L. leucocephala*	pH	Total N %	Available P %	Available K %	Organic matter %	NH_4^+ ppm	NO_3^- ppm
0	4.93 c	0.23 c	11.0	138 d	2.62 d	102.2	40.0 c
9	5.85 b	0.35 ab	12.0	304 c	3.50 c	108.4	62.0 b
12	6.80 a	0.33 b	11.6	368 b	3.77 b	98.5	56.8 b
21	6.95 a	0.38 a	10.0	424 a	4.56 a	104.8	71.8 a

forking and disc harrowing. It is also known that soils under *L. leucocephala* have good aggregate structure and a large percentage of macropores (Young 1991).

The infiltration rate was higher in the soils under *L. leucocephala*, again probably due to the larger number of macropores. Penetrometer readings were much higher in the open field than in the *L. leucocephala* soil, demonstrating the deleterious effects of intensive cultivation. The dry soil colour was not different in the various fields (Table 1). Results of particle size determination also showed no differences.

Table 2 shows the nutrient status of soils in the open field and under *L. leucocephala* cultivation. The pH was higher (5.85–6.95) under *L. leucocephala* than in the open field (4.93). Total nitrogen of the *L. leucocephala* soil ranged between 0.33% and 0.38%, compared to 0.23% in the open field. This substantial increase of 65% in total nitrogen corroborates the efficient nitrogen-fixing ability of *L. leucocephala*.

The available phosphorus was, however, not significantly different among the various treatments. The oxisols, having good phosphorus-fixing properties, may have been responsible for locking phosphorus released from *L. leucocephala* leaves and litter. The available potassium in the soil increased from an average of 138 ppm in the open field to 424 ppm under 21-year *L. leucocephala*, an increase of more than 200%. Similarly, an increase of 74% in organic matter was observed in the *L. leucocephala* soil. Ammonium nitrogen and nitrate nitrogen did not differ significantly in the different soils, probably due to the high mobility of these ions in soil.

Micronutrient levels in the soils are shown in Table 3. The only differences were in zinc, iron and boron contents. For boron, an increase of 135% was observed in the 21-year *L. leucocephala* soil compared to the open field.

Among the biological properties of the soils, respiration rate, percentage biomass C, biomass N and biomass P were all higher in *L. leucocephala* soil than in the open field (Table 4). The higher concentration of organic matter and its comparatively easy decomposition under *L. leucocephala* may explain these observations. Earthworm population, which is another index of soil fertility, was significantly higher in soils under *L. leucocephala*.

The above results confirm the beneficial effects of *L. leucocephala* (Kang et al. 1985). It can also be concluded that the longer the *L. leucocephala* trees are in the soil, the better the soil is in terms of its chemical, physical and biological properties.

The limitation to *L. leucocephala* in Mauritius and in many parts of the world (Young 1991) appears to be the *L. leucocephala* psyllid (*Heteropsylla cubana*). The authors are presently studying the effects of *L. diversifolia*, which has been observed to be resistant to the psyllid, on soil properties.

Table 3. Soil micronutrient status under *L. leucocephala* and in an open field. (Where significant differences exist, means within a column followed by the same letter are not significantly different at P = 0.05).

Years under *L. leucocephala*	Cu (ppm)	Zn (ppm)	Mn (%)	Fe (%)	B (ppm)
0	15.6	26.0 b	0.42	0.17 a	0.85 c
9	19.4	28.6 b	0.40	0.13 b	1.67 b
12	19.4	30.8 b	0.40	0.11 b	1.80 ab
21	19.8	42.4 a	0.40	0.12 b	2.00 a

Table 4. Biological properties of soil under *L. leucocephala* and in an open field. (Where significant differences exist, means within a column followed by the same letter are not significantly different at P = 0.05).

Years under *L. leucocephala*	Respiration rate × 10^{-9} g/g/s*	Earthworm population per m^2 at 30 cm depth	Microbial biomass C (%)	Microbial biomass N (%)	Microbial biomass × 10^{-5} P (%)
0	1.37 c	123 c	0.018 d	0.041 d	6.8 c
9	1.84 b	144 bc	0.040 c	0.140 c	9.6 bc
12	2.43 a	178 b	0.054 b	0.255 b	12.8 b
21	2.50 a	268 a	0.063 a	0.352 a	16.8 a

* g/g/s = grams CO_2 per gram air dried soil per second.

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Leucaena leucocephala and *Calliandra calothyrsus* for Soil Productivity Improvement in Sub-Humid Highlands of Kenya

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Abstract

The feasibility of integrating *Leucaena leucocephala* and *Calliandra calothyrsus* into a maize production system for soil productivity enhancement was investigated in the sub-humid highlands of central Kenya for seven cropping seasons during the period 1993 to 1996. The experiment consisted of four hedgerow intercropping and six sole maize (*Zea mays*) crop treatments. In six of these treatments, fresh leaf prunings of tree species (*L. leucocephala* and *C. calothyrsus*) were applied, the prunings being obtained from hedgerows grown *in situ* (intercropped) or ex situ (cut and carry) from other sources. There were no significant differences in maize grain yield during the 1993 long and short rainy seasons. During the 1994 long rains, although there was an attack on maize seedlings by chaffer grubs (*Cyclocephala* spp.), fertilised treatments significantly ($p<0.05$) out-yielded all other treatments in terms of maize grain yield. The decrease in yield in the non-fertiliser plots was attributed to low soil fertility status caused by greater nutrient removal than could be replenished via pruning applications due to low shrub biomass productivity. During subsequent seasons, when fertiliser P (triple superphospate) supplementation was carried out in all plots, mean yields averaged over four seasons showed that intercropped treatments with *L. leucocephala* produced higher yields than fertilised sole maize treatments without prunings application. *C. calothyrsus* was found to be more competitive than *L. leucocephala* with the maize crop.

IN THE central highlands of Kenya, soil productivity has been declining because of nutrient mining in intensively cultivated fields and soil erosion on steep slopes. This has resulted from increased population pressure with figures of 400–800 persons per km^2. Land holdings are very small, ranging from 0.1 to 4.0 ha with an average of 1.5 ha, and land is intensively cultivated with two crops every year (Minae and Nyamai 1988). Soil nitrogen and phosphorus have become major limiting nutrients for crop productivity. Fertilisers are expensive for small-scale farmers, and applications are usually below recommended rates. On-farm manure production is not sufficient to replace nutrients removed as crop products (Kihanda 1996).

Leguminous shrubs can either be incorporated into the farming systems by growing a linear arrangement of tree species in situ as in hedgerow intercropping (HI) systems or by an ex situ cut and carry system. In HI systems, trees are lopped at the beginning of, and sometimes during, the growing season. Leafy prunings are incorporated into the soil with the aim of providing nutrients to the adjacent crops. In the cut and carry system, niches for growing leguminous shrubs are utilised and leafy prunings obtained from these shrubs can subsequently be carried to cropped areas. Despite these potentials, the use of green manure by farmers in the coffee-based land use system has been minimal (Murithi et al. 1993). Results from HI work carried out elsewhere have been variable depending on site conditions (Ong 1994; Kang 1993), but little work has been carried out in the Kenyan central highlands. The aim of this study was, therefore, to evaluate the feasibility of using leaf prunings of *L. leucocephala* and *C. calothyrsus* for soil productivity improvement in both HI and sole cropping systems.

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Materials and Methods

The experiment was conducted at Embu (0° 30'S, 37° 27'E) in the central highlands of Kenya at an altitude of 1490 m. The common soils are humic nitisols (FAO-UNESCO 1977) derived from basic volcanic rocks. Total annual rainfall of 1252, 1600, 1417 and 908 mm was received in a bimodal manner during 1993 through 1996, respectively.

The test crop was maize (*Zea mays*), Hybrid 511. The experiment was a randomised complete block design with 10 treatments replicated four times. Plots were 10 × 6 m with two rows of shrubs 4.5 m apart in the HI treatments. Maize was planted at 75 × 25 cm in all plots, with 6 rows between hedges. Experimental treatments are shown in Table 1.

Results

Although there were no significant differences (p = 0.05) in maize grain yield during 1993 long rains (LR), treatments where leaf prunings were incorporated into the soil had higher maize grain yield than those in which leaf prunings were not incorporated.

During 1993 short rains (SR) the maize grain yield was significantly higher in non-HI treatments than in HI treatments. The maize grain yield for 1994 LR (Table 2) was generally low due to a serious attack by chaffer grubs (*Cyclocephala* sp.) during germination and a possible P deficiency. A blanket application of 50 kg P/ha was, therefore, applied to all treatments during subsequent seasons. Fertilised treatments, i.e., 7, 8 and 9 had significantly higher yields than all other treatments ($P<0.05$) in 1994 LR.

From the 1994 SR and through the following seasons (Table 2), sole cropped treatments that received ex situ applied prunings without or with fertiliser (Trts 5 and 6, and Trts 7 and 8) generally produced the highest maize grain yields (Table 2). Maize intercropped with leucaena (Trt 2) produced higher yields than both the fertilised, non-intercropped treatment (Trt 9) and the non-intercropped, non-fertilised treatment (Trt 10), the absolute control. Yield of HI calliandra (Trt 1) did not exceed that of absolute control. The lowest yields were obtained from the HI

Table 1. Treatments (Trt) for a hedgerow intercropping experiment carried out in Embu, Kenya from 1993 through 1996.

Treatment	Cropping system	Tree species	Prunings	Fertiliser (N) kg/ha
1	Intercrop	*C. calothyrsus*	Incorporated	0
2	Intercrop	*L. leucocephala*	Incorporated	0
3	Intercrop	*C. calothyrsus*	Removed to Trt 5	0
4	Intercrop	*L. leucocephala*	Removed to Trt 6	0
5	Monocrop	*C. calothyrsus*	Imported from Trt 3	0
6	Monocrop	*L. leucocephala*	Imported from Trt 4	0
7	Monocrop	*C. calothyrsus*	Imported at half rate of Trt 5	25
8	Monocrop	*L. leucocephala*	Imported at half rate of Trt 6	25
9	Monocrop	none	none	50
10	Monocrop	none	none	0

Table 2. Mean maize grain yield (t/ha) for 1993–1996 seasons from various treatments in Embu, Kenya. Means followed by the same letter within a column are not significantly different at $P>0.05$. Abbreviations: SR = short rains; LR = long rains.

Trt	LR 93	SR 93	LR 94	SR 94	LR 95	SR 95	LR 96	MeanSR 94 to LR 96
1	2.4 a	0.1 b	0.2 cd	3.2 ab	3.4 b	2.4 e	2.0 c	2.7 d
2	2.2 a	0.2 ab	0.2 d	3.8 a	4.4 a	3.9 bc	3.6 b	3.9 b
3	1.7 a	0.1 b	0.3 cd	1.6 c	1.1 e	1.0 g	1.3 d	1.3 f
4	1.5 a	0.2 ab	0.5 cd	2.7 b	1.8 de	1.7 f	1.5 cd	1.9 e
5	1.9 a	0.6 a	0.3 cd	3.6 ab	4.0 ab	4.9 a	3.8 b	4.1 a
6	1.6 a	0.3 ab	0.9 c	3.3 ab	4.2 a	4.7 ab	3.9 ab	4.1 a
7	2.1 a	0.6 a	2.1 b	3.6 ab	2.2 cd	5.6 a	4.2 a	3.9 b
8	1.8 a	0.3 ab	2.5 ab	3.2 ab	3.1 bc	5.0 a	4.0 ab	3.8 b
9	1.6 a	0.3 ab	3.0 a	3.1 ab	3.1 bc	3.5 c	3.6 b	3.3 c
10	1.4 a	0.2 ab	1.1 c	3.0 ab	4.0 ab	3.5 cd	1.8 c	3.1 c

treatments where leaf prunings were removed and no supplemental fertiliser was applied (Trts 3 and 4).

Discussion

The low tree biomass production, in the range of 1.1 to 3.1 t/ha per season (Table 3), limited the amount of nutrients supplied to the soil via incorporated prunings. Consequently, soil-incorporated prunings did not contribute sufficient amounts of nutrients to compensate for nutrients lost through crop harvests. As a result, nutrient deficiencies, especially N and P, occurred and led to declining crop yields especially during the first phase of this experiment. Indeed, during 1994 long rains, the highest yields were obtained from treatments which had fertiliser applied. Since nutrients are availed to crops by prunings (green manure) harvested from the hedgerows, this technology is likely to be limited by low biomass production in sub-humid and semi-arid environments.

The poor performance of HI treatments (both *L. leucocephala* and *C. calothyrsus*) in terms of crop yields during the first phase of this experiment may be attributed to competition between the tree hedges with the crop for the same growth resources, mainly light, nutrients and water. The competitiveness of *C. calothyrsus* tree hedges compared with *L. leucocephala* may be explained by the root morphology of the two species. *C. calothyrsus* trees develop a strong superficial root system in addition to the taproot (NAS 1993) whereas *L. leucocephala* has a deep tap-root system and develops very few lateral roots which usually grow downwards at a sharp angle (NAS 1977).

The amount of P supplied to the soil via the soil-incorporated leaf prunings was low (Table 3). These results agree with the findings of Palm (1995) who, from a detailed analysis of P contribution by leguminous agroforestry tree species, concluded that the tree species were not able to supply sufficient P to meet crop demands. As such, supplementation of P through the use of fertilisers was recommended. The site had fairly uniform soil fertility at the beginning of the season, but after four years of study a general decline in the soil nutrient levels was observed, with the greatest decline occurring in the treatments that did not receive prunings.

Conclusions

Results from this study indicate that in already nutrient deficient soils, especially in terms of P, soil productivity improvement through HI using *L. leucocephala* or *C. calothyrsus* is limited in sub-humid environments. Production of biomass from the hedgerows is inadequate and contains insufficient P to meet crop demand. Competition for the same growth resources (light, water and nutrients) between the hedgerow species and the associated crop could also contribute to the unsustainable nature of HI system without supplemental fertiliser applications in this region.

Hedgerow intercropping with *L. leucocephala* is advantageous in the sub-humid highlands of Kenya with supplementation of P through use of inorganic fertilisers. However inclusion of *C. calothyrsus* hedges adversely affected crop yields in the short term. Due to its growing importance as animal fodder within smallholder farms of the central highlands of Kenya and in the reduction of soil erosion on steep slopes, opportunities exist for using *C. calothyrsus*. The advantage of improving soil fertility through recycling nutrients by manure applications should be explored.

The cut and carry treatments, with both *L. leucocephala* and *C. calothyrsus*, maintained maize yield at the same level of production (or even better) as treatments supplemented with recommended levels of inorganic fertilisers. Supplementing prunings with inorganic fertilisers, however, produced even better yields. As such, farmers who can afford limited amounts of inorganic fertilisers should be encouraged to supplement in addition to tree legume prunings.

Table 3. Amount of soil-incorporated prunings (t/ha) and their nutrient contribution (kg/ha) to the soil over the period 1993–1996. Abbreviations: SR = short rains; LR = long rains.

Trt	SR 93	LR 94	SR 94	LR 95	SR 95	LR 96	Mean	Mean N	Mean P
	t/ha							kg/ha	
1	2.2	1.4	2.6	1.1	2.3	1.5	1.9	55	1.9
2	1.7	1.2	2.5	2.2	1.3	1.3	1.7	54	3.6
5	2.3	1.3	2.3	1.5	3.1	2.3	2.1	61	2.1
6	2.3	1.2	2.6	2.4	1.9	2.1	2.1	65	4.2
7	2.2	1.3	2.3	1.5	3.1	2.3	2.1	61	2.1
8	2.3	1.2	2.6	2.4	1.9	2.1	2.1	65	4.2

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Propagation

Cloning Ability of *Leucaena* Species and Hybrids

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Abstract

The success of capitalising on interspecific heterosis in trees depends largely on the cloning ability of species. This study was conducted to test cloning ability of *Leucaena* species and hybrids in Hawaii. Thirteen *Leucaena* species, five interspecific hybrids, and one selection KX3 of *L. diversifolia* × *L. leucocephala* were tested. Binodal cuttings were prepared from 4 to 6-week regrowth shoots. The cuttings were dipped into a solution of 1.0% indole-3-butyric acid and 0.5% 1-naphthalenacetic acid, inserted into a medium consisting of half perlite and half vermiculite, and placed under a fine misting system at short intervals with a 30% sunlight reduction. The system also included a bottom-heating mat operated at 35 °C. The rooting percentage of the *Leucaena* species averaged 32% and varied from 0 to 100%. *Leucaena* species with large and medium leaflet size were easier to root than species with small leaflet size. Species with poor rooting ability were *L. collinsii* ssp. *zacapana*, *L. diversifolia*, and *L. pallida*. The rooting percentage of three *L. pallida* × *L. leucocephala* interspecific hybrids averaged 20% and ranged from 10% to 28%. The cloning methods described and the results presented here can be employed to propagate fast-growing *Leucaena* species and hybrids for large-scale plantations, and to produce clonal materials for *Leucaena* tree breeding programs.

LEUCAENA is a small genus under the tribe Mimosoideae, which includes about 22 species that are distributed from southern Texas to northern Peru (Hughes 1998). It has a great number of uses including forage, firewood, timber, green manure, shade, reforestation, and food for human consumption (NAS 1984; Brewbaker 1987).

Leucaena breeding presently focuses on exploiting interspecific heterosis to improve biomass yield, resistance to the leucaena psyllid (*Heteropsylla cubana*), and environmental adaptability (cold temperature and acid soil tolerance). Interspecific crosses among three tetraploid species *L. diversifolia*, *L. leucocephala*, and *L. pallida* were very promising for higher yield, psyllid resistance, and wide adaptability (Brewbaker and Sorensson 1990; Sun 1996; Austin et al. 1997). Brewbaker and Sun (1996) reported that average forage yield of 14 interspecific hybrids of *L. pallida* and *L. leucocephala* over 7 harvests in an 18-month period was 24 t/ha/year. This was four times higher than *L. leucocephala* ssp. *glabrata* in Hawaii under moderate psyllid pressure. Other interesting hybrids include the triploids between the diploids of *L. esculenta*, *L. pulverulenta*, *L. trichandra* and the tetraploid *L. leucocephala* (Gonzalez et al. 1967; Bray 1984; Brewbaker and Sorensson 1990). However, large-scale planting of these hybrids has been limited due to high cost of seed production through hand pollination and unsuccessful cloning.

Prior cloning research using softwood stem cuttings has been confined to *L. leucocephala* (Hu and Liu 1981; Bristow 1983). Sun (1996) developed a simple cloning method having 80% success for softwood cuttings of the triploids between *L. esculenta* and *L. leucocephala* and between *L. trichandra* and *L. leucocephala*. There is an urgent need to test the cloning ability of additional *Leucaena* species, especially those that are self-incompatible, which could be explored for interspecific heterosis and for hybrid seed production.

Materials and Methods

A series of experiments was conducted to test the cloning ability of *Leucaena* species and hybrids at the Hawaii Agriculture Research Center (HARC) Maunawili greenhouse on Oahu from December 1996 to October 1997.

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Thirteen *Leucaena* species, five interspecific hybrids, and one KX3 selection, were studied (Table 1). The cloning test of *Leucaena* species was unduplicated with variable sample size from 10 to 350 (Table 1), but the test of hybrids and selection was duplicated in December 1996 and February 1997. The triploid between *L. esculenta* and *L. leucocephala* (K1000) was used as a check to ensure that cloning conditions were optimal for rooting. Cloning method followed the protocol of Sun (1996) with modification of medium, misting intervals, and sanitation procedures.

Softwood cuttings of the species were taken from 4 to 6-week old regrowth shoots of coppiced seven-year old trees. Cuttings of the hybrids and selections were taken from the regrowth shoots of two-year hedge-managed trees. Binodal cuttings were prepared with one pair of trimmed pinnae. They were dipped into a commercial plant-rooting growth regulator, DIP'N GROW with 1.0% indole-3-butyric acid (IBA) and 0.5% 1-naphthalenacetic acid (NAA) for one second, and then inserted into a medium under a fine misting system with a 30% sunlight reduction. The misting frequency was 5 seconds at 8-minute intervals during the day and 15-minute intervals at night. The medium consisted of half perlite and half vermiculite. Fifty-hole plastic seedling trays were used to hold cuttings. Finally, trays with cuttings and media were drenched with fungicide (Dithane M45). After three weeks, cuttings were evaluated for rooting and transplanted into 4-inch pots.

The mean monthly temperature of the greenhouse ranged from 21 °C to 26 °C, daylight ranged from 11 to 13 hours, and mean monthly solar radiation ranged from 180 to 300 cal/m^2/day.

Results

Leucaena species and interspecific hybrids showed great differences of rooting ability (Table 1).

Table 1. Percentage of cuttings rooted among *Leucaena* species, interspecific hybrids, and selections, all cuttings having one pair of trimmed pinnae treated with a solution of 1.0% IBA and 0.5% NAA under a fine interval misting system with a 30% sunlight reduction at HARC Maunawili greenhouse on Oahu, Hawaii.

Species and hybrids	K number[1]	No. of cuttings		
		Tested	Rooted	%
Species				
L. collinsii ssp. *collinsii*	905	13	4	31
L. collinsii ssp. *zacapana*	972	20	0	0
L. diversifolia	947	16	0	0
L. esculenta	949	15	0	0
L. leucocephala	Intraspecific hybrids[2]	350	280	80
L. macrophylla	902	35	17	49
L. magnifica	941	29	21	72
L. multicapitula	959	14	5	36
L. pallida	748	85	1	1
L. pulverulenta	957	32	18	56
L. shannoni	976	10	10	100
L. trichandra	909	31	0	0
L. trichandra	927	12	1	8
L. trichandra	928	29	9	31
L. trichandra	981	15	2	13
L. trichandra	991	12	3	25
L. trichodes	903	21	13	41
Average				32
Hybrids				
L. esculenta × *L. leucocephala*	1000(CK)	50	45	90
L. pallida × *L. leucocephala*	748 × 481	236	65	28
L. pallida × *L. leucocephala*	748 × 584	48	5	10
L. pallida × *L. leucocephala*	748 × 636	99	23	23
L. pallida × KX3 F_1	748 × (156 × 636)	70	3	4
KX3 selection F_4	156 × 636	128	22	17
Average				29

1: Accession number used by University of Hawaii
2: F1 hybrids including parent trees of K397, K565, K584, K608, and K636.

The species with greater rooting ability were *L. shannonii* (K976), *L. leucocephala* (intraspecific hybrids), and a triploid clone (K1000) of *L. esculenta* × *L. leucocephala*. The species more difficult to root were *L. collinsii* ssp. *zacapana*, *L. diversifolia*, *L. esculenta*, and *L. pallida*. The rooting percentage among 13 tested species averaged 32% and ranged from 0 to 100%. Among *L. trichandra* accessions, rooting percentage ranged from 0 to 31%.

Significant ($P<0.05$) differences for cloning ability among three KX2 F1 hybrids between *L. pallida* and *L. leucocephala* were observed with no significant difference between two rooting evaluation dates. The rooting percentage for these KX2 F1 trees averaged 20% and ranged from 10% to 28% (Table 1).

Discussion

The cloning technique presented in this study should facilitate exploiting interspecific heterosis in *Leucaena*. It is proposed that fast-growing interspecific *Leucaena* hybrids might be cloned economically for large-scale plantations. Similarly, cloning self-incompatible mother trees may facilitate production of hybrid seed. HARC has used this technique to establish four clonal *Leucaena* seed orchards.

Cuttings of *L. pallida* proved to be very difficult to root. However, a recent expedition to Mexico has greatly expanded germplasm of *L. pallida* and may provide germplasm with better rooting ability. Use of *L. pallida* as a female tree surrounded by *L. leucocephala* has led to hybrid seed of low purity (Brennan 1995; H.M. Shelton, pers. comm. 1997). Interspecific KX2 F1 hybrids between *L. pallida* and *L. leucocephala* are self-incompatible (Sun and Kamemoto, unpublished data) but can be propagated by cuttings. At HARC, KX2 F1 hybrids have been cloned and used as female parent to produce crosses with *L. leucocephala*, using varieties that show high heterosis with both parents of the KX2 clone (Sun 1996).

The results also indicated that *Leucaena* species with small leaflet size were more difficult to root than the species with large and medium leaflet size. In general, cuttings of the species with small leaflet size are more vulnerable to desiccation during propagation, especially prior to root development. This may contribute to the poor rooting ability of these species since gas exchange during propagation is one of the critical factors influencing rooting for many tropical trees (Leakey et al. 1994). Better techniques for prevention of leaf desiccation during propagation for these species need to be pursued.

Leucaena vegetative propagation has been considered easy by some and difficult by others. The problems facing leucaena researchers in repeating the reported successful vegetative propagation methods could be attributed to selection of plant materials and experimental environments. The modified cloning method reported here is simple and reliable and the technique can possibly be adapted to large-scale cloning of interesting *Leucaena* hybrids and selections for plantations. It can also be incorporated into *Leucaena* hybrid breeding programs.

Acknowledgment

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Rooting Ability of *Leucaena leucocephala* Leafy and Leafless Stem Cuttings in a Non-mist Propagator

J. Dick[1] and F. Magingo[2]

Abstract

Leafy stem cuttings of *Leucaena leucocephala* produced roots more successfully (71%) than leafless cuttings (39%). The mean length of the newly emerged shoot, presence of a leaf, proportion of original leaf lost while in the propagator, position of origin of the cutting on the stock plant (node position) and parental clone were all significantly associated with a cutting's ability to root. In the present study, 98% of cuttings harvested from nodes 5 to 13 formed roots within 7 weeks.

LEUCAENA *leucocephala* has been promoted as a multi-purpose tree in agroforestry systems but recent studies have indicated that other species and hybrids of the genus may be useful (Brewbaker and Sorensson 1994). The need for a simple and successful vegetative propagation technique for *Leucaena* spp. is widely acknowledged, as many of the new interspecific hybrids being developed are seedless (Brewbaker and Sorensson 1994). However, *L. leucocephala* has been variously reported as difficult (Litzow and Shelton 1991) and easy (Bristow 1983) to propagate vegetatively. This study was initiated to improve the current knowledge of the vegetative propagation requirements of *L. leucocephala*. A full report of the experiment has been submitted to Agroforestry Systems.

Materials and Methods

Stock plants

Seeds of *L. leucocephala* collected from trees growing at Machakos, Kenya, were sown at ITE, Edinburgh, Scotland UK on 1 May 1996. Germinated seedlings were potted into plastic pots 13 × 13 × 10 cm and maintained in a tropical glasshouse for one year. Glasshouse temperatures ranged diurnally between 22 °C and 35 °C. Daylight was supplemented by mercury vapour lighting to provide a year-long day length of 19.5 h and an approximate minimum photon flux density (PAR) of 150 μmol/m^2/s at plant level. Maximum PAR in the glasshouse on bright summer days was about 1400 μmol/m^2/s. Thirteen months after germination the seedlings were 1.3–1.5 metres tall with root collar diameter of 0.9–1 cm.

Stem cuttings

A total of 125 single-node cuttings were harvested from five seedlings (clones) on 30 June 1997. The number of cuttings taken per stock plant varied depending on the number of nodes present (25, 23, 24, 25 and 28 for clones 1–5 respectively). Every single-node cutting was harvested unless a branch was growing from the node. The length, basal diameter and node number, relative to the apex, was recorded for each cutting (Figure 1). The apical cuttings each had a leaf which was trimmed to four pinnae (76 cuttings) while cuttings from the lower nodes were leafless (49 cuttings) (Figure 1a).

Each cutting was dipped in a commercial rooting powder (Seradix, May and Baker Ltd; active ingredient 0.8% IBA). The cuttings were placed in node order in a non-mist propagator (Leakey et al. 1990) containing quartz grit (0.001–12.7 mm) rooting media and situated in a temperature-controlled glasshouse. The bed temperature of the propagator was maintained at between 23–33 °C. Each propagator was covered with one sheet of 30% neutral density shade cloth (Tildenet, Bristol, UK), which was removed on dull and overcast days.

Each cutting was assessed once or twice a week for number of roots, total root length, leaf abscission,

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leaf regeneration and cutting death until eight weeks after insertion in the propagator. The number of cuttings rooting was calculated as the percentage of cuttings with a root equal to or greater than 1 mm length, and dead cuttings as the percentage of cuttings with a completely brown stem. A stepwise procedure (Genstat, NAG Ltd, Oxford, UK) was utilised to determine which of the recorded variables were significantly associated with the rooting ability of each cutting.

Results and Discussion

Clonal variation

There was clear clonal variation in the rooting ability of *L. leucocephala* cuttings with an almost two-fold difference between the best and worst rooting clones (Figure 2a). Clone 3 was the fastest and most successful rooting clone with the first cuttings rooting after 14 days in the non-mist propagator and a final rooting percentage of 71%. Clone 5 (Figure 2b) had the highest mortality (57%) and clone 3 the least (29%). There was, however, no significant difference in the length or diameter of the cuttings harvested from each seedling (clone). The overall average cutting length was 51 mm and diameter was 4.7 mm. Many studies have found clonal variation in rooting ability of a large number of species. Such variation is important when considering a large scale vegetative propagation program.

Leaf and leafless cuttings

There were significant differences in cutting length and diameter between leafy and leafless cuttings (Figures 1b and 1c). The average lengths of leafy and leafless cuttings were 64.8 mm and 29.3 mm respectively, while the difference in diameter was 3.9 mm and 5.9 respectively. The leafy cuttings had a much higher capacity to root (71%) compared with the leafless cuttings (39%).

Regression analysis showed (Table 1) that both the presence of a leaf and the persistence of that leaf when the cutting was in the propagation environment were significantly associated with a cutting's ability

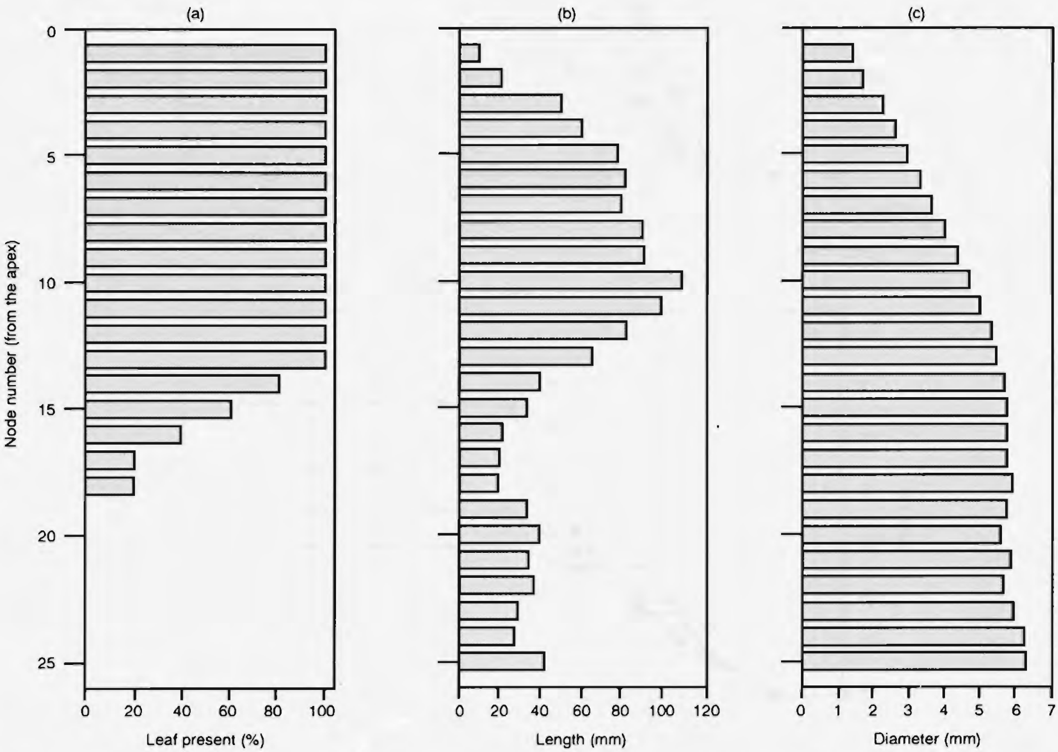

Figure 1. Morphological characteristics of single-node cuttings harvested sequentially down the mainstem of five *Leucaena leucocephala* seedlings: (a) the percentage of the cuttings with a leaf attached; (b) mean cutting length; and (c) mean cutting diameter (N.B.: node number 1 = apex of the plant).

Table 1. Analysis of deviance for a stepwise regression to determine the influence of genotypic variation and morphological characteristics on the rooting ability of *Leucaena leucocephala* cuttings. The node number reflects the original position of the cuttings on the stock plant.

	DF	Deviance	Mean deviance	Deviance ratio	p-value
Mean shoot length	1	76.5892	76.5892	76.59 (+)	<0.001
Presence of a leaf	1	9.2499	9.2499	9.25 (+)	<0.001
Clone	4	9.5421	2.3855	2.39	<0.01
Node No.	1	7.3186	7.3186	7.32 (+)	<0.01
Percentage leaf loss	1	4.5619	4.5619	4.56 (–)	<0.05
Residual	110	53.2339	0.4839		
Total	118	160.4956			

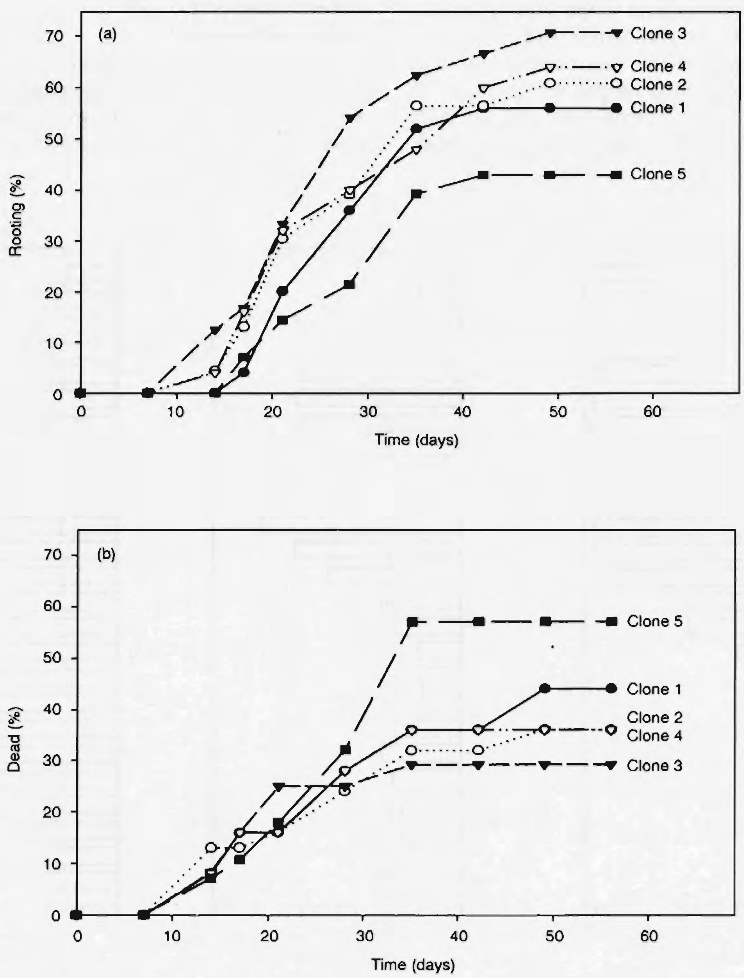

Figure 2. (a) Rooting and (b) mortality rate of *Leucaena leucocephala* single-node cuttings harvested from five seedlings (clones).

to form adventitious roots. The importance of maintaining a viable leaf on leafy stem cuttings was also recognised in a variety of tropical tree species (Tchoundjeu and Leakey 1996).

Cutting origin (node position)

There was distinct variation in the rooting ability and death of the cuttings within the leafy and leafless classes depending on the node position on the stock plant (Figure 3). Node position also influenced the rate of rooting (Figure 4). Cuttings from nodes 5, 6 and 7 rooted fastest while root emergence was not recorded on cuttings below node 18 (i.e., leafless) until day 21.

Cutting origin has been found to be closely related to rooting ability in a number of other tree species (Tchoundjeu and Leakey 1996). It is generally recognised that there is a gradient of cellular activity, endogenous growth regulators, levels of available and stored assimilates and also different levels of lignification and secondary thickening down the mainstem, all of which influence the rooting response of cuttings.

Conclusion

This study clearly shows that cuttings from one-year-old seedlings of *L. leucocephala* can be readily propagated vegetatively by leafy stem cuttings in a non-mist propagator. This result is in agreement with work by Bristow (1983) and Hu and Chih-Cheng (1981). The non-mist propagator used in this study (Leakey et al. 1990) is appropriate for semi-arid and moist tropical areas as it does not require electricity or piped water and can be constructed from locally-available material.

The study has further shown the importance of collecting morphological data on each cutting during initial propagation runs in order to understand fully the rooting response of an untested species. The authors believe that one of the reasons many species are classified as difficult to root is because data on the success and failure of cuttings to root is not reported; future research is therefore not well directed.

It is vital to report two out of the three possible responses that a cutting can display, i.e., rooted, dead or alive but unrooted on the propagation bed. The

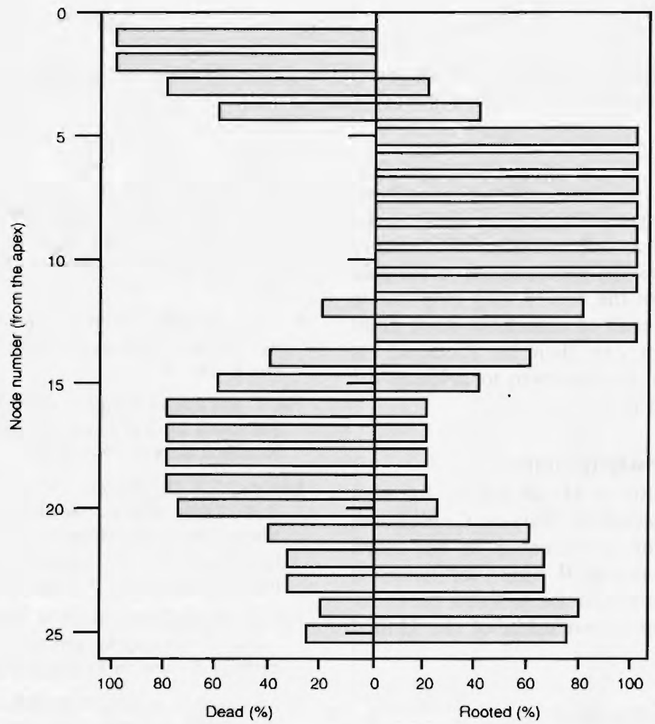

Figure 3. Percentage rooting and mortality of single-node cuttings harvested sequentially down the mainstem of *Leucaena leucocephala* seedlings eight weeks after insertion in non-mist propagators (N.B.: node number 1 = apex of the plant).

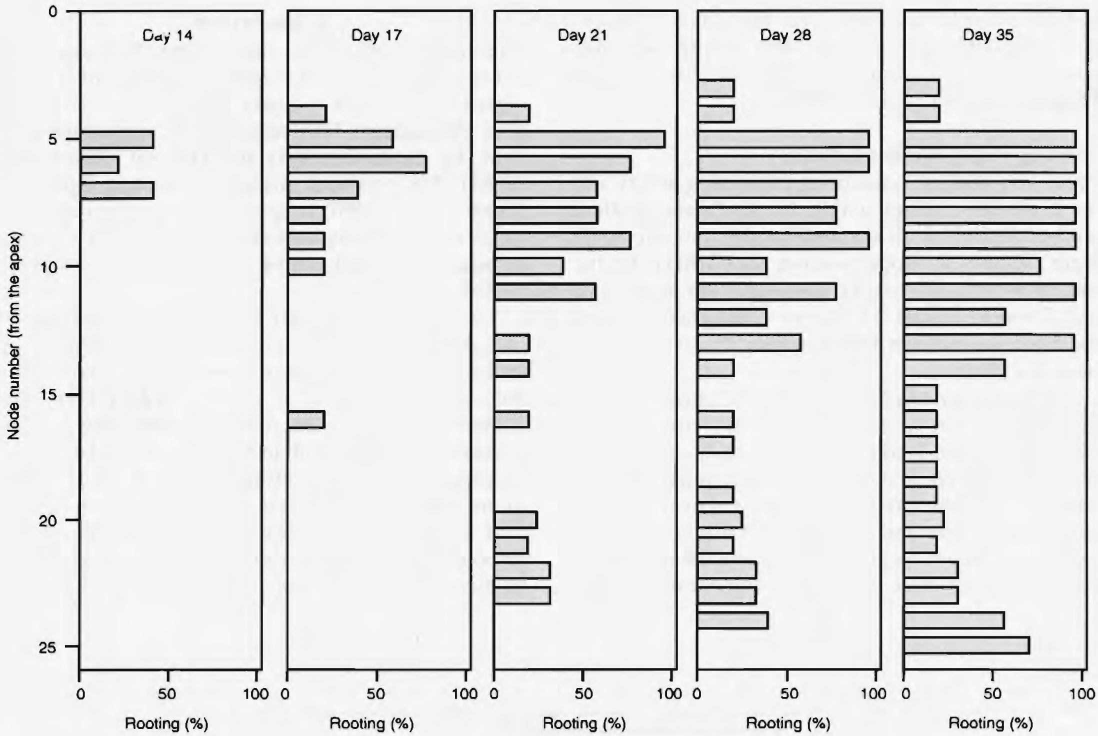

Figure 4. Rooting response of single-node cuttings harvested sequentially down the mainstem of *Leucaena leucocephala* seedlings on days 14–35 after insertion in a non-mist propagator.

latter two responses have quite different interpretations. If a cutting remains unrooted but alive on the propagation bed for several months, this clearly means that the propagation environment is suitable for that species and that the non-rooting response is more likely to be the result of unsuitable stock plant management. Research can then be focussed on altering the stock plant management to enhance the number of cuttings that root.

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Seed Scarification and Establishment of *Leucaena leucocephala* — A Farmer's View

P.H. Larsen[1]

Abstract

Using boiling water to scarify *Leucaena leucocephala* (leucaena) seed produces variable results, and immersion time must be varied to suit individual seed lots. Mechanical scarification produces better germination, quicker emergence and more vigorous seedlings. Successful leucaena establishment can be achieved by ensuring weed-free fallows, good soil moisture profile, quick, effective germination, good insect control for emerging seedlings, and good weed control until leucaena is 2 m high.

THERE are 800 ha of *Leucaena leucocephala* cv. Peru in full grazing, and 105 ha of cv. Tarramba for seed production on a property in Central Queensland. Seed scarification and subsequent methods of *Leucaena* establishment are important to the success of the operation.

Seed Scarification

Leucaena seed was first scarified for planting 13 years ago. The procedure in those days was immersion in hot water at 80 °C for several minutes or acid treatment. The acid treatment was not recommended as it was considered too dangerous, so the 80 °C hot-water treatment was chosen. However, the practical implications of this were out of the question. Firstly, how does one keep water at 80 °C while dipping large volumes of seed into it for several minutes; and secondly, what farmer has that much time on his hands? It simply was too time-consuming.

On further inquiry, it was found that seed scarification could be effected by immersion in boiling water for a number of seconds but no one could say how many seconds that should be. Seed was boiled in 100-seed lots in a saucepan in the kitchen for 1, 3, 5, 7 and 10 seconds and the germination recorded over a 21-day period. The results were clear, with 80% germination in 5 seconds and 87% in 3 seconds. The germination fell considerably at 7 seconds and many non-imbibed seeds were present at 1 second. Therefore, 4 seconds in boiling water was considered to be the proper immersion time period.

These findings were reported to DPI advisers who abruptly published 4 seconds boiling water treatment as the best way of scarifying *Leucaena* seed. However, because a germination test was always carried out using the scarification procedure every time another field was planted, it was subsequently found that every line of seed must be treated individually without regard to prior experience. This means that time intervals of immersion in boiling water need to be calibrated for each individual seed lot within a variety. Within the cv. Peru, one line of seed could only be immersed in boiling water for 1 second for maximum germination while a later line of seed needed 7 to 10 seconds for maximum germination. All seed sales of 'Peru' were therefore made with individual boiling water treatment recommendations. It was found that although 4 seconds immersion in boiling water seemed to be close to the average requirement, this figure could not be recommended for all *Leucaena* seed, because certain lines of seed could be completely ruined by overheating and yet other lines were not scarified enough at 4 seconds.

When the first Tarramba (K636) seed was harvested, an interesting obstacle with boiling water scarification was found. The usual 1, 3, 5, 7, 10 second boiling water scarification and germination tests were carried out only to find that even at 10 seconds immersion in boiling water, approximately only 50% imbibed in 21 days. Boiling water

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treatments were extended to 10, 20, 30 seconds only to find that at 20 seconds 75%–80% imbibed but many seeds rotted instead of shooting. At 30 seconds, while almost all seeds imbibed, only a small percentage survived the excessive heat.

Consequently, mechanical scarification using fingernail clippers was tried. A preliminary trial produced 99% germination in just a few days. The leucaena seed germinated quickly, and with healthy roots. However, manual scarification is clearly not an option for large quantities of seed. As a consequence, a machine to mechanically scarify Tarramba seed was built so that scarified seed could be offered at no additional cost to clients. Because machine-scarified seed has a lower shelf life than boiling water-treated seed, it is packed in 20 kg lots in a sealed steel pail for dry keeping and an on-farm insulated container installed to keep the seed temperature constant at 20 °C. An attempt is made to scarify seed as near in time as possible to clients' planting requirements.

A most interesting offshoot to the above experience was the way that machine scarified Tarramba seed performed in the field compared to boiling water-treated seed. The emergence of boiling water-treated seed is only 35% of that of machine scarified seed, and does not grow as quickly after emergence. The difference can be seen even six months later. This author believes the difference can be attributed to healthier root stock, as observed in the germination trays.

Many methods of abrasion of leucaena seed have been tried. The humble cement mixer has been trialed considerably. Leucaena seed mixed with copious quantities of sand, road screenings (blue metal), zinc oxide and aluminium oxide have all been tried for periods up to 10 hours with absolutely no scarification being achieved. However, the internal surface of the mixer acquired quite a mirror finish!

Acid treatment has not been tried. One important outcome is that together with good scarification principles, good quality germination testing equipment is essential for seed production and sale.

Different lines of Tarramba seed are expected to respond in like manner to machine scarification provided the moisture content is constant in each line. However, this should never be assumed without constant checking. Machine scarified seed can be checked readily for effective scarification as it will all imbibe within 48 hours, whereas boiling water scarified seed will imbibe from 12 hours to 21 days. Nil visible seed coat damage with machine scarification is preferred. However, to date these methods achieve only 50%–60% non-visible damage, with a few percent partly or fully dehulled.

Leucaena Establishment

Effective large scale leucaena establishment is achieved under a 5-point plan.

1. Clean fallows;
2. Good soil moisture profile up to 1 m prior to planting;
3. Quick effective germination — 7 to 10 days;
4. Good insect control over emerging seedlings;
5. Good weed control until leucaena is 2 m tall.

This should result in 2 m high leucaena in 6 months which is ready for first grazing.

1. A weed free fallow, such as would be needed for a good grain crop, is necessary for a buildup of soil moisture and weed control. This is often achieved in a normal rainfall year by three or four cultivations after the preceding crop of wheat or sorghum, etc. A cultivation immediately following each weed germinating rain during the fallow is necessary.
2. In this 675 mm rainfall area, a good soil moisture profile of around 1 m in depth is achieved in most years by a 6-month fallow. In drought years, this will need to be extended. With a 1 m soil moisture profile, a successful leucaena establishment is assured provided the young trees are kept weed free. It takes 6 months for the leucaena to use up the moisture in a good fallow especially if the row spacings are 5 m apart or greater.
3. Quick and effective germination is of the utmost importance to get the young trees away to a healthy start. A healthy start ensures a healthy finish. Machine scarified seed is preferred to seed scarified in boiling water. Seed planting rate has been 3 kg/ha with boiling water-treated seed. However, this has now been reduced to 2.5 kg/ha with machine scarified seed.

   Many row spacings have been tried from 1 m double rows to 10 m single rows. Our row spacings are in a skip row pattern with twin rows (91.5 cm apart), with a spacing between twin rows of 4.57 m.

   A dual press wheel arrangement where no pressure is exerted over the seed is extremely important for minimum emergence time. All of our early leucaena plantings were part emergence failures. However, since the introduction of dual press wheels there have been no emergence failures.

   The seedling can emerge from 5 cm very easily and up to 7 or 8 cm if the soil is soft and friable. The seedling should be straight and no greater than 2 mm in diameter underground on emergence. This is the guideline for easy emergence to be achieved. Any thickening or distortion of the seedling shaft is a good indication that the soil has been too firm for easy emergence. Should crusting occur before emergence, an application of Yetter wheels (rolling cultivators) will help break the crust and assist emergence. Full emergence from boiling water-scarified seed should be 7 to 21 days, while full emergence from machine-scarified seed should be 7 to 10 days.

4. Insect control is never more important than when leucaena is in its first few weeks of growth. On a clean fallow, the young leucaena is all there is for insects to eat. Lorsban powder is applied to the seed to protect the new shoot underground. It has been suggested that this insecticide will kill the *Rhizobium* inoculant. However, it is more important to have leucaena establishing without viable inoculant than to have inoculant without leucaena. That is why the inoculant is applied on the seed and again at first cultivation of the young trees. Lorsban beetle bait is broadcast across the field on the day the first seedlings of leucaena emerge. This controls above-ground insects which have a habit of marching down a field in straight lines 5 m apart and feeding on the new cotyledon leaves. The beetle bait is a mixture of $2^1/_2$ kg cracked grain, 125 mL vegetable oil and 100 mL Lorsban per hectare.

5. Good weed control of young leucaena (under 6 months of age) or under 2 m in height is most important to ensure a healthy leucaena establishment. This is achieved by using Yetter rolling cultivators and spring tynes to control young weeds in their first week of life. The Yetter wheels can be run over the emerging seedlings or even before the leucaena emerges. The wheels break the crust and thus remove the weed seedlings with the crust. They allow soil to be spread from the spring tynes over the leucaena seedling area in a thick band to cover the weeds but not the leucaena. Yetter wheels can be used over the leucaena until it is 30 to 50 cm in height. They allow spring tyne inter-row cultivation to be performed at twice to three times the normal speed of travel. The result is 2 m high leucaena in 6 months. Without weeds, 2 m high leucaena may not be achieved until 3 years.

Although some departures to the above 5-point plan have been successful, the author has noted that only experts in their field can succeed in a departure from any one of the outlined points.

Competition studies

The Effect of Cutting Intervals and Associate Grass Species on the Growth of *Leucaena* at Packchong

S. Tudsri[1], S. Swasdiphanich[1], S. Prasanpanich[2] and C. Kaewkunga[3]

Abstract

Leucaena (*Leucaena leucocephala*) was grown with three grasses: ruzi (*Brachiaria ruziziensis*), dwarf napier and Taiwan A 25 (both *Pennisetum purpureum*). The pastures were cut at 20, 30 and 40-day intervals for 840 days. Leucaena yield was lower in dwarf napier plots than in ruzi and Taiwan A25 plots, which gave similar legume yields. The yield of leucaena declined with increasing cutting intervals while grass yields increased. Growing leucaena with dwarf napier gave the highest total yield. Less frequent cutting increased total dry matter yields in all treatment combinations through increases in grass yields.

LEUCAENA (*Leucaena leucocephala*) is a shrub legume which is widely distributed throughout Thailand (Tudsri 1997). It serves as the most valuable dairy cattle feed in back yard feeding lots and is also tolerant of grazing. However, the productivity of this legume in mixed pastures may vary according to the associate grass species, and the compatability of the leucaena and grasses may be influenced by defoliation practices. The present experiment examined the effects of different cutting intervals on the growth of leucaena pastures with three grasses: ruzi (*Brachiaria ruziziensis*), dwarf napier and Taiwan A 25 (both *Pennisetum purpureum*).

Materials and Methods

The experiment was conducted on a sandy clay loam soil at the Kasetsart University farm, Packchong, approximately 150 km northeast of Bangkok. A split plot design with three replications was used. The main plots consisted of three tropical grasses (ruzi (*Brachiaria ruziziensis*), dwarf napier and Taiwan A 25 (both *Pennisetum purpureum*)) planted between rows of leucaena, and the sub-plots were the cutting intervals (20, 30 and 40 days).

The area was ploughed and cultivated to produce a good seedbed before sowing on November 10, 1993. Leucaena, dwarf napier and Taiwan A 25 were planted in a small plot prior to transplanting into the experimental area when the plants were 4–5 weeks old. Leucaena was transplanted into rows 2 m apart, and the transplanted grasses were grown between the leucaena rows at 50 × 25 cm spacing (between and within row, respectively). Ruzi grass was sown at 12 kg/ha. An initial fertiliser dressing of 15-15-15 (N:P:K) at 300 kg/ha was applied at sowing with further annual applications at the same rate in 1995 and 1996. The area was cut to 15 cm for grasses and 25 cm for leucaena on May 4, 1994. This date was taken as week 0, and the cutting intervals commenced from that date and continued for 840 days.

Results and Discussion

Results of this experiment suggested that the growth of leucaena was affected by the associate grass (Table 1). Averaged over the three cutting intervals, leucaena yields were higher when grown with Ruzi and Taiwan A 25 than with dwarf napier. Ruzi is stoloniferous with a low growing habit while Taiwan A 25 is tall with low leaf production. These growth habits may have resulted in these grasses having a less competitive effect on the leucaena than dwarf napier which is an erect and leafy grass. However, the total dry matter yield (grass + leucaena) was highest in the dwarf napier plot. This was due to an increase in the grass component (Table 1).

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Table 1. Total dry matter yield (t/ha) of three grasses grown with leucaena over 840 days.

	Cutting interval (days)			
	20	30	40	Average
A. Grass				
1. Ruzi	24.2	25.4	28.2	25.9
2. Dwarf napier	38.9	35.8	44.8	39.8
3. Taiwan A 25	25.6	29.6	40.3	31.8
Average	29.6	30.3	37.7	
B. Leucaena				
grown with:				
1. Ruzi	5.8	4.8	5.5	5.3
2. Dwarf napier	5.7	4.9	3.7	4.8
3. Taiwan A 25	5.0	5.3	5.0	5.1
Average	5.5	5.0	4.7	
C. Grass + Leucaena				
1. Ruzi	30.0	30.2	33.7	31.3
2. Dwarf napier	44.6	40.6	48.5	44.6
3. Taiwan A 25	30.6	34.9	45.3	36.9
Average	35.0	35.2	42.5	

Yield of leucaena declined with increasing cutting intervals. This was in contrast to what has been found in other pasture legumes such as Siratro (Jones 1967), Desmodium (Jones 1973) and *Psoralea eriantha* (Gutteridge and Whitman 1975) where the yields increased under less frequent cuttings. On the other hand, grass yield increased as the cutting intervals increased.

This experiment also showed that moderate (30 day) and frequent (20 day) cuttings of leucaena grown with grasses reduced total dry matter yield (grass + luecaena) by approximately 17% compared with infrequent (40 day) cuttings over a period of 840 days. The increase in total dry matter yield recorded under less frequent cuttings was due to an increase in the grass component.

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Interference Effects of Allelospoly and Allelopathy by *Leucaena leucocephala* — a Comparative Study

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Abstract

Five crops (sunflower, greengram, sesame, sorghum and cowpea) were intercropped with three tree species (*Casuarina equisetifolia*, *Eucalyptus tereticornis*, and *Leucaena leucocephala*) when the trees were 24 and 30 months-old. Compared to monocrops, all intercrops suffered yield depression, with the exception of sesame and cowpea intercropped with *C. equisetifolia* at 24 months. *L. leucocephala* was most inhibitory and *C. equisetifolia* least so. The depression of crop yields is attributed to competition for light, water and nutrients. *L. leucocephala* had high root content and maximum light interception, implying intense subterranean and aerial competition. *C. equisetifolia* had least root content and highest soil moisture content, indicating its lesser level of below ground competition. Though light interception was least in *E. tereticornis*, its water extraction was high. Allelopathic effects on germination and seedling growth were also evident for all three tree species. The effects were greatest for *E. tereticornis* and least for *C. equisetifolia*.

ALTHOUGH many benefits (such as mitigation of soil erosion, augmentation of soil fertility, concurrent production of food and wood, provision of shade and shelter, amelioration of microclimate etc) have been imputed to agroforestry, farmers are often wary of the concept, owing, *inter alia*, to reduced crop yields caused by interference effects of the trees. The interference effects are of two kinds, viz., competition for resource pools of light, water and nutrients (termed allelospoly by Szezpanski 1977) and allelopathic influence (Rice 1984).

Although numerous reports on intercropping with *Leucaena leucocephala* are available, there are few reports on its interference effects relative to other tree species. In an intercropping system, the yield penalty sustained by the crops was greater for *Eucalyptus tereticornis* and least in *Casuarina equisetifolia* (Vinaya Rai and Suresh 1988). However, intercropping eight leaf-yielding crops with five year old trees of *E. tereticornis* and *L. leucocephala* indicated more yield depression with *L. leucocephala* (78%) than *E. tereticornis* (27%) (Suresh et al. 1991). Allelopathic studies showed that *E. tereticornis* was more toxic than either *C. equisetifolia* or *L. leucocephala* (Suresh and Vinaya Rai 1987).

This paper reports the interference effects in an intercropping system with three tree species (*C. equisetifolia*, *E. tereticornis*, and *L. leucocephala*) in terms of competition effects and allelopathy.

Materials and Methods

Allelospolic effects

The studies were carried out at the Forest College and Research Institute, Mettupalayam, India (11°19'N, 75°56'E, 300 m above sea level, soil pH 7.1). Five crops (Table 1) were raised in the interspaces of three tree species (*C. equisetifolia*, *E. tereticornis*, and *L. leucocephala*) when the trees were 24 and 30 months-old. The trees were spaced 4 × 1 m in 8 × 8 m plots. The experiment was a split plot design with tree species as the main plots and crops as subplots. Monocrops served as control. There were three replications.

Light intensity under the trees was determined every month from the 13th to the 36th month and the mean light transmission in a year was calculated. Thirty months after planting, the root content of the trees at various depths (0–30, 31–60, and 61–90 cm)

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was assessed at two distances of 1 and 2 m from the tree base. Available soil moisture under the trees was also assessed at this time.

Table 1. Details of the crops grown.

Common name	Latin name	Cultivar	Spacing (cm)
Sunflower	*Helianthus annuus*	Modern Elite	45 × 20
Greengram	*Vigna radiata*	CO 4	30 × 10
Sesame	*Sesamum indicum*	CO 24	45 × 15
Sorghum	*Sorghum bicolor*	CO 26	45 × 15
Cowpea	*Vigna unguiculata*	CO 1	30 × 10

Allelopathic effects

Foliage from the 30 month old trees of the three species was soaked in distilled water (1:10 weight : volume) for 24 hours. This ratio produces low osmolality. The extracts were filtered through Whatman No. 1 filter paper. The near neutral pH of the extracts obviated the need for adjusted controls. Seeds of the five crop species were sown in sterile 10 cm petri dishes lined with one sheet of germination paper soaked with 5 mL of the extract. Moisture in the paper was maintained by adding 5 mL of the extract every second day. Distilled water served as the control, and there were three replicates. Germination percentage was recorded seven days after sowing and seedling length after 30 days.

Results and Discussion

Allelospolic effects

Compared to their respective monocrops, all the intercrops raised in conjunction with the trees had lower yields, in both the 24 and 36-month treatments (Table 2). The only exceptions were sesame and cowpea intercropped with *C. equisetifolia*, which did not show significant yield reduction with 24 month-old trees. The crop yield reduction was greatest with *L. leucocephala* and least with *C. equisetifolia*. This agrees with earlier results of Vinaya Rai et al. (1989), although in an intercropping study involving fodder crops with the same tree species, *E. tereticornis* was more injurious than *L. leucocephala*.

Light, moisture and nutrients are the chief determinants of crop growth. The crop yield reduction in the present study was the result of the reduction in the pool size of these resources imposed by the trees. The different effects of the trees may be attributed to their differential resource sharing capabilities. Among the three tree species, *C. equisetifolia* had the least root weight (Table 3) and the highest soil

Table 2. Yields of crops (t/ha) intercropped with three tree species 24 and 30 months after planting. (LSDs (0.05) at 24 months are: main plots 0.45, subplots 0.82; at 30 months, 0.35 and 0.82).

Intercrop	24 months				30 months			
	MC*	CE	ET	LL	MC	CE	ET	LL
Sunflower	1.81	1.54	1.42	1.25	1.45	1.09	0.80	0.73
Greengram	1.15	0.96	0.92	0.83	0.98	0.67	0.60	0.48
Sesame	1.31	1.15	0.95	0.81	1.01	0.71	0.60	0.58
Sorghum	4.91	4.57	4.17	3.57	4.33	2.85	2.38	2.28
Cowpea	1.29	1.14	1.06	0.96	1.12	0.84	0.70	0.55
Mean	2.09	1.87	1.70	1.48	1.77·	1.28	1 01	0.92

* MC — monocrop, CE — *Casuarina equisetifolia*, ET — *Eucalyptus tereticornis*, LL — *Leucaena leucocephala*.

Table 3. Root dry weight (kg/m^3) of trees intercropped with agricultural crops 30 months after planting. (LSDs (0.05) between trees 7.4, between depths 5.1).

Tree species	Depth (cm)			Total
	0–30	31–60	61–90	
Casuarina equisetifolia	35.0	6.9	3.8	45.7
Eucalyptus tereticornis	38.8	14.4	11.1	64.3
Leucaena leucocephala	41.4	24.1	10.3	75.9
Mean	38.4	15.1	8.4	

moisture content (Table 4), implying the least below ground competition.

Table 4. Available soil moisture (%) under trees intercropped with agricultural crops 30 months after planting. (LSD (0.05) between tree species 2.0).

Crop	Monocrop	CE*	ET	LL
Sunflower	38.6	20.6	16.0	17.2
Greengram	41.5	20.2	16.2	18.0
Sesame	42.5	21.5	16.9	18.5
Sorghum	37.6	19.4	13.7	14.5
Cowpea	41.6	20.3	14.7	17.9
Mean	40.3	20.7	15.5	17.6

* CE — *Casuarina equisetifolia*; ET — *Eucalyptus tereticornis*; LL — *Leucaena leucocephala.*

On the other hand, *L. leucocephala* had not only the highest root weight but also maximum light interception (Table 5). Thus both subterranean and aerial competitions were intense, resulting in maximum crop yield reduction. *E. tereticornis* allowed more light to the ground level but extracted more soil moisture, resulting in an intermediate level of crop yield depression.

Allelopathic effects

Not only did the trees differ in their allelopathic effects but the crops also differed in their response (Table 6). While germination of sunflower was depressed by all three extracts, that of cowpea was not affected by any of them. Greengram, sesame and sorghum showed reduced germination only with *E. tereticornis* extract. Compared to the control, seedling growth was impaired in all crops except cowpea.

Considering the tree species, *L. leucocephala* was least phytotoxic, and *E. tereticornis* most phytotoxic,

Table 5. Light transmission ratio (%) under three tree species 24 and 36 months after planting.

Tree	13–24 months		25–36 months	
	Time of day		Time of day	
	0820	1420	0820	1420
Casuarina equisetifolia	37	71	25	45
Eucalyptus tereticornis	41	77	29	55
Leucaena leucocephala	35	66	24	43
LSD (0.05) between trees	2.4	3.8	1.8	2.9

Table 6. The effect of aqueous leaf extract on germination and seedling growth of five crops. (For germination %, LSDs (0.05) between trees 2.9, within trees or crops 4.9; for seedling length, LSDs (0.05) between trees 0.16, within trees or crops 0.33).

Crop species	Tree species			
	C. equisetifolia	*E. tereticornis*	*L. leucocephala*	Control
Germination (%)				
Sunflower	31	26	22	42
Greengram	97	85	97	100
Sesame	97	90	94	100
Sorghum	96	72	91	100
Cowpea	100	92	100	100
Mean	84	73	81	88
Seedling length (cm)				
Sunflower	17.8	15.0	17.0	20.8
Greengram	14.0	12.5	12.9	16.6
Sesame	13.9	12.7	12.9	14.9
Sorghum	11.6	12.3	11.7	16.2
Cowpea	17.4	16.9	17.0	17.6
Mean	14.9	13.8	14.3	17.2

both for germination and seedling growth. The inhibitory effect of *E. tereticornis* may be ascribed to the production of phenols or volatile terpenes, while the phytotoxic effects of *L. leucocephala* may be attributed to mimosine, which has previously been reported to be phytotoxic in mungbean (Ling et al. 1969) and lettuce (Wilson and Bell 1979).

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Forage Quality

Presented Papers

Condensed Tannins in the Genus *Leucaena* and their Nutritional Significance for Ruminants

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Abstract

Condensed tannin (CT) can dramatically reduce the utilisation of protein in ruminants. However, at low levels (<3–6% DM) it is hypothesised that CT can be advantageous. The ability of CTs to protect protein in the rumen could increase the flow of bypass protein and, provided they do not reduce the flow of microbial protein, increase the total supply of protein for absorption. To assess these hypotheses, the effect of inactivating tannins by treatment with polyethylene glycol (PEG) on the nutritive value of *Leucaena leucocephala* (K636) was assessed. In addition, three other *Leucaena* species (*L. trichandra* CPI 46568, *L. pallida* CQ 3439, *L. collinsii* OFI 51/88) were compared to *L. leucocephala* (K636). All *Leucaena* species were fed fresh to sheep in metabolism crates. Purified CTs from the *Leucaena* species were assessed for their abilities to bind protein in vitro. Also measured was the ability of the CTs to release previously complexed protein, between the abomasum and end of the small intestine in sheep. The high CT *Leucaena* species (*L. trichandra* CPI 46568 and *L. pallida* CQ 3439) were associated with poor retentions and apparent digestibilities of N, and lower dry matter digestibilities, compared to the lower tannin *L. leucocephala* (K636) and virtually tannin devoid *L. collinsii*. The CT content (i.e., untreated v. PEG treated) of *L. leucocephala* (K636) enhanced its ability to supply protein to the abomasum (1.003 v. 0.635 g/g N intake, pooled s.e. = 0.138, $P<0.10$) by increasing the amount of feed protein that bypassed the rumen (0.499 v. 0.077 g/g N intake, pooled s.e. = 0.138, $P<0.10$) without inhibiting the supply of microbial protein (0.554 v. 0.558, pooled s.e. = 0.043, $P>0.10$). Part of the advantageous effect of *L. leucocephala* (K636) CTs on the delivery of protein post-rumen may be attributed to their weaker ability to bind protein, especially at abomasal pH. On a g/g basis, purified *L. leucocephala* (K636) CT had approximately half the binding power of *L. pallida* (CQ 3439), *L. trichandra* (CPI 46568), *Lotus pedunculatus* (cv. Maku) and *Acacia aneura* CTs at pH 5, and no measurable binding at pH 2.5, in vitro. There was also an indication that *L. leucocephala* CT was better able to release protein between the abomasum and end of the small intestine than *L. pallida* (CQ 3439) and *Acacia aneura* CT. *L. leucocephala* (K636) may be an example of a forage with a CT fraction that stimulates a better than expected supply of protein to ruminants. However, the authors, and others, have been unable to directly link enhanced protein flow to enhanced N retention. It is postulated that this lack of translation is because gains in protein delivery are offset by enhanced losses of endogenous protein due to interactions between CT and proteolytic enzymes and/or the gut wall distal to the rumen. The data indicate a promising future for *L. leucocephala* (K636) and *L. collinsii* (51/88) forage in productive feeding systems for ruminants in the tropics. In contrast, *L. pallida* (CQ 3439) and *L. trichandra* (CPI 46568), whose protein availabilities are dramatically inhibited by CT, should not be recognised as valuable protein supplements.

LEUCAENA leucocephala is one of the most nutritious tropical forages fed to ruminants. However, the nutritive value of some of the lesser-known *Leucaena* species, particularly in regard to their ability to supply metabolisable protein to ruminants, is open to question (Norton 1994 a, b). Many contain excessive amounts of condensed tannin (CT) (Wheeler et al. 1994; Dalzell et al., these Proceedings). Tannins are a problem because of their ability to bind to and effectively form a protective coating around protein (Figure 1, Spencer et al. 1988). When

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tannins coat feed-protein, they reduce the ability of digestive enzymes in the animal's gut to attach to and digest that protein. Furthermore, tannin can coat the digestive enzymes themselves, as enzymes are also proteins, further exacerbating the problem (Mangan 1988; Tanner et al. 1994). Excessive levels of dietary tannin would also be expected to reduce the supply of microbial protein to the animal (Barry et al. 1986; Field and Lettinga 1992). Too much tannin in the rumen would protect feed protein to the extent that the microbes are starved of the nitrogen (N) they need for growth. Moreover, tannin may stimulate the animal to secrete more endogenous proteolytic enzyme than normal, and may attach to the inner lining of the gut, potentially accelerating the natural process of cell death and damaging the ability of the gut to absorb nutrients (Butler 1992). Hence, despite a feed test indicating adequate levels of protein, if the feed also contains tannin, less of that protein than expected would be converted into animal product.

Despite the deleterious effects of tannin outlined above, it has been hypothesised that small amounts (3–6% of DM) may not cause problems, and may even be advantageous (Barry et al. 1986; Waghorn 1990; Mangan 1988). If the protein content of a forage is in excess of microbial needs for protein synthesis, a small amount of tannin may protect the excess protein from otherwise wasteful degradation, the result being a greater flow of protein to the small intestine of the animal for absorption. However, the success of this hypothesis depends on the assumption that the tannin-induced 'bypass protein' is useable; i.e., is it released from the tannin post-ruminally for digestion at the level of the abomasum and small intestine?

The protein may well be released, because the bond between the tannin and protein can be broken by acidic conditions such as those in the abomasum (Jones and Mangan 1977; Mangan 1988; Perez-Maldonado et al. 1995). Tannins in *Lotus* spp. and in *Desmodium ovalifolium* appear to have the ability to bind protein in the rumen but release it post-ruminally to the animal's advantage (Barry et al. 1986; Waghorn 1990; Rosales 1995). However, whether all tannins will release protein post-ruminally is still open to question. Tannins differ in their abilities to bind to protein (Perez-Maldonado et al. 1995). If tannins differ in their binding ability they may also differ in their releasing ability. Finally, even if low concentrations of dietary tannin improve the flow of useable protein to the small intestine does it translate into an improved accretion of N in the animal? The lesser-known *Leucaena* species were evaluated with regard to these questions.

Materials and Methods

Two feeding trials, using penned sheep, were conducted to assess the digestibility of dry matter and N in selected *Leucaena* species. A further in vivo trial, using sheep surgically prepared with ileal and abomasal cannulae, was conducted to determine the

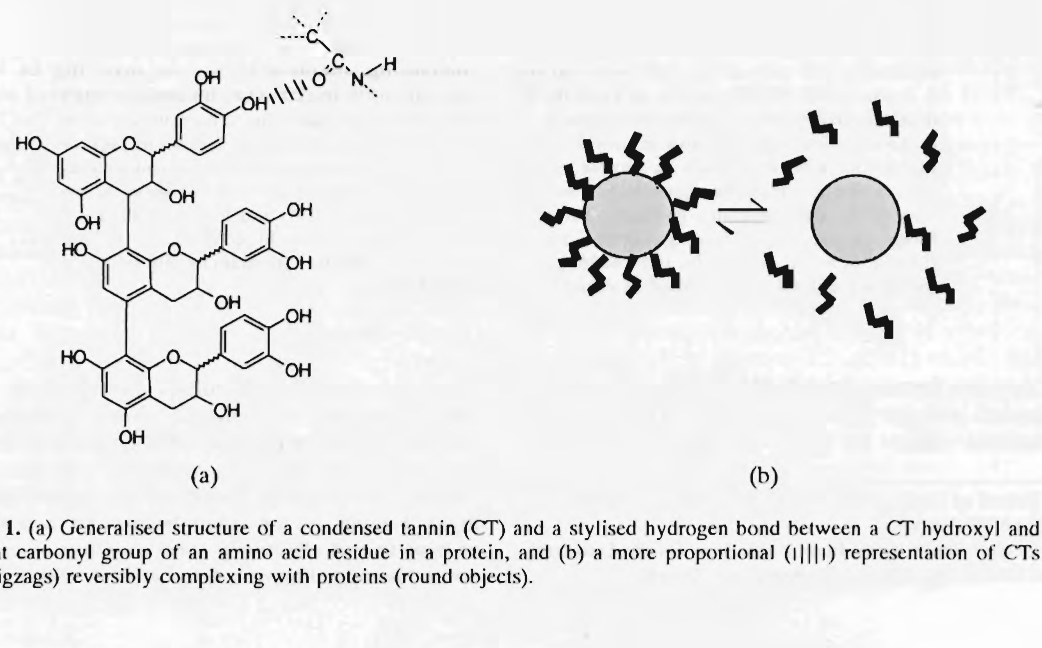

Figure 1. (a) Generalised structure of a condensed tannin (CT) and a stylised hydrogen bond between a CT hydroxyl and adjacent carbonyl group of an amino acid residue in a protein, and (b) a more proportional (ı||||ı) representation of CTs (dark zigzags) reversibly complexing with proteins (round objects).

ability of infused CT to release plant protein post-ruminally. These trials were further complemented by in vitro assessments of the abilities of various *Leucaena* and other CTs to bind with protein.

Feeding (in vivo) trials

In the first feeding trial, at the University of Queensland farm, Brisbane, Australia, the consequences of CT on the flow of N and the digestibility of organic matter (OM) in 15 crossbred weaner ewes (Merino/Dorset/Border Leicester, mean liveweight = 35.3 kg) was examined by feeding them a sole diet of either fresh *L. leucocephala* (K636) with or without the addition of polyethylene glycol (PEG, mw = 4000), or a sole diet of lucerne (*Medicago sativa*) chaff as a positive control (n = 5 ewes per treatment). PEG effectively neutralises CT without affecting the non-tannin components of the feed, such that any changes due to PEG treatment can be attributed to an effect of CT. PEG was applied at a rate of 50 g/day/sheep by spraying a 1 in 3 (g/g) aqueous solution of it onto the *Leucaena* immediately before feeding.

For each treatment, 1000 g of DM was offered on the assumption that the freshly harvested *Leucaena* had a DM content of 30% and the lucerne chaff 88%. The *Leucaena* was harvested daily, kept refrigerated until needed, and fed in equal aliquots every 2 hours by automatic feeder over a 20-hour period/day. The feeder was reloaded, and refusals collected, twice/day. The animals were given 5 days to acclimatise to the treatments and their metabolism pens, and faecal and urine collections were made over the next 7 days, for the determination of N balance and the apparent digestibility of N and OM. Representative samples of the fed and refused forage were collected daily, freeze-dried, and ground for subsequent analyses for N and OM contents. Post-ruminal flows of total non-ammonia N (NAN) were determined by euthanasing the animals, and relating the concentration of Cr_2O_3 and NAN in the total mixed contents of the abomasum to N intake relative to the constant release rate of Cr_2O_3 from a slow release capsule administered into the rumen of the sheep 16 days earlier. Microbial protein production was estimated from the total excretion of purines in the urine over the 7-day N balance period, as described by Chen and Gomes (1995). CT contents of the forage were assayed using the Butanol-HCl method, as modified by Dalzell and Kerven (1998), with purified *L. pallida* CT as the assay standard.

The second feeding trial, conducted at the University of Technology (Unitech) in Lae, Papua New Guinea, was a comparison of nutritive value of four *Leucaena* species, freshly harvested 100% *Leucaena* diets (750 g DM/d, assuming 30% DM) for sheep (Priangan × Highland ram lambs, mean liveweight = 24.3 kg, n = 6/treatment). The four *Leucaena* diets were *L. leucocephala* (K636), *L. collinsii* (OFI 51/88), *L. pallida* (CQ 3439) and *L. trichandra* (OFI 53/88). Nutritive value was assessed in terms of N retention and the apparent digestibility of N and OM. Procedure for total collection of faeces and urine and chemical analyses (N, OM and CT) were similar to the first feeding trial. The one exception was that the assays were completed on oven-dried (65 °C), rather than freeze-dried forage samples.

In the final in vivo trial, at the University of Queensland, CT fractions extracted and purified from *L. leucocephala* (K636), *L. collinsii* (OFI 51/88), *L. pallida* (CQ 3439), *L. trichandra* (CPI 46568), *Lotus pedunculatus* cv. Maku, and *Acacia aneura* were each complexed with *Leucaena* leaf proteins labelled with the isotope ^{15}N and infused into the abomasum of sheep together with a solution of Cr-EDTA. Several hours later, digesta from the end of the small intestine was collected and analysed for the ratio of ^{15}N (above natural background levels) to Cr-EDTA. The change in ratio of Cr-EDTA to ^{15}N infused to that collected at the ileum is directly indicative of the true digestibility of the complexed protein and hence a measure of the ability of a given CT to release protein post-rumen for digestion and absorption into the blood stream. CT from each genotype was extracted and purified as described by Perez-Maldonado and Norton (1996a, b).

In vitro trials

The relative binding abilities of the purified CTs used in the final in vivo trial (above) were also assessed in vitro. Their abilities to bind and precipitate protein (i.e., astringency) were measured by adding increasing amounts of CT to 0.75 mg of bovine serum albumin (BSA) in an acetate buffered solution (0.2 M sodium acetate buffer with 0.17 M NaCl at pH 5) until all the BSA was bound to and precipitated by the CT (i.e., maximal binding), according to the method of Makkar et al. (1987). Astringency was defined as the amount of CT required to precipitate half the total protein. Amounts of protein bound were measured by hydrolysing the protein in the precipitates and assaying with ninhydrin. Binding parameters were determined by fitting the sigmoid equation $y = a/(1+\exp(-(x-b)/c))$ where 'a' is the maximal amount of protein precipitated and 'b' is the concentration of CT at 50% of maximal precipitation. CT astringency was defined as the 'b' value. Typical binding curves are shown in Figure 2. Astringencies for CT extracted from *L. leucocephala* (K636), *L. pallida* (CQ 3439), *L. trichandra* (CPI 46568), *Lotus pedunculatus*, and *Acacia aneura*, were determined at pH 5.0 (chosen as this is close to the

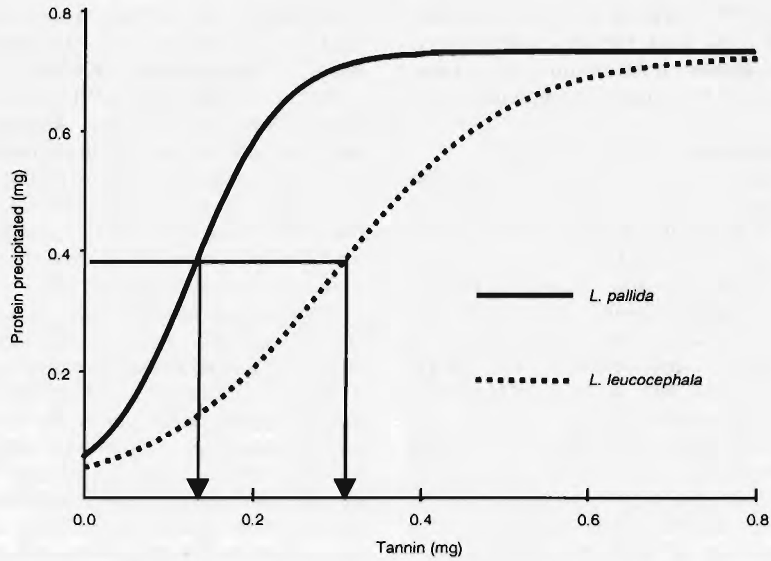

Figure 2. Binding curves for *L. leucocephala* and *L. pallida* tannins added in increasing amounts to BSA protein in an acetate buffered solution at pH 5. The horizontal line running across the curves indicates the point at which half-maximal binding occurred, and the corresponding vertical arrows indicate the amount of tannin at which half-maximal binding occurred, this amount being the definition of the astringency of a given tannin.

isoelectric point of BSA, which is the pH at which BSA is expected to bind CT most readily), and at 2.5 units above (pH 7.5) or below (pH 2.5) the optimal pH. The lower pH represents that which may be expected in the abomasum, and pH 7.5 that in the initial sections of the small intestine. Ruminal pHs would commonly lie between 5.5 and 7.5.

Purified CT from each of *L. leucocephala* (K636), *L. pallida* (CQ 3439), and *L. trichandra* (CPI 46568) were further differentiated, using a size-exclusion column, to reveal a range of CT fractions within each genotype. Spectrophotometric profiles (read at 350 nm) of these fractions, as they eluted from the column are shown in Figure 3. These fractions were collected as they passed from the size exclusion column, and their astringencies measured at pH 5, as described previously. It was expected that the larger CT fractions should elute from the column first and the smaller ones last, and so, by relating elution time to astringency, the authors hoped to relate CT size to astringency.

The fractionation procedure was an adaptation of Derdelinkx and Jerumanis (1984) and Perez-Maldonado (1994). A glass column was packed with Fractogel TSK-HW-40(S) (Merk, Australia) after being pre-swollen with 50% aqueous acetone. The 50% aqueous acetone was degassed and filtered, and pumped through the column at 1.0 mL/min. CT was dissolved in 50% aqueous acetone and 1 mL applied to the column at a concentration of 5 mg/mL. Internal standards of dextran blue and vitamin B12 were used to ascertain the dependability of the column elution times. Elutant from the column was detected with Knauer UV spectrophotometer at 350 nm and the resulting chromatogram fed directly into the Maxima 820 computer program (Dynamic Solutions/Millipore, USA) for analysis. Individual CT peaks were separated by collecting the outflow from the Fractogel TSK-HW-40(S) column on an automated fraction collector (Model 2110, Biorad, Richmond USA). Fractions were collected every minute into a plastic tube. Fractions were bulked and rotary evaporated and frozen before being freeze-dried and stored at 4 °C.

Results and Discussion

Condensed tannins and digestibility

The common hypothesis of action of CTs is that they reduce animal performance by their ability to bind to and hence reduce the digestibility of protein. The interaction between CTs and protein appears to be confined primarily to the digestive tract as CTs are thought to be too large to be absorbed into the blood stream (Mangan 1988; Terrill et al. 1994), although there is some evidence to the contrary (Perez–Maldonado and Norton 1996a). In most fresh forages, the majority of CT is in the unbound (free) form. CTs complex with protein as the animal ingests and/or ruminates the forage, and when the CTs and proteins are mixed in the rumen. Resultant complexes can potentially remain intact throughout the entire digestive tract, exit in the faeces, and represent an important wastage of feed protein. On first analysis, this hypothesis is well supported by the data of others (Table 1), and of these authors (Tables 2 and 3). An elevated excretion of faecal N and a reduced 'apparent' digestibility of N across the whole tract is a consistent consequence of the presence of active dietary CT.

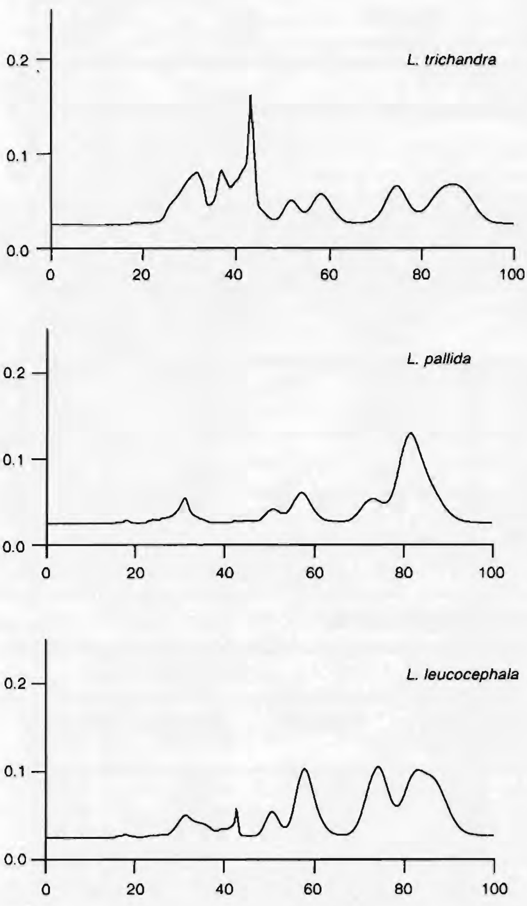

Figure 3. Size-exclusion chromatograms of *L. trichandra, L. pallida,* and *L. leucocephala* CT fractionated on Fractogel TSK-HW-40(S). Mobile phase 50% aqueous acetone at a flow rate of 1 mL/min. and recorded at 350 nm over 100 minutes.

The apparent digestibility of N in the sheep fed *L. leucocephala* with its CTs active was 13% units less and faecal N was 51% higher than *L. leucocephala* with its CTs inactivated by PEG ($P<0.05$, Table 2). When the high CT (*L. trichandra, L. pallida*) and low CT (*L. leucocephala* and *L. collinsii*) species are compared, the apparent digestibilities of the high CT species are more than half that of the lower CT species and the resultant excretion of faecal N almost twice as high (Table 3).

In the comparison of *L. leucocephala* with or without its CTs intact, a high quality lucerne chaff was also included as a positive control to address the assertion of some that the nutritive value of *L. leucocephala* approximates that of lucerne (Table 2). *L. leucocephala* did match luceme chaff for its ability to supply digestible OM, and it approached the apparent digestibility of N for lucerne once its CTs were neutralised. In the case of *L. collinsii*, because it had a similar digestibility of OM to *L. leucocephala* in the Unitech trial, it is reasonable to predict that *L. collinsii* also has a digestibility of OM approximating that of lucerne.

The data in Tables 2 and 3 indicate a promising future for the virtually unknown *L. collinsii* (OFI 51/88) in productive feeding systems, and confirm the superior feeding value of *L. leucocephala*. Conversely, a 100% diet of either *L. pallida* or *L. trichandra* should at best be considered to be little more than a maintenance feed, and of substantially less value as protein supplement than one might expect from an assay of their protein content.

Tannins and bypass protein

A more recent extension of the hypothesis that CTs reduce N digestibility is that the depression of N digestibility can sometimes prove advantageous. CTs could promote bypass protein by protecting feed protein from excessive degradation in the rumen. If the bypass protein is subsequently released post-ruminally, it would prove valuable as a top-up to the microbial protein that is already available, such that the animal absorbs more total protein than would otherwise have been the case (Barry et al. 1986). The rationale behind this possibility is that extremes of pH reduce the strength of the hydrogen bonds between protein and tannin, causing the complexes to fall apart (Jones and Mangan 1977). Ruminal pH, being relatively close to neutral, promotes binding between CT and protein, but when the complex reaches the abomasum, where pH drops dramatically, the hydrogen bond is weakened to the extent that the CT may dissociate from the protein leaving it open to attack by proteolytic enzymes. When the protein and CTs move from the abomasum to the beginning of the small intestine, pH rises as a result

Table 1. Studies in which the effect of CT on nutritive value parameters has been determined by treating tanniniferous forages with or without the CT neutralising agent, PEG.

Diet	DMD or OMD	N digestibility (apparent)	Faecal N	NAN absorbed post-ruminally	N retention
Lotus pedunculatus (Barry et al. 1986)	negative	negative	positive	positive	n.s.
Desmodium ovalifolium (Carrulla 1994)	n.s.	negative	positive	NR	negative
Desmodium ovalifolium	n.s.	negative	positive	positive	NR
Flemingia macrophylla (Rosales 1995)	negative	negative	positive	n.s.	
Acacia aneura (Mulga) (Pritchard et al. 1992)	n.s.	negative	NR	NR	n.s.
Lotus corniculatus	n.s.	negative	positive	positive	NR
Lotus pedunculatus (Waghorn 1990)	n.s.	negative	positive	n.s.	
Calliandra calothyrsus (Norton and Ahn 1998)					
frozen	n.s.	negative	positive	NR	n.s.
dried	n.s.	negative	positive	NR	n.s.

NR denotes not reported
negative denotes a significant ($P<0.05$) reduction, and positive denotes an increase, in the measure due to active CT
n.s. denotes no significant ($P>0.05$) change detected

Table 2. The digestibility of OM, N, and the excretion of N in the faeces of sheep (n = 5/treatment) fed either fresh *Leucaena* with or without its CTs neutralised by a foliar application of PEG, compared to lucerne chaff.

	Extractable CT (% DM)	DM intake (g/d)	N intake (g/d)	OM digestibility (apparent) (%)	N digestibility (apparent) (%)	Faecal N (g/d)
Lucerne chaff	0.54	1042^{a}	36.3	66.2	78.8^{a}	7.6^{a}
L. leucocephala	7.30	934^{b}	31.7	65.0	64.2^{b}	11.3^{b}
L. leucocephala (CTs neutralised)	4.23	984^{b}	33.5	64.4	77.5^{a}	7.5^{a}
Pooled s.e.		17	1.1	0.8	1.2	0.3

Within a row, means lacking a common superscript letter differ ($P<0.05$)
Extractable CT determined on freeze-dried samples

Table 3. Nutritive value of four *Leucaena* species fed fresh to sheep (n = 6/treatment)

	Extractable CT (% DM)	DM intake (g/d)	OM digestibility (apparent) (%)	N digestibility (apparent) (%)	N (g/day) Ingested	N (g/day) Faecal	N (g/day) Retained
L. leucocephala	3.75	555	60.1^{a}	66.4^{a}	18.08^{a}	6.04^{a}	2.46^{ab*}
L. collinsii	0.58	561	58.8^{a}	80.5^{b}	21.80^{b}	4.25^{b}	4.70^{a}
L. pallida	5.76	563	48.2^{b}	37.5^{c}	17.47^{a}	10.91^{c}	−0.01^{bc*}
L. trichandra	6.51	504	42.3^{c}	37.8^{c}	15.77^{c}	9.69^{d}	−0.53^{c}
Pooled s.e.	—	22	1.9	2.2	0.56	0.4	0.91

**L. pallida* was different to *L. leucocephala* at $P = 0.07$
Within a column, means lacking a common superscript letter differ ($P<0.05$)
ND, not detectable
Extractable CT determined on oven-dried samples and are therefore underestimates of true values in the fresh forage fed (see Dalzell et al. 1998)

of the entry of bicarbonate and this alkaline environment also weakens the hydrogen bonds, this process being further aided by the detergent action of bile, allowing further digestion and consequently absorption of the protein to occur (Mangan 1988).

In agreement with data from studies on *Lotus* and *Desmodium* (Table 1), it has been demonstrated that *L. leucocephala*, with its CT active, tends to stimulate a greater supply of protein to the small intestine of sheep (Table 4). Per unit of N intake, CT enhanced the total supply of protein by 37% units, relative to *L. leucocephala* with its CTs inactivated by PEG. The supply of microbial protein was unchanged due to the presence of active CT, indicating that the amount of CT in *L. leucocephala* was such that it did not bind feed protein to the extent that the rumen microbes were deprived of N.

Surprisingly, the enhanced flow of protein due to *L. leucocephala* CT did not translate into an improved retention of N. This raises the question of whether the *L. leucocephala* CTs were releasing the protein post-ruminally.

To screen *L. leucocephala* CTs for an ability to release protein post-ruminally, the authors characterised the interactions with protein both in vitro and in vivo. *Leucaena leucocephala* CT was compared to CT from *L. trichandra* and *L. pallida*. To place the behaviour of *Leucaena* CT in the context of better known CTs, fractions extracted from *Acacia aneura*, and *Lotus pedunculatus* were also included. In vitro, *L. leucocephala* CT was the weakest binder of BSA protein of all those tested, and *L. pallida* the strongest at pH 2.5, 5 and 7.5 (Table 5). Twice as much *L. leucocephala* CT as *L. pallida* CT was required to bind the same amount of protein, at pH 5. The astringencies of other CTs fell between *L. leucocephala* and *L. pallida*, with the majority tending toward the *L. pallida*. Clearly, *L. leucocephala* CT is an exceptionally weak binder of protein.

The variability in the in vitro astringencies of *Leucaena* CTs may be attributed to the size of the CT, abundance of hydroxyl groups, and the presence of side chains on the CT backbone. Size, or more specifically polymer length, has been considered to be the most important factor influencing the astringency of CTs (Spencer et al. 1988).

The speed with which CTs elute from a size exclusion column is one means of ranking CTs on size. When the CT fraction from specific *Leucaena* species were compared in this way it became immediately evident that within a specific *Leucaena*, there was not one CT, but many (Figure 3). The variety and relative amounts of individual CTs also differed between *Leucaena* species. It was also apparent that some peaks (representative of individual CTs) were similar across species, raising the possibility that they were the same CTs. This proved not to be the case.

Similar peaks from different *Leucaena* species varied in their astringencies sometimes by as much as two-fold (Table 6). Furthermore, astringency did not necessarily increase with apparent increases in CT size. In Table 6, Peak 1 is the first peak to elute from the column, and therefore expected to be the largest CT fraction, and Peak 7 the smallest. Remembering that the lower b values indicate a higher astringency, only for *L. trichandra* was there a decrease in astringency as the size of the CT decreased. For *L. pallida* and *L. leucocephala*, there was only an obvious difference decrease in astringency between the largest CT and the rest. In fact, for *L. leucocephala*, after a point, as its CTs became smaller their astringency began to increase again. Most of the *L. leucocephala* CTs exhibited low astringencies. Clearly, CT size is only part of the explanation for astringency differences between individual CTs in *Leucaena* species.

Table 4. Non-ammonia N (NAN) flows in relation to N intake, and N retention, in sheep (n = 5/treatment) fed *L. leucocephala* with or without its CTs neutralised by PEG.

	N intake (g/d)	Abomasal NAN flow (g/g N intake)			N retention	
		Total	Microbial	Dietary (i.e. bypass)	(g/d)	(g/g N intake)
L. leucocephala	31.7	1.003	0.554	0.449	7.2	0.228
L. leucocephala (CTs neutralised)	33.5	0.635	0.558	0.077	10.4	0.306
Pooled s.e.	0.8	0.138	0.043	0.138	1.4	0.038
P value	0.16	0.095	0.95	0.092	0.142	0.187

Table 5. Influence of pH on the astringency of CT from three *Leucaena* species in comparison to better known CTs.

CT source	pH 2.5	pH 5	pH 7.5
Leucaena pallida	0.435	0.141	0.216
Lotus pendunculatus	0.459	0.156	0.254
Leucaena trichandra	0.612	0.162	0.28
Acacia aneura	0.744	0.182	0.343
Leucaena leucocephala	No binding	0.295	0.558

Table 6. Astringency (g tannin required for half maximal precipitation of 0.75g of BSA protein) of individual CTs isolated from within the CT fraction of three *Leucaena* species, relative to their order of elution from a fractogel TSK-HW-40 (S) size exclusion column (see Figure 2).

Peak	*L. leucocephala*	*L. trichandra*	*L. pallida*
1 (largest)	0.226	0.151	0.139
2			
3		0.145	
4	0.289		
5	0.375	0.170	0.241
6	0.277	0.209	0.227
7 (smallest)	0.304	0.293	0.264

In vitro, when pH was either increased to pH 7.5 or decreased to pH 2.5, relative to pH 5, CT astringencies were reduced (Table 5). The reduction in astringency from pH 5 to pH 2.5 was most dramatic, in the order of 3–4 fold. All CTs maintained their original astringency rankings in response to the pH changes. Most importantly, *L. leucocephala* lost its ability to precipitate protein at abomasal pH (pH 2.5). This marked the CTs in *L. leucocephala* as prime candidates for those most likely to promote useable bypass-protein. The next step was to verify this in vivo, in the gut of the sheep.

Leucaena leucocephala and *Lotus pedunculatus* CT, when complexed with leaf protein and infused into the abomasum of the sheep, did not significantly reduce the digestibility of the protein relative to the uncomplexed protein control (Table 7). This indicated a high level of protein release between the abomasum and the end of the small intestine. The *L. trichandra* CT, and the *Acacia aneura* CT, both reputed to be highly astringent, did reduce the true digestibility of the protein they were associated with, as had been expected. However, it was surprising that even though the *A. aneura* and *L. trichandra* CTs interfered with protein digestion, the interference was relatively small. They still released at least 78% of the protein that they had previously bound. The expectation was that the more astringent CTs would release very little, if any, of their protein. This questions the common understanding that 'bad tannins' carry protein in an unavailable form through the entire digestive tract.

Table 7. In vivo ability of CT to release protein post-ruminally.

CT source	n	True digestibility (%)
Leucaena trichandra	3	77.8[a]
Acacia aneura	3	77.7[a]
Lotus pedunculatus	2	86.9[ab]
Leucaena leucocephala	3	88.3[ab]
Control (no CT)	2	94.2[b]
Pooled s.e. (n = 3)		4.7

Within a column, means lacking a common superscript letter differ ($P<0.05$)

Hence it is evident that *L. leucocephala* CT is particularly good at releasing protein post-ruminally. The data of Barry et al. (1986), Waghorn (1990), Carrulla (1994) and Rosales (1995) indicates similarly for *Lotus* and *Desmodium* CT. Yet, even though the evidence is for CTs enhancing the supply of useable protein, in the pen trials and others that have also measured N retention, this extra supply of protein has not translated into a higher retention of N (Barry et al. 1986; Carulla 1994; and Rosales 1995, Table 1). Only in some grazing trials has a positive effect on N retention, measured in terms of improved milk and wool production, been noted. This was with sheep fed *Lotus corniculatus* forage and drenched with water or PEG twice daily to determine the effect of CT alone (Wang et al. 1996a, b). Why there is no consistent link between improved N flow and improved N retention remains to be explained. One explanation for N retention not increasing may be that there was an insufficient supply of metabolisable energy to complement the enhanced supply of N (MacRae and Lobley 1986).

However, an alternative explanation may be derived from the 'endogenous protein' hypothesis of Butler (1989, 1992). It is possible that CTs may enhance the natural loss of endogenous protein such that this loss offsets any gains in protein flow due to CT, the end result being a minor if any effect of CT on N retention.

Tannins and the loss of endogenous protein

From the perspective of monogastrics, Butler (1989, 1992) suggests than tannins may exert their major action on protein utilisation by increasing the loss of endogenous protein, rather than by inhibiting the true digestibility of feed protein. Transferring the situation from the monogastric to the ruminant, if tannin protects feed protein through the rumen without reducing the production of microbial protein, and then releases that extra protein for digestion due to the pH extremes and bile in the abomasum and duodenum, the animal will receive more protein. However, the free CT may re-activate further along the small intestine, as the pH becomes more neutral and the activity of bile declines. Once re-activated, the CTs could then bind to endogenous proteins such as the epithelial cells lining the gut wall and to enzymes in the digesta, causing the premature death of the epithelial cells and preventing the reabsorption of the protein in these cells and enzymes by the animal.

Butler (1989, 1992) supports his hypothesis by referring to rat and chicken studies in which isotopically-labelled feed protein does not appear in faeces, despite it being fed with active CT. Whereas when endogenous protein is labelled with isotopes, the appearance of the isotope in the faeces increases when CTs are added to the diet. Concentrations of proteolytic enzymes in the monogastric gut can also increase in response to tanniniferous diets (Glick and Joslyn 1970; Tamir and Alumot 1970; Shahkhalili et al. 1990). The endogenous protein hypothesis is also consistent with data in ruminants which shows CTs reduce the 'apparent' digestibility of protein (Table 1), if one considers how 'apparent digestibility' is calculated, i.e., apparent digestibility = 1 — (faecal N/intake N), where faecal N comprises undigested feed N + endogenous N. Hence an increase in endogenous N will reduce 'apparent digestibility', just as an increase in undigested feed N would. That CTs induce an excessive loss of endogenous protein and that this offsets any advantage CTs might confer by promoting bypass protein is a hypothesis worthy of pursuit in the ruminant.

Conclusions

Leucaena leucocephala CTs are exceptionally weak binders of protein, in comparison to CTs from *L. pallida*, *L. trichandra*, *Lotus pedunculatus*, and *Acacia aneura*. *Leucaena leucocephala* CT can enhance the supply of protein to sheep by the provision of extra bypass protein, but this does not necessarily translate to an improved retention of N. The quality of *L. leucocephala* approaches the quality of lucerne, despite its content of CT. With virtually no detectable CT, *L. collinsii* is of similar quality to *L. leucocephala*, and more so in terms of its ability to supply rumen degradable protein. In contrast, the high concentrations of CT in *L. pallida* and *L. trichandra* forage are consistent with a greatly reduced availability of N, to the extent that their value as protein supplements could be severely limited.

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Palatability of *Leucaena* to Ruminants

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Abstract

The palatability of up to 27 *Leucaena* accessions was evaluated in four trials in Australia, Philippines and Honduras. In Australia, 21 *Leucaena* accessions and one accession each of *Calliandra calothyrsus*, *Sesbania sesban* and *Gliricidia sepium* were grazed by cattle. In a second Australian trial, three foliar treatments were applied to the accessions before grazing, namely NaCl, polyethylene glycol and fructose, in an attempt to improve the palatability of the plants. In the Philippines and Honduras, the palatability of 19 and 27 *Leucaena* accessions respectively were assessed in cut-and-carry experiments with sheep. *Leucaena* accessions were deemed palatable if they were eaten as readily as the reference accession, *L. leucocephala* subsp. *glabrata* K636. The relative palatability of the accessions was determined by leaf defoliation, grazing observation and dry matter intake data. For both sheep and cattle, accessions of *L. diversifolia* (OFI 45/87, 46/87, 82/92, 83/92 and K156), *L. leucocephala* subsp. *glabrata* cv Cunningham and hybrids of *L. pallida* × *L. leucocephala* (K376 × K8, (K748 × K806) × K636, K748 × K636) were found to be similarly palatable as K636. Those accessions with a palatability consistently less than K636 were *L. collinsii* subsp. *zacapana* (OFI 56/88, 18/84, 57/88), *L. esculenta* (OFI 47/87, 48/87), *L. macrophylla* subsp. *istmensis* (OFI 47/85), *L. pallida* (OFI 79/92) and *L. salvadorensis* (OFI 17/86, 36/88). Cattle found most of the *Leucaena* accessions to be highly palatable, in contrast to sheep which rejected more accessions. Chemical composition data gave little insight into why some accessions had either acceptable or low palatabilities. In particular, no relationship was found between palatability and condensed tannin content except for a weak but positive relationship in the second Australian trial ($r^2 = 0.23$, $P<0.05$). Foliar sprays did not alter the palatability of accessions ($P>0.05$) suggesting that Na, fructose and condensed tannins were not significantly involved in determining palatability in these short-term trials.

THE high palatability of *Leucaena leucocephala* has contributed significantly to its widespread use as forage in directly grazed and cut-and-carry systems. However, the *Leucaena* genus consists of a large number of other species of unknown palatability. Some of these are agronomically superior to *L. leucocephala*, and their chemical compositions suggest they are of high quality for sheep and cattle (see Dalzell et al.; Mullen and Shelton et al., these Proceedings). To determine which of these relatively unknown species deserve detailed evaluation in livestock feeding systems it is essential firstly to demonstrate that livestock will readily eat them. Then, if some are not readily eaten, an attempt should be made to understand why.

The low palatability and intakes of some forage plants have been related to the presence of high levels of condensed tannin (CT) (*Acacia aneura* — Pritchard et al. 1992; *Coleogyne ramosissma* — Provenza and Malechek 1984; *Lotus pedunculatus* — Barry and Duncan 1984; *Sericea lespedeza* — Petersen et al. 1989). Lesser-known *Leucaena* species contain a range of total CT concentrations from negligible levels to greater than 25% dry matter (see Dalzell et al., these Proceedings). Consequently,

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a similarly large range in palatability may be evident within the *Leucaena* genus.

A limitation of specific nutrients can also reduce intake (Ternouth 1991; Muinga et al. 1992). Some *Leucaena* species contain inadequate levels of sodium (Na) (Kleinjans 1984; Austin et al. 1992), and possibly an excessive nitrogen to energy ratio. The addition of Na and increases in water soluble carbohydrates (WSC) content to reduce the N:energy ratio have been demonstrated to improve the palatability of other forages (Goto et al. 1986; Michell and Moss 1988; Chiy and Phillips 1991; Jones and Roberts 1991; Ciavarella et al. 1998) and may improve the palatability of the *Leucaena* species.

This paper presents the results of four palatability trials: two direct grazing field trials with cattle in northern Australia, involving 21 accessions of *Leucaena* and one accession each of *Calliandra calothyrsus* (calliandra), *Sesbania sesban* (sesbania) and *Gliricidia sepium* (gliricidia), and two cut-and-carry trials with sheep; one in the Philippines with 19 *Leucaena* accessions, and the other in Honduras with 27 *Leucaena* accessions bulked to taxon and hybrid level resulting in 15 feed treatments (Stewart and Dunsdon 1998). The existence of a relationship between tannin content and palatability rating was investigated in the Australian and Honduran trials.

In the second field trial with cattle in Australia, an attempt was made to improve palatability by the foliar application of fructose to increase energy levels on offer, sodium chloride (NaCl) to correct for Na deficiency and polyethylene glycol (PEG, which binds to tannins rendering them biologically inactive) to relate a reduction in CT content to improved palatability. In all trials, the palatability of the *Leucaena* accessions is expressed relative to the reference variety, *L. leucocephala* subsp. *glabrata* K636 (registered under the cultivar name Tarramba in Australia). The term palatability is used in a relative rather than an absolute sense, to overcome the much debated vagueness associated with it (Forbes 1995; Nolan et al. 1995).

Materials and Methods

Palatability trials were conducted in Australia, the Philippines and Honduras between 1993–1997. Site descriptions are listed in Table 1 and the accessions examined are listed in Table 2.

Mt Cotton, Australia

Trials were conducted at the Australian site during summer (Trial 1, January/February) and winter (Trial 2, June/July). For Trial 1, the relative palatabilities of 21 *Leucaena* accessions and single accessions of calliandra, sesbania and gliricidia were assessed in a grazing trial with cattle (Table 2).

The accessions were planted as paired trees within an area of 270 m^2, on a 3 × 6 m grid and these areas were replicated 16 times over 2 sites (8 replicates per site set out in a randomised complete block design). Trees were pruned to 75 cm in height one month prior to the commencement of the experiment.

Four crossbred steers (Charolais × Brahman) approximately 16-18 months old with a liveweight of 218 kg (±22 kg) were used. The steers' normal diet was native grass pastures in southeast Queensland and they had no previous exposure to the forage tree accessions in this trial. Six weeks prior to the commencement of the experiment they were exposed individually to the taste and smell of each accession by offering them 0.5 to 2.5 kg of freshly cut edible foliage (leaf and stem <6 mm in diameter) for approximately 45 minutes or until totally consumed. Sesbania was offered a second time due to low intake levels in the first exposure. The steers ate no

Table 1. Site description of forage production areas used in the palatability trials.

	Mt Cotton Australia	**Batangas** Philippines	**La Soledad** Honduras
Altitude (m)	25	5	593
Soil pH (1:5 water)	5.9	5.9	6.7–7.0
Soil type	Altisol	Vertisol	—
Soil texture	clay-loam	silty loam	loam
Soil fertility	Poor/Medium	Very good	Good
Latitude	27°37'S	13°09'N	14°27'N
Longitude	153°14'E	121°25'E	87°41'W
Climate	Sub-tropical	Tropical	Tropical
MAR[1] (mm)	1200 (+ irrigation)	1900	1035
Sown or planted	Dec 1995	Jun 1995	1989
Established from:	seedlings	seedlings	seedlings

[1] Mean annual rainfall

Table 2. Forage tree accessions[1] included in each trial.

Taxon/hybrid	Mt Cotton, Australia	Batangas, Philippines	La Soledad, Honduras[2]
Leucaena collinsii subsp. *collinsii*	OFI 52/88 (1[3])	OFI 52/88	OFI 45/85, OFI 51/88
L. collinsii subsp. *zacapana*	OFI 56/88 (2)	OFI 56/88	OFI 18/84, OFI 56/88, OFI 57/88
L. diversifolia	OFI 82/92 (3) OFI 83/92 (4)	K156 OFI 83/92	K156, OFI 45/87, OFI 46/87
L. diversifolia × *L. pallida* — KX1			KX1
L. esculenta	OFI 47/87 (5)	OFI 47/87	OFI 47/87, OFI 48/87
L. involucrata			
L. lanceolata var. *lanceolata*	OFI 43/85 (6)	OFI 43/85	OFI 43/85, OFI 44/85
L. lempirana	OFI 6/91 (7)	OFI 6/91	
L. leucocephala subsp. *glabrata*	cv Cunningham (8) K636 (9)	cv Cunningham K636 Peru	K636, K8
L. leucocephala × *L. diversifolia* — KX3		K8 × K156	K8 × K156, K636 × K156
L. macrophylla subsp. *macrophylla*			OFI 55/88
L. macrophylla istmensis	OFI 47/85 (10)	OFI 47/85	OFI 47/85
L. magnifica	OFI 19/84 (11)	OFI 19/84	
L. multicapitula			OFI 81/87
L. pallida	OFI 52/87 (12) OFI 79/92 (13) CQ3439 (14)	OFI 52/87 OFI 79/92 CQ3439	
L. pallida × *L. leucocephala* — KX2	K376 × K8, F5 (15)	K376 × K8, F5	KX2 88-1
L. pallida × *L. leucocephala* — KX2	(K806 × K748) × K636, F1 (16)	K748 × K636, F1	
L. pulverulenta			OFI 83/87, OFI 84/87
L. salvadorensis	OFI 36/88 (17)	OFI 36/88	OFI 17/86, OFI 34/88
L. trichandra	CPI46568 (18) OFI 4/91 (19) OFI 53/88 (20)	CPI46568 OFI 53/88	OFI 53/88
L. trichodes	OFI 61/88 (21)		OFI 2/86, OFI 61/88
Calliandra calothyrsus	CPI115690 (22)		
Gliricidia sepium	cv Retalhuleu (23)		
Sesbania sesban	cv Mt Cotton (24)		

[1] OFI prefaces Oxford Forestry Institute ID No., K prefaces University of Hawaii ID. No., CQ prefaces CSIRO introduction No. and CPI prefaces Commonwealth Plant ID No.
[2] Taxa with more than one accession were bulked when offered to sheep.
[3] Accession codes used in Figures 1, 2 and 3.

gliricidia despite it being offered on four separate occassions.

Steers were housed in a pen beside the trial sites with *ad libitum* access to pangola grass hay (*Digitaria eriantha*) and water. The eight replications of the first site were grazed before moving onto the second site. They were allowed to graze one replicate per day for 2 hours from approximately 6 am. The grazing period consisted of 1 hour grazing, 1 hour in the pen and then a further 1-hour grazing. Before and after the grazing of each replicate, the leaves on each accession were counted to measure leaf removal during grazing. The grazing behaviour of each steer was recorded in 20-second time intervals, from a 4 m tower placed beside the replicate. The number of times an accession was observed being grazed, termed as grazing frequency, was recorded within each replicate. Indices of palatability used for accessions tested were leaf defoliation and grazing frequency.

Trial 2 was carried out four months later on the same sites, using the same steers (275 kg ±12 kg), and a similar but modified protocol to Trial 1. Trees were pruned two months before the trial to 75 cm in height. Differences to Trial 1 were that the sites were grazed in reverse order, replicates were grazed at approximately 11 a.m., the grazing behaviour of each steer was recorded every 30 seconds, and immediately before being grazed the plants in each replicate were sprayed until dripping with one of four treatments: (1) 50 g/L NaCl, (2) 167 g/L fructose, (3) 167 g/L PEG (mw = 4000), or (4) de-ionised water. These foliar treatments were randomly assigned to the eight replicates within each site with the provision that the cattle were not exposed to the same treatment for two consecutive replicates.

For leaf defoliation data from both trials, replicates were treated as consecutive grazing occassions in time and these were considered to be the 16 defoliation attributes measured on each accession. The frequency data from both trials were expressed as the average grazing frequency for each 30-minute time period over the 2-hour grazing periods. From this, the grazing frequencies for each accession within each consecutive 30-minute period were expressed as percentages of the accession grazing frequency for the 2-hour period.

For Trial 1, cluster analysis (Williams 1976) was used to group accessions that performed similarly according to leaf defoliation and grazing frequency.

For Trial 2, the grazing frequency data were used to test for differences in rate of intake (changes in palatability) between foliar treatments. Analysis of variance was used to determine differences.

Batangas, Philippines

The palatability of 19 freshly-cut accessions of *Leucaena* species for sheep was evaluated in Batangas, Philippines in November 1997 (Table 2). All forage was sourced from a nearby germplasm evaluation site based at the Bureau of Plant Industry, Lipa City. The animals' normal diet was native grasses supplemented occassionally with *Desmodium rensonii* and *Desmanthus virgatus*. They had no previous experience with *Leucaena* species except in one preliminary palatability trial conducted with the same species earlier in the year in April/May.

A circular pen (50 m^2) was constructed and all vegetation was removed. Three days prior to the trial, three ewes (8–9 months old, live weight average 16 kg) were exposed to a small amount of each accession in randomly arranged troughs around the perimeter of the pen. To further familiarise the sheep with the arrangement of the troughs, the sheep were placed in the pen and concentrate (100 g/trough) was given in the troughs for the following two days. During this time, an observer practised recording the time each sheep spent eating the concentrate.

When the experiment started the sheep were offered 500 g of fresh edible forage (leaf + fine stem ≤6 mm, up to the fifth fully expanded leaf) in clearly labelled troughs placed randomly and equally around the inside perimeter of the pen. The sheep were allowed access to the pen for 40 minutes, rested in a side pen with no feed for 40 minutes and then placed back into the main pen for a further 40 minutes. During the exposure, accessions being eaten by each sheep, if any, were recorded every 20 seconds. Fresh weight of forage after feeding was measured. Dry matter content before and after feeding was estimated using a 100 g subsample which was then used to determine dry matter intake (DMI).

This protocol was repeated for 4 consecutive days. Dry matter intake for each accession and the number of times the sheep were observed eating each accession were the two indices used to assess palatability.

Analysis of variance was used to determine least significant differences between accessions based on DMI and grazing frequency data.

La Soledad, Honduras

A total of 27 *Leucaena* accessions were bulked to taxon and hybrid level, resulting in 15 feed treatments being tested at La Soledad, Honduras in 1994 (Table 2). The forage was sourced in 1993 from the main experimental site of the Conservation and Silviculture of the Dry Zone Species Project (CONSEFORTH) in the Comayagua Valley of Honduras.

Nine adult Barbados Blackbelly ewes (live weight 15–25 kg) with no previous experience of the *Leucaena* accessions tested or forages high in secondary compounds were divided into three groups of three. The animals' normal diet was native grasses. Each group (replicate) was placed in a circular pen, with 15 randomly positioned troughs containing the feeds placed within the perimeter. The position of the troughs was re-randomised daily. Each morning, 500 g of fresh leaf material was placed in troughs within the three pens. A 100 g sub-sample (of similar material to that offered to sheep) was used for dry matter content determination. The sheep had no food overnight and were given access to the pens for 4 hours daily. The consumption of the feeds by each group was recorded daily for 18 consecutive days.

Refusals were weighed after the 4-hour exposure period and another sub-sample for dry matter content determination taken. The time for finishing was recorded for those feeds that were finished completely (or for which <50 g remained) before the time period ended. These data were converted to DMI per hour, and used as a measure of palatability, on the assumption that the most palatable feeds would be eaten most quickly.

Dry matter intake differences between accessions were determined by analysis of variance.

Palatability and plant composition

For both Australian trials, correlations between palatability (measured as grazing frequency for each accession in the first 30 minutes and expressed as a percentage of the total grazing frequency recorded for the full 2 hours) of the *Leucaena* accessions and total CT content, nitrogen (N) percentage (measured in the first trial only) or N/total CT (Cork 1992) were examined. Tissue samples of the four youngest fully expanded leaves (YFELs) were taken from each accession, in each replicate, before grazing and placed on dry ice, frozen at –20 °C and later freeze-dried. For sesbania, three YFELs were sampled from eight different shoots. All leaf samples were individually ground and equal amounts from replicates 1–4, 5–8, 9–12 and 13–16 were bulked to produce four pooled samples per accession and analysed for CT content (modified Butanol-HCl as defined by Dalzell and Kerven 1998) and nitrogen (Leco-CNS 2000, version 4.06). Correlations were also examined between palatability and dry matter digestibility (DMD), neutral detergent fibre (NDF), ash, macro elements (calcium, magnesium, sodium, potassium, sulfur, phosphorus) and micro elements (boron, copper, iron, manganese, zinc) measured on the same accessions grown on a nearby site (see Dalzell et al., these Proceedings for full sampling and analyses details).

The palatability results from the Honduras trial were also correlated with plant composition analyses carried out 1 to 3 years before the palatability trial commenced. Refer to Stewart and Dunsdon (1998) for sampling and analyses details. Plant samples were analysed for crude protein (CP), organic matter (OM), neutral detergent fibre (NDF), acid detergent fibre (ADF), condensed tannin (CT), total tannin (TT), dry matter digestibility (DMD), organic matter digestibility (OMD) and digestible organic matter in dry matter (DOMD).

Results

Mt Cotton, Australia

From the leaf defoliation data in Trial 1, three accession groupings were identified (Figure 1). Most of the *Leucaena* accessions (Group 1) were almost completely defoliated by the end of each grazing period and this occurred from the beginning of the trial to the end with the exception of *L. trichandra* (OFI 4/91) and *L. macrophylla* subsp. *istmensis* (OFI 47/85) (Group 2). These were poorly defoliated for at least the first six grazing occassions, but by the last five they were being totally defoliated. Calliandra was minimally grazed, while gliricidia and sesbania were not consumed at all throughout the trial (Group 3).

From the grazing frequency data, four accession groups were identified. The non-*Leucaena* accessions were not included in this analysis due to their low defoliation levels. Those accessions grazed to the greatest extent at the beginning of the 2-hour period included two commercially available varieties of *L. leucocephala* subsp. *glabrata* (cv Cunningham and K636), and accessions of *L. lanceolata* var. *lanceolata* (OFI 43/85), *L. pallida* (OFI 52/87), *L. magnifica* (OFI 19/84), *L. trichandra* (CPI 46568) and *L. trichodes* (OFI 61/88). Accessions grazed least at the beginning of grazing were *L. trichandra* (OFI 4/91) and *L. macrophylla* subsp. *istmensis* (OFI 47/85).

The grazing frequency in the first 30 minutes of the 2-hour grazing period of all accessions was compared against that of K636 (Table 3). Accessions that were within one LSD ($P<0.05$) of K636 were considered palatable. Accessions that were more than one LSD ($P<0.05$) lower than K636 were classed as less palatable. The differentiation between the accessions was carried out at the 30-minute mark because variation in leaf defoliation was greatest at this time. Accessions found to have a similar palatability to K636 were *L. collinsii* subsp. *collinsii* (OFI 52/88), *L. diversifolia* (OFI 83/92), *L. lanceolata* var. *lanceolata* (OFI 43/85), *L. lempirana* (OFI 6/91), *L. leucocephala* subsp. *glabrata* cv Cunningham, *L. magnifica* (OFI 19/84), *L. pallida* (OFI 52/87), *L. pallida* × *L. leucocephala* hybrids (K376 × K8 – F5, (K748 × K806) × K636 – F1), *L. trichandra* (OFI 53/88, CPI 46568) and *L. trichodes* (OFI 61/88). All other accessions were found to be significantly less palatable than K636.

In Trial 2, foliar applications of NaCl, fructose or PEG did not alter palatability ($P>0.05$). Consequently, data were analysed as for Trial 1 by pooling data across treatments and testing for accession groups which behaved similarly over time. Accession groupings mirrored those defined in Trial 1 on the basis of grazing frequency observations (data not shown) and extent of defoliation (Figure 3), with the exception that the defoliation of calliandra and sesbania increased markedly with time. However, gliricidia remained ungrazed throughout.

Batangas, Philippines

Grazing frequency data gave similar results to DMI data (Table 4). The DMI data only was used to classify the palatability relative to K636. Accessions found to be within one LSD ($P<0.05$) of K636 were the two *L. leucocephala* accessions (cv. Cunningham and Alabang) and the two KX2 accessions (K376 × K8 – F5 and K748 × K636 – F1), whereas all other accessions had significantly lower DMIs.

La Soledad, Honduras

Dry matter intakes of the accessions were compared to the *L. leucocephala* subsp. *glabrata* taxon which contained accessions K8 and K636 (Table 5). Only

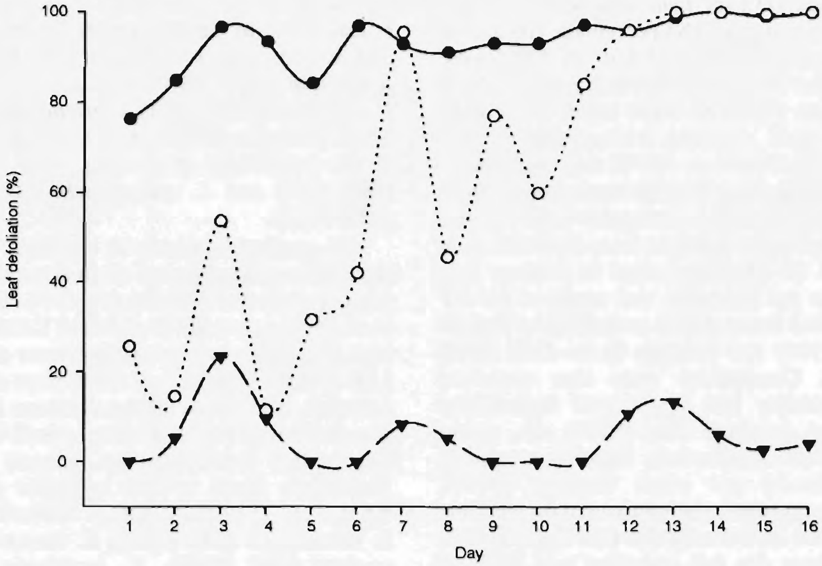

Figure 1. Mean percentage of leaf defoliation for 3 clustered groups of accessions over 16 days for cattle in Australia. Group 1 (●) 1–9, 11–18, 20–21; Group 2 (○) 10, 19; Group 3 (▼) 22–24 (see Table 2 for accession details).

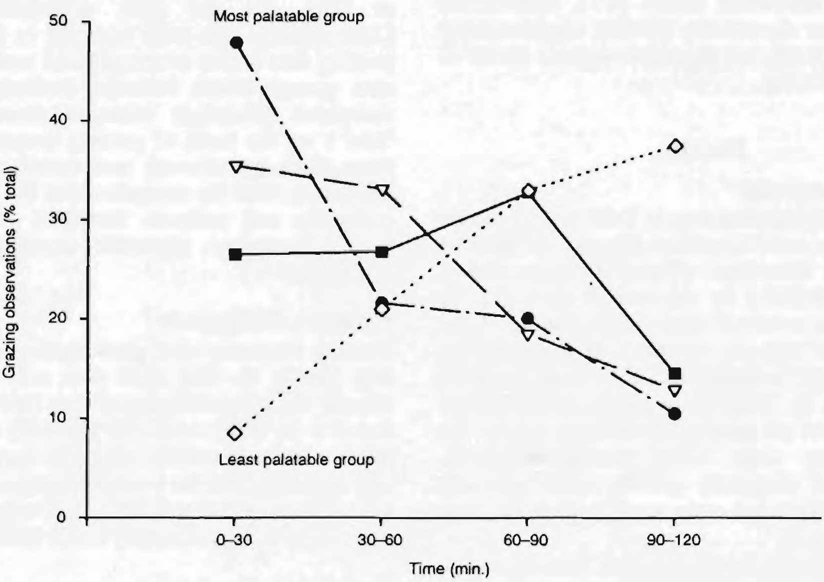

Figure 2. Mean percentage of total grazing frequency per *Leucaena* accession group, for each 30 minute time segment within the 2-hour grazing period, for cattle in Australia. Group 1 (●) 6, 8, 9, 11, 12, 18, 21; Group 2 (∇) 1-4, 7, 15, 16, 20; Group 3 (■) 5, 13, 14, 17; Group 4 (◊) 10, 19 (see Table 2 for accession details). Accessions 22–24 are not included.

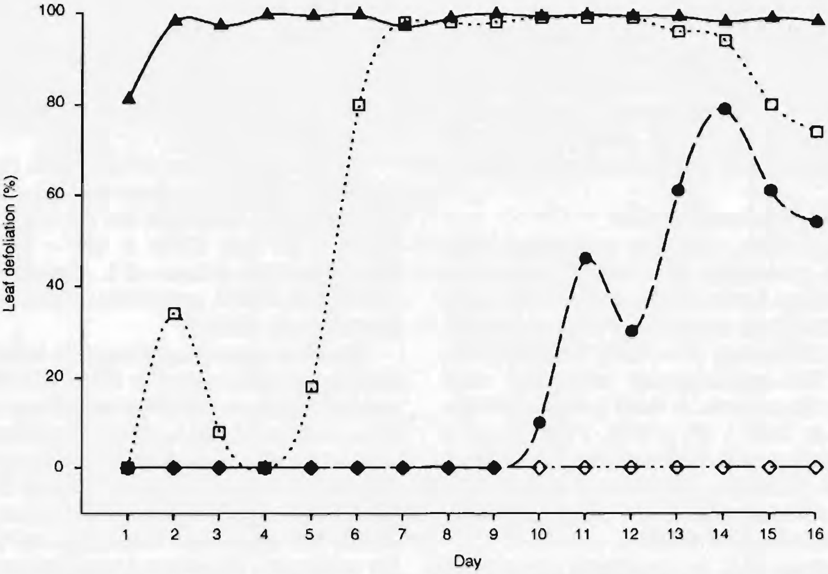

Figure 3. Mean percentage of leaf defoliation for 4 clustered accession groups of *Leucaena* accessions and non-*Leucaena* species over 16 days for cattle in Australia. Group 1 (▲) 1-20; Group 2 (□) 22; Group 3 (●) 24; Group 4 (◊) 23 (see Table 2 for accession details).

Table 3. Mean grazing frequency percentage in the first 30 minutes of the 2-hour grazing period, and palatability classification relative to K636, recorded for *Leucaena* and non-*Leucaena* accessions directly grazed by cattle in Australia.

Accession	Grazing frequency (% of total)	
	Trial 1	
Leucaena collinsii subsp. *collinsii* OFI 52/88	35	P[1]
L. collinsii subsp. *zacapana* OFI 56/88	26	L
L. diversifolia OFI 82/92	33	L
L. diversifolia OFI 83/92	39	P
L. esculenta OFI 47/87	30	L
L. lanceolata var. *lanceolata* OFI 43/85	44	P
L. lempirana OFI 6/91	37	P
L. leucocephala subsp. *glabrata* cv. Cunningham	49	P
L. leucocephala subsp. *glabrata* K636	48	P
L. macrophylla subsp. *istmensis* OFI 47/85	8	L
L. magnifica OFI 19/84	45	P
L. pallida OFI 52/87	47	P
L. pallida OFI 79/92	26	L
L. pallida CSIRO Composite CQ3439	20	L
L. pallida × *L. leucocephala* K376 × K8 Spec Comp — KX2	36	P
L. pallida × *L. leucocephala* (K748 × K806) × K636 — KX2	42	P
L. salvadorensis OFI 36/88	30	L
L. trichandra OFI 53/88	36	P
L. trichandra OFI 4/91	10	L
L. trichandra CPI 46568	43	P
L. trichodes OFI 61/88	57	P
Calliandra calothyrsus CPI 115690	—	
Sesbania sesban cv. Mt Cotton	—	
Gliricidia sepium cv. Retalhuleu	—	
LSD (P<0.05)	13	

[1] Accessions within one LSD of K636 were classified as palatable (P) and those more than one LSD lower were classified as less palatable (L).

one other taxon, *L. diversifolia*, was found to be within one LSD ($P<0.05$) of *L. leucocephala* subsp. *glabrata*. All other taxa had significantly lower DMIs. However, it should be noted that the KX3 hybrids were only slightly greater than one LSD from the *L. leucocephala* subsp. *glabrata* taxon and had a significantly higher DMI than all other taxa.

Palatability and plant composition

In the Australian trials, no strong correlations were found between palatability and total CT content or nitrogen percentage (measured in the first trial only) of *Leucaena* accessions except for a weak but significant positive relationship ($r^2 = 0.23$, $P<0.05$) in the second trial. The non-*Leucaena* accessions were excluded from the analysis. A weak positive correlation with ash in Trial 1 ($r^2 = 0.24$, $P<0.05$) and a negative correlation with NDF in Trial 2 ($r^2 = 0.40$, $P<0.01$) were identified. No strong relationships were found with the macro and micro elements measured when tested at $P<0.05$.

In the Honduras trial, no significant correlations were found between palatability and CT, TT, CP, DMD, OMD, NDF, ADF or DOMD.

Discussion

In this paper, the term palatability is used in a relative rather than an absolute sense to overcome the much debated vagueness associated with it (Forbes 1995; Nolan et al. 1995). The reference point for comparisons was *L. leucocephala* K636 which, at the species level, is widely regarded as a readily-eaten forage (Ibrahim et al. 1988; Burrows and Prinsen 1992; Kaitho et al. 1996, 1997). The superiority of K636 was well supported by these data. Across the Australian, Honduran and Filippino trials, K636 recorded high rates of intake by both sheep and cattle. Relative to K636, sheep exhibited similar preference for just a few *Leucaena* accessions, whereas cattle grazed more than half of the *Leucaena* accessions as readily as they grazed K636. From a practical standpoint, the cattle were even less selective, and given time, they completely defoliated all the *Leucaena* accessions. Yet the cattle showed little preference for the non-*Leucaena* accessions calliandra, sesbania, and gliricidia.

Cluster analysis of the cattle grazing-frequency data grouped the *Leucaena* accessions somewhat better than the leaf defoliation data. Alongside the *L. leucocephalas* in the most palatable group were *L. diversifolia* (OFI 83/92), *L. lanceolata, L. lempirana, L. magnifica, L. pallida* (OFI 52/87, *L. pallida* × *L. leucocephala* hybrid (K376 × K8 – F5), *L. trichandra* accessions (CPI 46568 and OFI 53/88) and *L. trichodes*. Using the LSD analysis, applied to the first 30 minutes of grazing observation data, the group of *Leucaena* accessions not significantly different to *L. leucocephala* (K636) expanded to include *L. collinsii, L. diversifolia* (OFI 82/92), *L. pallida* (CQ3439), and KX2 hybrid ((K806 × K748) × K636 – F1).

Similar applicantion of the LSD analysis to the dry matter intake data from sheep in the Philippines and Honduras, identified the KX2 hybrids (K748 × K636 – F1 and K376 × K8 – F5) and in the Honduran trial a mixture of *L. diversifolia* accessions (OFI 45/87, 46/87, and K156) to be as palatable as *L. leucocephala* (K636).

The most promising *Leucaena* accessions identified as palatable were the KX2 hybrids. They were eaten as readily as K636 by both sheep and cattle and this, combined with a superior agronomic performance to K636 and acceptable in vitro nutritive values (see Mullen and Shelton et al. and Dalzell et al., these Proceedings), identifies them as an appropriate choice for large-scale evaluations of feeding value for ruminants. The other *Leucaena* accessions in the 'palatable' group that deserve further nutritive evaluation with cattle include *L. lanceolata*, *L. pallida* accessions (OFI 52/87 and CQ3439), *L. trichandra* (OFI 53/88), and *L. collinsii* (OFI 52/88) as all show agronomic potentials at least as good as K636 (see Mullen and Shelton et al., these Proceedings). *Leucaena collinsii* subsp. *collinsii* (OFI 52/88) and *L. lanceolata* have the added advantage of containing minimal CT that could otherwise have interfered with their value as a protein source for ruminants (see Dalzell et al. and McNeill et al., these Proceedings). *Leucaena collinsii* has been found to be highly palatable in cattle grazing trials in Guatemala (Rodrigo Arias A. unpublished) and Southeast Asia (see Jones et al., these Proceedings). However, both *L. collinsii* subspecies were found to be less palatable than K636 in both sheep trials which suggests that sheep have different preferences to cattle.

Leucaena diversifolia was found to be palatable for cattle and was the only taxon with a similar palatability to the *L. leucocephala* taxon for sheep in Honduras. Brewbaker (1988) observed that wild deer had selectively grazed *L. diversifolia* in plot experiments. However, the potential of this species is limited due to poor performances agronomically (see Mullen and Shelton et al., these Proceedings).

It is important to note that these palatability measurements were determined over short periods of time and even some apparently palatable forages, after long-term exposure, may become less palatable due to negative post-ingestive feedback (Provenza and Malechek 1984; Provenza et al. 1994). For example, accessions of *L. pallida* were found to be highly palatable in trials with cattle (Austin et al.

1991), and sheep and goats (Kaitho et al. 1996, 1997). However, in several live-weight gain trials conducted by Jones et al. (these Proceedings) with cattle, it was reported that more leaf was left on *L. pallida* (CQ3439) than *L. leucocephala* cultivars at the end of experimental grazing periods, and this was most pronounced during the dry times of the year. Consequently, having identified more palatable *Leucaena* accessions, the next essential step is to devise trials to test if ruminants will be prepared to eat these new *Leucaena* accessions for appropriate extended periods and as complex mixed diets. This might include the entire growing phase of a young animal to slaughter, and at appropriate proportions of their diets, which may be 30% to 50% of total dry matter intake in grazing and cut-and-carry systems (Norton 1994).

There were several taxa/accessions which were consistent poor performers in both the sheep and cattle trials. These were *L. collinsii* subsp. *zacapana* (OFI 56/88), *L. esculenta* (OFI 47/87), *L. macrophylla* subsp. *istmensis* (OFI 47/85), *L. salvadorensis* (OFI 36/88 and 36/89) and *L. pallida* (OFI 79/92) (in Australia and Philippines only). However, these accessions should not be dismissed from further research. Factors such as plant nutrient status, animal species, animals past experiences and the physiological status of the animals, can all have a significant influence on the apparent palatability of a feed (see review by Provenza 1995; Provenza 1996). The value of time for familiarisation was well illustrated in the cattle trials where two *Leucaena* accessions were ranked as less palatable (relative to K636) in Trial 1 and palatable in Trial 2. These data, and those of Stewart and Dunsdon (1998), also show that the animals will eventually eat some accessions that were initially untouched, as the offering of forage continued over the longer term. This was illustrated in the case of the non-*Leucaena* species calliandra and the sesbania in the second compared to the first cattle trial. Both trials involved the same cattle. However, differences between trials may also have been related to seasonal effects on palatability (Cooper and Owen-Smith 1985).

Leucaena esculenta has been found to be poorly palatable in other studies with cattle (Austin et al. 1991; Rodrigo Arias A. unpublished) and goats (Otsyina and Msangi 1995). It had the lowest in vitro DM digestibility of the accessions tested in the Australian trials (see Dalzell et al., these Proceedings). However, no significant relationship was found between in vitro DM digestibility and palatability. Foliage of *L. macrophylla* subsp. *istmensis* (OFI 47/85) had a noticeable odour when crushed which may have acted as a deterrent to grazing, resulting in

Table 4. Short-term mean dry matter intakes (DMIs), grazing frequency, and palatability classification, relative to K636, recorded for freshly cut *Leucaena* accessions assessed with sheep in the Philippines.

Accession	Mean grazing frequency per accession[1]	Mean DMI (g/hd/80 mins)	
Leucaena collinsii subsp. *collinsii* 52/88	3.5	9.6	L[2]
L. collinsii subsp. *zacapana* 56/88	8.7	19.0	L
L. diversifolia K156	1.3	6.8	L
L. diversifolia 83/92	8.5	10.6	L
L. esculenta 47/87	2.4	2.4	L
L. lanceolata var. *lanceolata* 43/85	3.3	0.3	L
L. leucocephala subsp. *glabrata* Alabang (cv. Peru)	17.7	22.5	P
L. leucocephala subsp. *glabrata* cv Cunningham	15.2	21.7	P
L. leucocephala subsp. *glabrata* K636	16.6	35.2	P
L. leucocephala × *L. diversifolia* (K8 × K156) — KX3	11.4	13.8	L
L. macrophylla subsp. *istmensis* 47/85	0.5	0.3	L
L. magnifica 19/84	5.3	19.5	L
L. pallida 52/87	5.8	7.9	L
L. pallida 79/92	0.4	1.6	L
L. pallida CSIRO Composite CQ3439	2.3	1.3	L
L. pallida × *L. leucocephala* K376 × K8 Spec Comp — KX2	18.7	35.2	P
L. pallida × *L. leucocephala* K748 × K636 — KX2	18.6	27.1	P
L. salvadorensis 36/89	2.7	2.7	L
L. trichandra 53/88	2.6	6.4	L
LSD ($P<0.05$)	7.9	14.5	

[1] Number of times sheep were observed feeding on a particular accession/80 minutes.
[2] Accessions within one LSD of K636, based on DMI intake data only, were classified as palatable (P) and those more than one LSD lower were classified as less palatable (L).

Table 5. Short-term mean dry matter intakes and palatability classification relative to K636, for freshly cut *Leucaena* taxa in Honduras assessed with sheep (Stewart and Dunsdon 1998).

Species/sub-species/accession numbers	Dry matter intake (g/hour)	
Leucaena collinsii subsp. *collinsii* (OFI 45/85 & 51/88)	10	L[1]
L. collinsii subsp. *zacapana* (OFI 18/84, 56/88 & 57/88)	9	L
L. diversifolia (OFI 45/87, 46/87 & K156)	121	P
L. diversifolia × *L. leucocephala* (K8 × K156 & K636 × K156) — KX3/KX3+	106	L
L. esculenta OFI 47/87	31	L
L. lanceolata var. *lanceolata* (OFI 43/85 & 44/85)	13	L
L. leucocephala glabrata (K636 & K8)	173	P
L. macrophylla subsp. *macrophylla* OFI 55/88	21	L
L. macrophylla subsp. *istmensis* OFI 47/85	37	L
L. multicapitula OFI 81/87	47	L
L. pallida × *L. diversifolia* — KX1	28	L
L. pulverulenta (OFI 83/87 & 84/87)	15	L
L. salvadorensis (OFI 17/86 & 34/88)	3	L
L. trichandra OFI 53/88	45	L
L. trichodes (OFI 2/86 & 61/88)	45	L
LSD ($P<0.05$)	59	

[1] Accessions within one LSD of K636 were classified as palatable (P) and those more than one LSD lower were classified as less palatable (L).

its poor initial defoliation in the Australian trials, and its overall low palatability rating.

Species of the *Leucaena* genus were found to be more palatable than non-*Leucaena* species included in the Australian trials which has been previously found for sheep (Ibrahim et al. 1988; Kaitho et al. 1996, 1997), goats (Hove et al. 1994) and cattle (Rodrigo Arias A. unpublished). The pungent odour of gliricidia has been suggested as one of the main reasons for its poor palatability as it appears to be rejected on the basis of smell only (Stewart 1996). Poor palatability has been commonly reported for gliricidia (Stewart 1996) and this was observed in both trials in Australia.

Background information on the chemical composition of the *Leucaena* accessions gave little insight into why some were more readily eaten than others. The lack of any strong relationship between total CT content and palatability within both the Australian and Honduras trials clearly shows that condensed tannin content does not play a major role in determining palatability in the *Leucaena* genus in the short term. The absence of any change in palatability with the application of PEG in the second trial in Australia supports this conclusion.

Both *L. macrophylla* subsp. *istmensis* (OFI 47/85) and *L. salvadorensis* (OFI 36/88) contain low to negligible amounts of CT and yet were among the least palatable of the *Leucaena* accessions trialled. Conversely, *L. trichandra* (OFI 53/88) and *L. diversifolia* (OFI 83/92), with some of the highest CT contents, were readily eaten. These results conflict with the common perception that palatability is negatively related to the CT content of feeds (Hagerman and Butler 1991; Kumar and D'Mello 1995). The conflicting findings for palatability/CT relationships for different genera/species may arise from the assumption that CTs behave similarly irrespective of genera and species (Meuller-Harvey and McAllan 1992), which is clearly not the case.

Recent work has shown that CTs do vary greatly in their activity between species and genera (see McNeill et al., these Proceedings). Alternatively, the differences between the accessions may be due to variation in protein content masking the CT effect. This possibility was hypothesised by Cork (1992) who reported that folivorous marsupials of *Eucalypt* forests prefer forests with a high N/non-CT phenols. However, no relationship was found in the Australian trials between N/total CT ratio and palatability.

The positive relationship between ash and palatability in the first Australian trial indicates that some minerals may have a significant role in determining palatability in *Leucaena* species. However, no significant relationships were found between palatability and a range of macro/micro elements measured. These results were reinforced in the second Australian trial for Na where no change in palatability resulted from the foliar application of NaCl.

The negative relationship between NDF and palatability in the second Australian trial reflects the importance of cell wall content in forages and its negative affect on intake (Jung and Allen 1995).

Preferences for high WSC content in forages have been found for ruminants (Goto et al. 1986; Jones and Roberts 1991; Ciavarella et al. 1998). However, the palatability of the *Leucaena* accessions did not change as a result of fructose application which suggests that WSC is not limiting the palatability of *Leucaena* species.

Conclusion

The most promising lesser-known *Leucaena* accessions that deserve long term evaluation are the KX2 hybrids, and *L. collinsii* (OFI 52/88) for cattle in particular. Sheep were more selective than cattle when grazing the *Leucaena* accessions, underlining the need to conduct palatability trials with relevant animal species. Chemical composition, including CT concentration, gave little insight into why some *Leucaena* accessions were preferred over others.

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Chemical Composition of *Leucaena* and Implications for Forage Quality

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Abstract

The high nutritive value of *Leucaena leucocephala* forage is well documented, but little is known about the forage quality of other taxa in the genus. Preliminary in vitro evaluations of the chemical composition of the *Leucaena* genus, to identify accessions worthy of further evaluation, were conducted in Honduras by the Oxford Forestry Institute and in Australia by the University of Queensland. In vitro dry matter digestibility (IVDMD), condensed tannin (CT), crude protein (CP), neutral detergent fibre (NDF) and mineral composition measured in the Australian trial are presented and discussed in the context of the results of the Honduran study. Direct comparison of the data generated at both sites was confounded by differences in environment, sample tissue and laboratory procedures, although it was possible to compare the ranking of taxa at the two sites. The IVDMD of the genus was high compared to other tropical forages, ranging from 42–70%. There was considerable variation in CT content within taxa and across the genus (undetectable — 31% DM). The CP content (15–40% DM) of the genus exceeded recommended concentrations for ruminants. However, CP digestibility and IVDMD may be reduced in accessions containing high concentrations of CT. Generally low NDF contents (15–38% DM) were observed. All *Leucaena* spp. contained adequate levels of the essential elements measured, except Na and Cu. Many were marginal in Mg. Based on chemical composition, there were a number of taxa with the potential to exceed the excellent forage quality of *L. leucocephala*, including *L. collinsii*, *L. lanceolata*, *L. lempirana*, *L. macrophylla*, *L. magnifica*, *L. shannonii*, and *L. trichodes*. A number of limitations to the interpretation of in vitro analyses were identified, including the use of different sampling tissue, sample preparation and laboratory techniques, and the possibility of environmental effects on plant chemical composition. The effects of environmental factors, such as soil nutrient deficiency, water stress, temperature, and insecticide phytotoxicity, on the CT content of the *Leucaena* genus were discussed. Future research priorities were identified.

LEUCAENA *leucocephala* is renowned as a high quality, tropical forage. It is utilised pantropically for ruminant production in cut and carry forage systems, grazed in situ in extensive pastoral systems in Australia and used as a leaf meal protein source in monogastric diets.

The concept of forage quality describes the ability of a feed to provide the essential nutrients, energy, protein, minerals and vitamins, required by animals to achieve a desired level of production. Forage quality is a function of chemical composition, feed/dry matter intake, the digestibility of nutrients in the dry matter and the efficiency of utilisation of digested nutrients by the animal.

Laboratory chemical analyses have been developed to predict forage quality as in vitro chemical analyses are cheap, rapid, and require only small amounts of forage compared to expensive, time-consuming animal feeding trials. In vitro dry matter digestibility, condensed tannin, crude protein, cell wall fractions, and mineral composition are common parameters used to estimate forage quality. However, there are a number of limitations in extrapolating in vitro data to in vivo nutritive value. Despite these limitations, chemical analyses can be used to crudely rank forages for quality and are useful for screening

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large numbers of feed samples to identify forages worthy of detailed investigation.

This paper presents the findings of an investigation of the in vitro forage quality of the *Leucaena* genus undertaken in Australia by the University of Queensland. Our results are compared to those of a recent study conducted by the Oxford Forestry Institute on *Leucaena* samples collected in Honduras. Past studies have investigated limited numbers of taxa and accessions and these have been thoroughly reviewed by Norton et al. (1995). However, it is difficult to interpret in vitro forage quality data from different experiments due to the use of different methods of analyses and environmental variation in forage quality parameters.

This paper presents the chemical composition data of 116 accessions from 31 taxa, grown under the same environmental conditions and analysed using standardised procedures. Limitations in interpreting chemical composition data will be discussed, with particular emphasis on environmental effects on the condensed tannin status of the *Leucaena* genus.

Chemical Composition and In Vitro Dry Matter Digestibility

An evaluation of the chemical composition of a comprehensive collection of 116 *Leucaena* accessions from 31 taxa was made at the University of Queensland (UQ). Samples of youngest fully expanded leaves (YFEL) were taken from this collection established at Redland Bay, Queensland, Australia (27°37'S, 153°19'E) (Mullen and Shelton et al., these Proceedings), in April 1996. The YFEL of 8–10 individual plants were frozen in dry-ice in the field, lyophilised and ground to pass a 1 mm sieve. Measurements included pepsin/cellulase in vitro dry matter digestibility (IVDMD) (McLeod and Minson 1978) corrected to artificial in vivo dry matter digestibility using a standard curve generated from actual in vivo data for a range of lucerne (*Medicago sativa*) and stylo (*Stylosanthes hamata*) samples; condensed tannin (CT) content (Dalzell and Kerven, in press); crude protein (CP) content (combustion CNS analysis (LECO 2000)); neutral detergent fibre (NDF) (Van Soest 1963); ash content; and elemental composition (nitric-perchloric acid digestion and inductively-coupled plasma atomic emission spectroscopy (ICPAES)). Duplicates of each sample were analysed for all parameters and were repeated when disparity between observations exceeded 5%. Means of the duplicates are presented.

In another experiment, Stewart and Dunsdon (1998) from the Oxford Forestry Institute (OFI) evaluated the forage quality of 43 *Leucaena* accessions from 22 taxa and 5 interspecific hybrids in a trial at La Soledad, Comayagua Valley, Honduras. Mature leaves were collected from trees of each accession, bulked, sub-sampled, oven-dried at 50 °C for 72 h and ground to pass a 1 mm sieve. Rumen liquor-pepsin IVDMD (Tilley and Terry 1963), extractable CT (Porter et al. 1986), "total tannin" estimated by the radial diffusion protein-precipitation technique (Hagerman 1987), CP and NDF (Van Soest et al. 1991) were measured in these samples.

In vitro dry matter digestibility (IVDMD)

Dry matter digestibility (DMD) represents the proportion of a feed that is capable of being digested by animal or microbial enzymes, and absorbed by the animal (Van Soest 1994). In vitro dry matter digestibility (IVDMD), corrected to artificial in vivo DMD, of the Australian samples ranged from 42.0–69.7% (Table 1). Individual accession IVDMD data are presented in APPENDIX 1. The taxa *L. trichodes*, *L. shannonii*, *L. magnifica*, *L. macrophylla*, *L. lempirana*, *L. lanceolata* and *L. collinsii* were highly digestible (IVDMD >65%). Accessions of *L. leucocephala*, including commercially available cultivars, had IVDMD ranging from 61–66%. Thus, many of the lesser-known *Leucaena* spp. may equal or exceed the excellent forage quality of *L. leucocephala*. Conversely, *L. confertiflora*, *L. cuspidata* and *L. greggii* had very low IVDMD (42–47%). Considerable intraspecific variation in IVDMD existed within *L. pallida*, *L. trichandra* and the KX2 (*L. pallida* × *L. leucocephala*) and KX3 (*L. diversifolia* × *L. leucocephala*) hybrids. The IVDMD of the *Leucaena* genus appears to be equal to or superior to that of other forages analysed in the same laboratory using the same assay, including lucerne (66%), *Stylosanthes hamata* cv. Verano (31–52%), buffel grass (*Cenchrus ciliaris*) (39–48%) and black speargrass (*Heteropogon contortus*) (39–43%).

Stewart and Dunsdon (1998) observed an even greater range in IVDMD of 23.2–67.3% in mature leaves (ML) harvested from *Leucaena* accessions grown in Honduras, however the ranking of taxa remained similar to the Australian data. Accessions lacking CT, such as *L. collinsii* subsp. *zacapana*, had high rumen liquor-pepsin IVDMD (64%) (Stewart and Dunsdon, 1998) similar those digested by pepsin-cellulase (66%). The rumen liquor-pepsin IVDMD of accessions containing significant amounts of CT, such as *L. pulverulenta*, were dramatically lower (28%) (Stewart and Dunsdon, 1998) than IVDMD analysed using pepsin-cellulase (53%).

Balogun et al. (1995) also observed that IVDMD of tree legumes measured by rumen liquor-pepsin were significantly lower (half) than those measured by the pepsin-cellulase method, due to CT interference. Oven-drying tanniferous forages also

Table 1. In vitro dry matter digestibility (IVDMD), crude protein (CP), neutral detergent fibre (NDF) and ash contents (%DM) of the YFEL of the *Leucaena* genus grown at Redland Bay, Australia.

Species	Subspecies/ variety	No. of acces-sions	IVDMD		CP		NDF		Ash	
			Mean	Range	Mean	Range	Mean	Range	Mean	Range
L. ? hybrid		2	63.7	62.4–65.0	29.8	29.0–30.6	20.7	17.4–24.0	6.1	6.0–6.3
L. collinsii	*collinsii*	2	68.9	68.0–69.7	37.0	36.4–37.6	18.8	18.6–19.1	7.9	7.8–7.9
L. collinsii	*zacapana*	3	66.4	65.3–67.0	33.8 (2)	33.2–34.4	23.7	21.3–26.7	7.7	6.9–8.6
L. confertiflora	var. *adenotheloidea*	2	42.0	42.0–42.0	17.7	17.6–17.8	22.8	22.8–26.7	5.8	5.8–6.0
L. cuspidata		1	42.9	–	14.7	–	26.7	–	5.8	–
L. diversifolia		13	58.8	56.0–61.0	27.8	24.7–32.0	21.6	17.2–27.9	6.2	5.6–6.8
L. diversifolia × *L. leucocephala* (KX3)[1]		7	61.9	59.0–63.0	31.5	28.7–36.3	19.9	16.9–22.9	6.7	6.2–7.6
L. esculenta		2	57.5	57.0–58.0	30.3	29.5–31.2	18.6	17.5–19.8	6.3	6.2–6.3
L. greggii		1	47.1	–	19.4	–	22.6	–	5.5	–
L. involucrata		1	53.7	–	25.9	–	19.5	–	6.5	–
L. lanceolata	var. *lanceolata*	4	64.3	63.0–67.0	29.6	28.5–30.3	27.9	24.9–30.3	7.0	6.9–7.1
L. lanceolata	var. *sousae*	2	66.5	65.6–67.0	30.7	29.8–31.6	21.9	18.9–25.0	6.4	6.2–6.6
L. lempirana		2	66.2	66.0–66.3	27.6	31.1–24.1	24.2	23.3–25.1	6.6	6.2–6.3
L. leucocephala	*glabrata*	21	63.4	60.9–66.0	30.0	23.9–34.2	21.3 (20)	16.4–26.7	7.2 (20)	6.2–8.4
L. leucocephala	*ixtahuacana*	1	61.5	–	39.6	–	38.1	–	6.7	–
L. leucocephala	*leucocephala*	5	63.3	60.7–65.3	30.5	24.8–33.3	20.7	16.7–23.4	7.1	5.5–8.0
L. macrophylla	*istmensis*	2	68.5	68.0–68.9	37.2	36.9–37.6	21.9	18.2–25.7	6.4	6.3–6.5
L. macrophylla	*macrophylla*	2	66.2	65.9–66.6	37.4 (1)	–	25.9	25.0–26.8	6.2	6.0–6.5
L. magnifica		2	68.0	67.9–68.0	37.3	36.7–37.9	24.3	23.8–24.9	7.3	7.2–7.4
L. matudae		1	51.0	–	19.7	–	23.2	–	5.2	–
L. multicapitula		2	64.0	62.0–66.0	37.8	36.3–39.4	25.8	23.0–28.6	6.2	6.1–6.4
L. pallida		7	59.9	55.0–64.4	31.3 (6)	27.5–35.1	18.6 (6)	15.4–22.2	6.3	5.7–6.8
L. pallida × *L. leucocephala* (KX2)[1]		6	61.9	54.0–65.0	30.6	26.8–35.1	17.8	14.6–19.3	6.5	6.2–6.7
L. pueblana		2	51.4	51.1–51.6	28.4 (1)	–	22.7	19.5–26.0	5.2	4.9–5.6
L. pulverulenta		3	52.3	52.0–53.0	25.1	24.1–26.8	20.5	16.3–23.2	5.9	5.7–6.0
L. retusa		1	63.0	–	21.7	–	22.1	–	6.4	–
L. salvadorensis		3	63.8	62.5–65.0	29.5	26.9–31.2	30.4	29.4–32.0	7.1	7.0–7.2
L. shannonii		4	67.2	66.4–68.5	33.7	31.5–35.6	21.3	18.8–24.0	6.7	6.5–7.0
L. trichandra		10	61.8	56.0–68.1	26.9	17.4–33.0	22.3	17.4–26.7	6.1 (9)	5.5–6.6
L. trichodes		2	67.0	67.0–67.0	34.6	29.3–40.0	24.4	24.2–24.6	7.9	7.2–8.6
L. xspontanea		2	62.8	62.0–63.6	31.3	28.7–33.8	21.8	20.4–23.2	6.8	6.6–7.0

* Numbers in brackets represent the number of accessions used to calculate mean when different from the number of accessions sampled.

[1] KX2 and KX3 accessions are artificial interspecific hybrids generated at the University of Hawaii.

exacerbates CT induced IVDMD suppression compared to lyophilisation (Dzowela et al. 1995).

Condensed tannin content

Condensed tannins (CT) are polymeric flavanol secondary plant metabolites capable of binding to protein, carbohydrates and minerals. The protein binding capacity of CT has a significant impact on forage quality. Moderate levels of CT in forage legumes may improve ruminant N retention by protecting protein, that is in excess of microbial requirements, from wasteful degradation in the rumen, thus enhancing the supply of amino acids to the small intestine. However, excessive quantities of astringent CT can severely reduce N retention in ruminants by depriving rumen microbes of the N required for fermentation of dietary fibre and microbial protein synthesis, inhibiting post-ruminal protein absorption and suppressing forage intake (Waghorn et al. 1990). Condensed tannins can also bind directly to microbial enzymes, further limiting protein and fibre digestion. More detail on the implications of CT on dietary protein, fibre and mineral utilisation in vivo are discussed elsewhere (McNeill et al., these Proceedings).

Condensed tannins exist in two forms within plant tissues. Extractable (or free) CT (ECT) is the soluble component and is stored in vacuoles within the cytoplasm of plant cells. This CT component is particularly biologically active and may interfere with animal feed utilisation. Bound condensed tannin (BCT) is bonded to cellular protein and fibre components and is likely to be less nutritionally significant (Mangan 1988).

In the Australian study, extractable CT and bound (protein and fibre bound) CT and total CT (TCT=ECT+BCT) were measured in the YFEL of 116 *Leucaena* accessions (APPENDIX 1). Mean CT concentrations for all taxa are presented in Table 2. Concentrations presented are not absolute, but are expressed as % DM *L. pallida* CT. This is because the spectrophotometric assay was calibrated with purified *L. pallida* CT. Absolute CT values can only be measured for a specific accession when the assay is calibrated with purified CT isolated from that accession. Considerable interspecific variation in TCT concentration was observed in the *Leucaena* genus varying from undetectable amounts (*L. collinsii*) to 30.6% DM (*L. cuspidata*).

As was observed by Castillo et al. (1997), intraspecific variation in CT was dramatic within most taxonomic divisions, but particularly in *L. diversifolia* (5.7–18.5% DM), *L. trichandra* (0.4–22.6% DM), and *L. pallida* (5.0–17.1% DM). Similar ECT distributions within the genus were observed by Stewart and Dunsdon (1998). These authors also measured the "total tannin" of each accession using a protein precipitation technique that accounts for tannin biological activity, a function of both tannin concentration and tannin-protein binding capacity.

In the Honduran study, different accession rankings were observed between ECT and tannin-protein precipitation, indicating that the protein binding capacity of CT and other compounds that precipitate protein, differed within and between taxa. An evaluation of 19 accessions of *L. diversifolia*, *L. leucocephala*, *L. pallida*, *L. trichandra*, and interspecific hybrids by Austin et al. (1997), also revealed significant genetic diversity in the concentration of total phenolics (CT and other phenolic compounds) which ranged from 8.6–12.2% DM.

Extractable CT was the dominant CT fraction in the YFEL of *Leucaena* accessions with high TCT concentrations in the Australian samples. Similar high ECT fractions were observed in *L. diversifolia*, *L. pallida* and *L. leucocephala* by Jackson et al. (1996), with 69–91% of CT being extractable, indicating that most of the CT in *Leucaena* spp. is likely to be biologically active.

Crude protein content

Forages provide protein primarily to satisfy the N requirement for protein synthesis by rumen microorganisms, and additional bypass protein for direct absorption by the host animal. A minimum ruminant dietary crude protein (CP) content of 6–8% DM is required to maintain rumen ammonia N concentrations in excess of 70 mg ammonia N/L, the threshold needed for efficient microbial fermentation and microbial protein synthesis for animal maintenance (Norton et al. 1995). Much higher dietary CP contents (12–25% DM) are required to maximise ruminant animal production (NRC 1985, 1996). Crude protein (CP = N% × 6.25) content of the YFEL of *Leucaena* taxa grown in Australia averaged 29.8% DM CP, ranging from 14.7% DM (*L. cuspidata*) to 40.0% DM CP (*L. trichodes*) (Table 1). The CP contents of individual accessions are presented in APPENDIX 1. Assuming most of the CP is digestible, the CP content of all of the *Leucaena* spp. evaluated were in excess of the nutritional requirements of ruminants for maintenance and production if consumed as a sole diet. Mature leaves harvested from the *Leucaena* genus in Honduras (Stewart and Dunsdon, 1998) contained less CP (17.4–25.8% DM) than the YFEL collected in Australia.

All *Leucaena* spp. contained significantly more CP than tropical grasses (e.g. immature *Digitaria decumbens* may contain 10% DM CP) and similar CP contents to top quality lucerne chaff (22–30% DM CP)(Van Soest 1994). However, most *Leucaena* spp. also contained variable amounts of CT, which will directly affect protein digestion and N retention in ruminant animals (McNeill et al., these Proceedings). Thus, it should be noted that not all the CP measured in accessions containing medium-high CT would be available for utilisation by rumen microflora or direct absorption by the animal.

Many of the high CP/low CT *Leucaena* accessions have the potential to provide highly digestible supplementary N when incorporated into low quality roughage diets. For example, a basal roughage (7% DM CP) supplemented with 30% *L. collinsii* forage (assuming edible DM contains 24% CP cf. 30% CP in YFEL) would produce a mixed ration containing 12% DM CP, which is sufficient to support growing and/or lactating ruminant animals (NRC 1985, 1996). *Leucaena leucocephala* has been successfully used as a supplement in tropical forage systems, significantly improving ruminant N nutrition when incorporated at 30–40% DM into low quality roughage diets (Abdulrazak et al. 1997, Bonsi et al. 1994; Bonsi and Osuji 1997; Chowdhury 1997).

Neutral detergent fibre (NDF)

Cell wall residues remaining after neutral detergent extraction (NDF) represent the proportion of plant dry matter made up of cellulose, hemicellulose and lignin (Van Soest and Robertson 1980). High

Table 2. Condensed tannin (CT) concentration (% DM LPCT*) of the YFEL of the *Leucaena* genus grown at Redland Bay, Australia.

Species	Subspecies/variety	No. of accessions	Extractable CT		Bound CT		Total CT	
			Mean	Range	Mean	Range	Mean	Range
L. ? hybrid		2	2.1	1.8–2.5	0.6	0.6–0.6	2.7	2.4–3.0
L. collinsii	*collinsii*	2	0.0	0.0–0.0	0.1	0.1–0.1	0.1	0.1–0.1
L. collinsii	*zacapana*	3	0.0	0.0–0.0	0.2	0.1–0.2	0.2	0.1–0.2
L. confertiflora	var. *adenotheloidea*	2	19.4	15.2–23.5	2.1	1.6–2.7	21.5	16.8–26.2
L. cuspidata		1	29.1	–	1.5	–	30.6	–
L. diversifolia		13	10.7	4.0–16.6	2.1	1.1–3.8	12.8	5.7–18.5
L. diversifolia × *L. leucocephala* (KX3)[1]		7	4.7	2.5–7.3	1.4	0.6–1.8	6.1	4.2–9.1
L. esculenta		2	11.2	10.0–12.3	1.3	1.2–1.4	12.5	11.2–13.7
L. greggii		1	18.4	–	1.3	–	19.7	–
L. involucrata		1	13.5	–	1.3	–	14.8	–
L. lanceolata	var. *lanceolata*	4	0.7	0.3–1.2	0.4	0.2–0.5	1.0	0.6–1.6
L. lanceolata	var. *sousae*	2	0.2	0.2–0.2	0.1	0.1–0.1	0.3	0.3–0.3
L. lempirana		2	0.2	0.2–0.2	0.1	0.1–0.1	0.3	0.3–0.4
L. leucocephala	*glabrata*	21	1.8	0.5–4.0	0.8	0.4–1.3	2.6	0.9–4.8
L. leucocephala	*ixtahaucana*	1	4.2	–	0.9	–	5.1	–
L. leucocephala	*leucocephala*	5	1.9	1.2–3.2	0.8	0.5–1.2	2.7	1.7–3.7
L. macrophylla	*istmensis*	2	0.8	0.6–1.0	0.4	0.2–0.6	1.2	1.2–1.2
L. macrophylla	*macrophylla*	2	1.3	0.9–1.7	0.3	0.3–0.4	1.6	1.3–2.0
L. magnifica		2	0.0	0.0–0.0	0.1	0.1–0.1	0.1	0.1–0.2
L. matudae		1	12.3	–	0.9	–	13.2	–
L. multicapitula		2	0.5	0.0–1.1	0.6	0.2–0.9	1.1	0.2–2.0
L. pallida		7	8.2	4.2–15.9	1.1	0.8–1.6	9.3	5.0–17.1
L. pallida × *L. leucocephala* (KX2)[1]		6	4.1	2.4–6.1	1.1	0.5–1.2	5.1	3.0–7.3
L. pueblana		2	10.0	9.3–10.6	0.5	0.5–0.6	10.5	9.9–11.1
L. pulverulenta		3	14.6	11.8–18.3	1.3	1.0–1.8	15.9	13.0–19.4
L. retusa		1	2.3	–	1.2	–	3.5	–
L. salvadorensis		3	0.0	0.0–0.1	0.2	0.1–0.2	0.2	0.2–0.2
L. shannonii		4	0.7	0.0–1.7	0.5	0.4–0.7	1.3	0.5–2.3
L. trichandra		10	8.7	0.2–20.5	2.2	0.2–3.1	11.0	0.4–22.6
L. trichodes		2	0.1	0.1–0.1	0.2	0.1–0.2	0.2	0.2–0.3
L. xspontanea		2	3.2	2.7–3.8	1.2	1.0–1.5	4.4	4.2–4.7

* LPCT = L. pallida CT.

[1] KX2 and KX3 accessions are artificial interspecific hybrids generated at the University of Hawaii.

proportions of dietary NDF can suppress forage intake due to reduced rates of fibre digestion and passage through the rumen (Van Soest 1994). Browse forages have different physical characteristics from grass diets, confounding the interpretation of NDF measurements using empirical relationships generated for herbaceous species. The compound leaves of many tree legumes yield small particle sized ingesta, resulting in more rapid passage through the rumen than grass digesta with a similar NDF content. Thus, forage intake of fodder trees is less affected by NDF than grass roughages.

The NDF fraction of YFEL sampled in Australia varied from 14.6–38.1% DM (Table 1). *Leucaena salvadorensis* (30.4% DM) and *L. leucocephala* subsp. *ixtahuacana* (38.1% DM) contained the highest amounts of NDF, while *L. esculenta* (18.6% DM), *L. collinsii* subsp. *collinsii* (18.8% DM) and the KX2 hybrid (17.8% DM) had the lowest NDF values. Considerable intraspecific variation in NDF existed within the genus, particularly within *L. diversifolia*, *L. leucocephala* subsp. *glabrata* and *L. trichandra*. The NDF contents of individual accessions are presented in APPENDIX 1. Stewart and Dunsdon (1998) also reported great diversity in NDF contents (21.5–50.9% DM) in ML harvested from 27 *Leucaena* taxa. Similar NDF concentrations of 26.2–39.9 % DM (Wandera et al. 1991), 45.7–56.8% DM (Berhe and Tothill 1995) and 40.9–49.1% DM (Tolera et al., these Proceedings) have been observed in the edible fraction (leaves and <6 mm stem) of different *Leucaena* spp.. These latter NDF values are much higher than those observed in the YFEL, probably due to the type and physiological maturity of the sample tissues, which comprised older and more fibrous (stem) plant material.

Leucaena spp. forages contain less NDF than tropical grasses (e.g. *Digitaria decumbens* may contain 70% DM NDF) and similar concentrations to lucerne chaff (33–53% DM NDF) (Van Soest 1994). With the exception of diets that contain a high proportion of fibrous stem material (NDF >45% DM), the forage quality (intake and digestibility) of *Leucaena* is unlikely to be limited by NDF content (Norton et al. 1995).

Ash and mineral composition

Ash analyses provide a crude guide to the ability of forages to meet the mineral requirements of animals. Ash (mineral and silica) content of the YFEL sampled in the Australian trial ranged from 4.9–8.6% DM (Table 1) (APPENDIX 1). These ash contents are slightly lower than those of lucerne chaff (8–10% DM) and *Digitaria decumbens* (10% DM) (Van Soest 1994).

The macronutrient composition of the YFEL of the taxa is presented in Table 3 and the micronutrient composition in Table 4. The mineral composition of the YFEL of individual *Leucaena* accessions is presented in APPENDIX 2. As a sole feed, the YFEL of the *Leucaena* genus provided most essential minerals in excess of the dietary requirements of growing/lactating sheep and cattle (SCA 1990). The exception was sodium, which was present at only 25–50% of ruminant requirements. Copper concentrations (<5 μg/g DM) were deficient and Mg (<0.19% DM) contents were marginal in many accessions. No mineral was detected in concentrations that were toxic or would interfere in the absorption and retention of other elements (SCA 1990). The mineral concentrations measured in this study are similar to those found in evaluations of the edible fraction of 20 *Leucaena* accessions by Austin et al. (1992) and *L. leucocephala* (Kabaija and Smith 1989; Faria-Marmol et al. 1996). Mineral composition data can readily identify elemental deficiencies in forages (e.g., Na in *Leucaena* spp.). However, despite adequate intake of elements in plant material, metabolic deficiencies may result if other non-mineral compounds in the plant impede mineral digestion/absorption by the animal.

The efficiency of mineral utilisation by animals may be affected by secondary plant metabolites. Phenolic compounds, such as CT, are capable of chelating metal cations (Laks 1989) and complexing S containing amino acids, potentially reducing the absorption of these elements in the gut. High CT *Leucaena* accessions may not provide animals with adequate quantities of digestible essential minerals. Other compounds, including phytin, oxalic acid and flavonol glycosides, have also been found in *Leucaena* spp. and may interfere in mineral utilisation.

Cobalt, selenium and iodine are also essential trace elements for animal nutrition, but were not measured in this study. Cobalt and selenium concentrations of 0.16 and 0.78 μg/g respectively (Faria-Marmol et al. 1996), and 62 μg/g iodine (Garcia et al. 1996) have been observed in *L. leucocephala* forage. These concentrations exceed ruminant dietary requirements of 0.11 μg/g Co, 0.05 μg/g Se and 0.5 μg/g I, if *L. leucocephala* was consumed as a sole feed (SCA 1990).

Relationships between forage quality parameters

Relationships between quality parameters measured in the Australian study were investigated using correlation techniques (Table 5). In vitro dry matter digestibility (IVDMD) was negatively related to both ECT and TCT (r^2=0.67). Similar tannin/IVDMD relationships were found by Stewart and Dunsdon (1998) for both ECT (r^2=0.41) and radial diffusion "total tannin" (r^2=0.59). Balogun et al. (1995) directly implicated CT in the suppression of IVDMD by adding polyethylene glycol (PEG) to the assay and observing large increases in digestibility of tanniferous tree legumes. IVDMD was positively correlated (r^2=0.47) to CP concentration. Ash was positively correlated to IVDMD and CP, and negatively correlated to all CT fractions. The proportional dominance of the ECT tannin fraction in the TCT measurement is reflected by a strong correlation between these observations (r^2=0.99). Bound CT was less strongly correlated to IVDMD, ECT and TCT. Cell wall content (NDF) was poorly correlated with all parameters, particularly IVDMD, in both experiments.

With the expectation that CT would interfere with digestibility, the interaction of CP and CT on IVDMD was investigated by correlating the ratio of CP:CT with IVDMD. A strong (r^2=0.73) non-linear relationship was observed (Figure 1). The most digestible accessions were those with high CP and low CT. Poorly digestible accessions had low CP and extremely high CT concentrations. The inflection point in the curve, at which IVDMD was rapidly suppressed with decreasing CP/CT ratio, corresponded to an average YFEL CT concentration of approximately 6% DM, assuming a mean CP content for *Leucaena* spp. of 30% DM. This provides an in vitro indication of the maximum desirable concentration of CT in *Leucaena* spp. forage of average CP content for optimal forage quality.

Variability among accessions in the derived relationship between the CP:CT ratio and IVDMD can be attributed to a number of factors. The CT measurements presented are not absolute, but are expressed as % DM *L. pallida* CT (% DM LPCT). It is possible that a better correlation could be derived

Table 3. Macronutrient composition (%DM) of the YFEL of the *Leucaena* genus grown at Redland Bay, Australia.

Species	Subspecies/ variety	No. of accessions	Ca		K		Mg		P		S	
			Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
L. ? hybrid		2	0.4	0.3–0.5	2.3	2.2–2.5	0.17	0.14–0.20	0.40	0.37–0.42	0.57	0.53–0.61
L. collinsii	*collinsii*	2	0.6	0.6–0.6	2.7	2.6–2.7	0.18	0.17–0.20	0.44	0.45–0.44	1.01	0.94–1.07
L. collinsii	*zacapana*	2	1.1	0.7–1.6	2.1	1.9–2.3	0.20	0.16–0.20	0.37	0.35–0.39	0.82	0.77–0.88
L. confertiflora	var. *adenotheloidea*	2	1.4	1.1–1.6	1.0	0.8–1.2	0.27	0.26–0.28	0.30	0.25–0.35	0.26	0.22–0.31
L. cuspidata		1	1.1	–	0.7	–	0.27	–	0.11	–	0.18	–
L. diversifolia		13	1.1	0.5–2.0	1.8	1.4–2.1	0.22	0.17–0.30	0.33	0.21–0.38	0.39	0.26–0.46
L. diversifolia × *L. leucocephala* (KX3)[1]		7	0.6	0.4–0.8	2.3	2.1–2.4	0.21	0.19–0.24	0.43	0.36–0.55	0.52	0.43–0.67
L. esculenta		2	0.5	0.5–0.5	1.9	1.9–2.0	0.23	0.20–0.27	0.49	0.47–0.52	0.86	0.78–0.94
L. greggii		1	0.2	–	1.5	–	0.20	–	0.33	–	0.63	–
L. involucrata		1	0.4	–	2.2	–	0.14	–	0.41	–	0.45	–
L. lanceolata	var. *lanceolata*	4	0.5	0.4–0.8	2.7	2.6–2.9	0.20	0.17–0.22	0.51	0.44–0.54	0.71	0.51–0.99
L. lanceolata	var. *sousae*	2	0.6	0.6–0.7	2.7	2.5–3.0	0.16	0.15–0.17	0.47	0.44–0.51	0.73	0.66–0.79
L. lempirana		2	1.5	1.0–2.1	1.8	1.6–2.0	0.22	0.18–0.26	0.37	0.32–0.42	0.41	0.37–0.45
L. leucocephala	*glabrata*	20	0.7	0.4–1.3	2.5	2.0–2.9	0.24	0.19–0.29	0.41	0.32–0.50	0.54	0.43–0.65
L. leucocephala	*ixtahuacana*	1	0.6	–	2.1	–	0.24	–	0.39	–	0.47	–
L. leucocephala	*leucocephala*	5	0.5	0.4–1.0	2.3	2.0–2.6	0.23	0.19–0.28	0.40	0.34–0.50	0.51	0.43–0.58
L. macrophylla	*istmensis*	2	0.4	0.3–0.5	2.6	2.5–2.6	0.16	0.16–0.17	0.58	0.52–0.63	0.44	0.40–0.48
L. macrophylla	*macrophylla*	2	0.5	0.3–0.6	2.7	2.3–3.0	0.17	0.15–0.19	0.60	0.55–0.65	0.43	0.40–0.45
L. magnifica		2	0.6	0.5–0.7	2.7	2.6–2.9	0.19	0.18–0.19	0.48	0.45–0.50	0.69	0.70–0.68
L. matudae		1	1.2	–	1.3	–	0.19	–	0.25	–	0.34	–
L. multicapitula		2	0.3	0.3–0.4	2.4	2.3–2.5	0.17	0.17–0.18	0.49	0.47–0.51	0.38	0.34–0.42
L. pallida		8	0.7	0.3–1.1	2.2	1.6–2.6	0.22	0.18–0.32	0.46	0.37–0.56	0.68	0.48–0.91
L. pallida × *L. leucocephala* (KX2)[1]		5	0.5	0.4–0.6	2.3	2.2–2.4	0.21	0.20–0.23	0.44	0.37–0.52	0.54	0.40–0.68
L. pueblana		2	0.6	0.6–0.6	1.5	1.4–1.6	0.19	0.18–0.20	0.39	0.34–0.43	0.53	0.52–0.54
L. pulverulenta		3	0.7	0.6–0.8	1.9	1.8–2.0	0.25	0.22–0.28	0.33	0.31–0.35	0.35	0.31–0.40
L. retusa		1	1.3	–	1.2	–	0.24	–	0.25	–	0.36	–
L. salvadorensis		3	1.0	0.6–1.3	2.3	1.9–2.5	0.17	0.15–0.19	0.43	0.37–0.46	0.46	0.43–0.51
L. shannonii		4	0.8	0.5–1.2	2.5	2.2–2.7	0.20	0.17–0.22	0.44	0.35–0.48	0.50	0.45–0.55
L. trichandra		10	1.3	0.6–2.0	1.6	0.9–2.2	0.18	0.14–0.23	0.34	0.27–0.52	0.36	0.29–0.58
L. trichodes		2	0.7	0.5–0.9	3.0	2.9–3.1	0.19	0.17–0.21	0.49	0.43–0.56	0.58	0.63–0.54
L. xspontanea		2	0.9	0.4–1.4	2.1	1.9–2.4	0.23	0.19–0.27	0.40	0.33–0.47	0.51	0.45–0.51
Genus mean			0.8	0.2–2.1	2.2	0.7–3.1	0.21	0.14–0.32	0.41	0.11–0.65	0.51	0.18–1.07
Animal requirements*		Cattle	0.19–0.40		0.5		0.19		0.18–0.32		0.15	
		Sheep	0.15–0.26		0.5		0.12		0.13–0.25		0.20	

* SCA (1990)

[1] KX2 and KX3 accessions are artificial interspecific hybrids generated at the University of Hawaii

Table 4. Micronutrient composition (μg/g) of the YFEL of the *Leucaena* genus grown at Redland Bay, Australia.

Species	Subspecies/ variety	No. of acces- sions	B		Cu		Fe		Mn		Na		Zn	
			Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
L. ? hybrid		2	35	31–39	8	7–9	95	93–97	53	50–56	215	189–242	39	38–40
L. collinsii	*collinsii*	2	43	43–43	7	6–8	93	86–99	38	36–40	326	276–375	34	32–35
L. collinsii	*zacapana*	2	45	38–51	5	5–5	233	85–380	48	34–61	241	227–254	35	32–38
L. confertiflora	var. *adenotheloidea*	2	66	55–77	3	2–4	168	139–196	62	38–85	240	214–265	35	30–40
L. cuspidata		1	53	–	1	–	117	–	75	–	270	–	22	–
L. diversifolia		13	71	44–117	6	4–7	102	81–137	58	36–111	426	172–682	35	27–42
L. diversifolia × *L. leucocephala* (KX3)[1]		7	33	26–41	7	5–8	98	83–114	50	37–63	244	104–343	33	27–39
L. esculenta		2	52	41–62	6	4–8	78	76–80	50	48–53	255	206–303	40	37–43
L. greggii		1	19	–	3	–	72	–	23	–	571	–	30	–
L. involucrata		1	28	–	5	–	92	–	41	–	442	–	36	–
L. lanceolata	var. *lanceolata*	4	35	29–38	8	6–9	89	86–95	37	31–43	338	228–407	42	38–50
L. lanceolata	var. *sousae*	2	40	39–42	5	5–6	82	79–84	35	33–38	288	280–297	36	36–36
L. lempirana		2	53	41–64	6	5–6	104	94–113	57	38–76	352	295–410	41	41–41
L. leucocephala	*glabrata*	20	31	23–53	7	6–8	109	77–158	65	38–117	329	245–453	37	33–43
L. leucocephala	*ixtahuacana*	1	31	–	6	–	93	–	60	–	259	–	34	–
L. leucocephala	*leucocephala*	5	34	25–53	6	6–7	104	89–120	55	38–70	374	323–453	34	28–40
L. macrophylla	*istmensis*	2	37	34–40	7	6–8	93	90–95	44	40–49	302	280–323	40	38–42
L. macrophylla	*macrophylla*	2	37	28–46	8	8–9	98	88–107	47	39–54	268	247–289	43	40–46
L. magnifica		2	49	39–59	5	5–5	103	101–105	41	40–41	332	290–375	34	33–34
L. matudae		1	37	–	2	–	120	–	70	–	258	–	33	–
L. multicapitula		2	28	28–28	8	7–8	112	110–114	45	37–52	394	343–445	36	34–39
L. pallida		8	52	32–111	8	4–10	108	89–119	58	47–90	333	195–680	45	39–51
L. pallida × *L. leucocephala* (KX2)[1]		5	28	25–31	6	5–7	95	77–115	49	42–56	304	233–364	37	33–42
L. pueblana		2	29	29–29	5	5–6	96	95–98	39	33–45	212	165–259	37	36–37
L. pulverulenta		3	31	26–37	5	4–6	92	71–104	35	26–43	536	465–607	34	29–41
L. retusa		1	38	–	2	–	90	–	36	–	287	–	36	–
L. salvadorensis		3	45	31–55	8	8–9	92	78–113	44	42–50	276	188–372	36	34–41
L. shannonii		4	35	29–39	8	6–10	107	97–118	41	32–49	295	216–380	40	39–44
L. trichandra		10	88	45–151	6	3–10	114	87–158	85	55–172	422	223–893	42	37–47
L. trichodes		2	30	28–31	7	6–8	100	99–101	50	49–50	447	433–461	40	35–44
L. xspontanea		2	56	35–76	7	6–8	101	93–109	58	34–82	329	328–329	35	34–37
Genus mean			46	19–151	6	1–10	106	72–380	49	23–172	340	104–893	37	22–51
Animal requirements*		Cattle	NR		7–10		40		15–25		800–1200		20–30	
		Sheep	NR		5		40		15–25		700–900		20–30	

* SCA (1990)

NR = no recommendation

[1] KX2 and KX3 accessions are artificial interspecific hybrids generated at the University of Hawaii.

Table 5. Linear correlation coefficients of determination (r^2) between forage quality parameters of the YFEL of the *Leucaena* genus grown at Redland Bay, Australia.

	DMD	CP	NDF	ASH	ECT	BCT
CP	0.466	–	–	–	–	–
NDF	0.000	0.001	–	–	–	–
ASH	0.319	0.147	0.000	–	–	–
ECT	0.670	0.350	0.013	0.361	–	–
BCT	0.267	0.209	0.027	0.190	0.356	–
TCT	0.669	0.361	0.015	0.369	0.990	0.452

Regressions significant ($P<0.01$) when $r^2>0.052$.

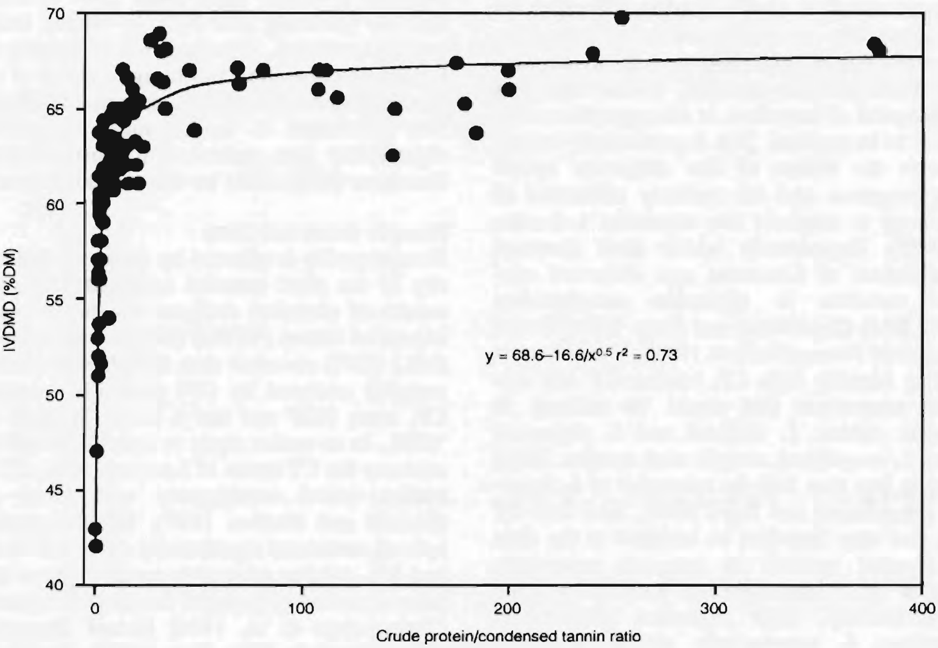

Figure 1. The effect of the ratio of the crude protein (CP) to total condensed tannin (TCT) on in vitro dry matter digestibility (IVDMD) of YFEL of the *Leucaena* genus grown at Redland Bay, Australia.

if absolute CT concentrations were observed. Furthermore, the biological activity of CT is a function of its concentration and protein-binding capacity. Theoretically, accessions lying above the response curve may contain inert CT and therefore still be highly digestible, while those below the curve may contain more reactive CT, which will suppress IVDMD.

Chemical Constituents of Importance Not Measured in These Studies

Non-structural carbohydrate fraction

The non-structural carbohydrate fraction (sugar, pectin and starch) of leguminous forages is important, as it provides a rapidly fermentable source of energy for rumen microbes. This source of energy is required to complement the rapidly degradable N fraction, improving the efficiency of N utilisation by rumen microflora (Van Soest 1994). To date, very little work has been published on the carbohydrate composition of *Leucaena* spp. forage and this aspect of forage quality was not evaluated in either the Australian or Honduran experiments. Sugar concentrations of 1.6–5.2% DM have been detected in *Leucaena* leaves (Toruan-Mathius and Suhendi 1992; Mtenga and Laswai 1994). These sugar levels are similar to tropical grass species, such as kikuyu grass (*Pennisetum clandestinum*) 2–6% DM, but low when compared to temperate rye grass (*Lolium* *perenne*) containing 3–9.5% DM of soluble carbohydrate (Fulkerson and Trevaskis 1997). This suggests using readily degradable carbohydrate supplements may benefit animals consuming *Leucaena* based diets.

Anti-nutritive compounds

A number of secondary plant metabolites, particularly CT and the toxic amino acid mimosine, restrict the utilisation of *Leucaena* forage as a sole or major component of the diet of monogastric animals. Based on the large variation in CT concentration and the other forage quality parameters measured, a comprehensive evaluation of the variation in mimosine content within the genus is essential. Without this data the full potential of *Leucaena* in monogastric animal nutrition is to be realised. This is particularly important due to the failure of low mimosine hybrid breeding programs and the unlikely utilisation of biotechnology to engineer low mimosine *Leucaena* (Bray 1995). Experiments which have screened limited numbers of *Leucaena* spp. observed considerable variation in mimosine concentration (0.5–8.7% DM) (Brewbaker and Kaye 1981; Hauad Marroquin and Foroughbakhch 1991). Thus, there is potential to identify high CP, low/no CT and low mimosine accessions that could be utilised in monogastric rations. *L. collinsii* and *L. shannonii* (including *L. magnifica*) are two such species. These taxa contain less than half the mimosine of *L. leucocephala* (Brewbaker and Kaye 1981), have low CT contents, and may therefore be included in the diets of monogastric animals in amounts potentially double that of *L. leucocephala*, without inducing mimosine toxicity. High mimosine contents in *L. lanceolata*, *L. macrophylla* and *L. trichodes* (Brewbaker and Kaye 1981) are likely to limit the role of these forages in monogastric rations.

Other anti-nutritive compounds have been detected in *Leucaena* spp. including oxalate (0.09% DM) and phytin (1.03% DM) (Aletor and Omodara 1994). These concentrations of oxalate and phytin are unlikely to interfere in ruminant metabolism but may affect monogastric utilisation of P, Ca, Mg, Fe and Zn (Hegarty 1982). Flavanol glycosides have been detected in *L. leucocephala* and *L. pulverulenta* at up to 6% DM (average 3–4% DM) in leaves on actively growing shoots (Lowry et al. 1984; Tangendjaja et al. 1986). Flavonol glycosides may also complex minerals (Laks 1989), potentially interfering with nutrient digestion. These low molecular weight secondary metabolites could also be absorbed into the blood and require detoxification at a metabolic cost to the animal (McNeill et al. 1997). The nutritional significance of these anti-nutritive compounds is only partially understood and requires further investigation (Lowry et al. 1996).

Factors Affecting Interpretation of Chemical Composition Data

The rankings of taxon by the forage quality parameters observed at the two sites were compared by rank correlation coefficients to assess how consistently the chemical analyses ranked forage quality across the genus. Condensed tannin (r^2=0.72) and IVDMD (r^2=0.61) ranks were quite similar, while the CP (r^2=0.34) and NDF (r^2=0.25) ranks were poorly correlated. This variation highlights the limitations of comparing the forage quality of different species based on single site or "one-off" evaluations. The differences in the chemical composition and digestibility data collected in Australia (UQ) and Honduras (OFI) could be due to a number of factors.

Sample tissue selection

Forage quality is affected by the physiological maturity of the plant material analysed. Comparing the results of chemical analyses on the youngest fully expanded leaves (YFEL) (UQ) to the mature leaves (ML) (OFI) revealed that the physiologically older material analysed by OFI generally contained less CP, more NDF and had a lower IVDMD than the YFEL. In an earlier study to select a sample tissue to evaluate the CT status of *Leucaena* spp., CT concentration varied considerably with tissue maturity (Dalzell and Shelton 1997). Shoot material (stem apices) contained significantly more CT than YFEL and ML. Higher mimosine concentrations have also been observed in younger leaves than mature leaves (Tangendjaja et al. 1986; Hauad Marroquin and Foroughbakhch 1991; Bray 1995). Toruan-Mathius and Suhendi (1992) compared the forage quality of young and mature *L. diversifolia* leaves, finding CP, mimosine, tannin, and phosphorus concentrations decreased as leaves matured, while NDF, cellulose, ADF, fat and sugar contents increased with leaf maturity. The mineral composition of *L. leucocephala* has also been reported to vary with leaf tissue maturity and is further confounded by inconsistent seasonal interactions (Kabaija and Smith 1989). Thus, the individual forage components of the edible fraction of *Leucaena* forage (leaves, shoots, stems, pods and flowers) differ significantly in chemical composition (Akbar and Gupta 1985; Bassala et al. 1991).

It can be concluded that the plant tissues sampled (ML and YFEL) only permit the ranking of different accessions on forage quality. The actual forage quality of edible *Leucaena* dry matter selected by browsing ruminants will be very different from that estimated from the specific sample tissues reported here.

Sample preparation and laboratory procedures
Comparison of results of chemical composition analyses from different laboratories is further confounded by the use of different sample preparation processes, laboratory procedures and assay calibration materials, which influence the absolute values of the forage quality parameters reported.

Freeze-drying (lyophilising) plant material preserves it in a state similar to fresh material, while oven-drying has been found to significantly affect the measurement of forage quality parameters, particularly N degradability (Maillard and CT precipitation reactions), CT, fibre (ADF, NDF and lignin) and subsequently IVDMD, in tanniferous forage tree legumes (Dzowela et al. 1995). This could explain some of the differences in the absolute values and taxonomic ranking of parameters measured in the Honduran (oven-dried 50 °C for 72 h) and Australian (lyophilised) leaf material.

The differences between rumen liquor-pepsin and pepsin-cellulase IVDMD values measured in these experiments are a good example of how different laboratory procedures and assay calibration methods affect the absolute values of the data generated. Thus, existing in vitro procedures may require modification to account for the presence of secondary plant metabolites present in browse legumes. In another example, CT have the potential to interfere in fibre analysis due to their capacity to bind to plant structural carbohydrates and protein, forming insoluble complexes in acid detergent solutions. This results in an over-estimation of ADF and lignin (Van Soest 1994; Makkar et al. 1997). Measurement of acid detergent lignin (ADL) (Van Soest and Robertson 1980), which is the combined lignin/bound CT content of forages, while not separating fibre components into pure fractions, has practical application in determining the forage quality of tanniferous feeds. Based on the assumption that neither rumen microflora nor animals can utilise bound CT or lignin as a source of energy or nutrients, ADL should delineate potential forage digestibility and nutritive value. Bamualim et al. (1980) highlighted the value of measuring ADL by observing a strong negative relationship between nylon bag DMD and ADL (r^2=0.85) in 27 accessions of browse legumes.

Environmental effects on forage quality parameters
Environmental conditions affect plant tissue physiology and in turn chemical composition. The Redland Bay site in Australia is an extremely fertile, moist (weakly seasonal), subtropical environment at which the forage quality of tissue samples of *Leucaena* taxa might be expected to be optimal. The La Soledad, Honduras, site is fertile but more environmentally challenging with a pronounced 7-month dry season (Stewart and Dunsdon 1998). This may explain some of the variation in forage quality parameter ranks and absolute values between the two sites.

Condensed tannin is a good example of a chemical composition parameter that is affected by environmental conditions. The effect of a number of environmental parameters on the CT status of *Leucaena* spp. was evaluated in glasshouse trials conducted at the University of Queensland.

The effect of soil nutrient deficiencies, soil acidity and water stress on the CT status of *L. leucocephala* and *L. pallida* was evaluated in a glasshouse experiment using an acid infertile soil. Severe phosphorus and nitrogen deficiency, and soil acidity stresses were induced, and were evidenced by foliar symptoms, retarded growth and plant tissue elemental composition. Soil acidity stress, predominately Ca deficiency, and phosphorus deficiency dramatically suppressed CT synthesis and accumulation in the YFEL of *Leucaena* spp. (Figure 2). This was in contrast to the results of Barry and Forss (1983), who observed CT in *Lotus pedunculatus* decreased by 50% with the amelioration of P and S deficiency on an acid infertile soil. Tiarks et al. (1989) also observed a decrease in CT with the application of P fertiliser to *Pinus* spp. The CT concentrations of water stressed *L. leucocephala* and *L. pallida* plants were only 32.5% and 71.4% that of the concentrations in unstressed plants respectively (Figure 2). Duarsa et al. (1993) observed an opposite trend in *Lotus pedunculatus* with CT increasing under water stress at high temperature. Finally, despite severe N deficiency symptoms and retarded growth in the -N treatment, the CT status of *Leucaena* spp. remained similar to that of the control plants. This observation is supported by the results of Tiarks et al. (1989), where the application of N fertiliser to pine trees had no effect on leaf CT content.

The effect of temperature on the CT status of *Leucaena* spp. was also evaluated in a controlled environment experiment at the University of Queensland. Accessions of *L. leucocephala*, *L. pallida*, KX2 hybrid, *L. trichandra* and *L. macrophylla* were grown for 20 weeks under day/night temperature regimes of 18/13, 23/18, 28/23 and 33/28 °C. The 18/13 °C temperature regime severely limited plant growth; however, these plants had the highest CT levels (Figure 3). In contrast, Duarsa et al. (1993) observed that the CT status of *Lotus pedunculatus* and *L. corniculatus* were not greatly affected by temperature.

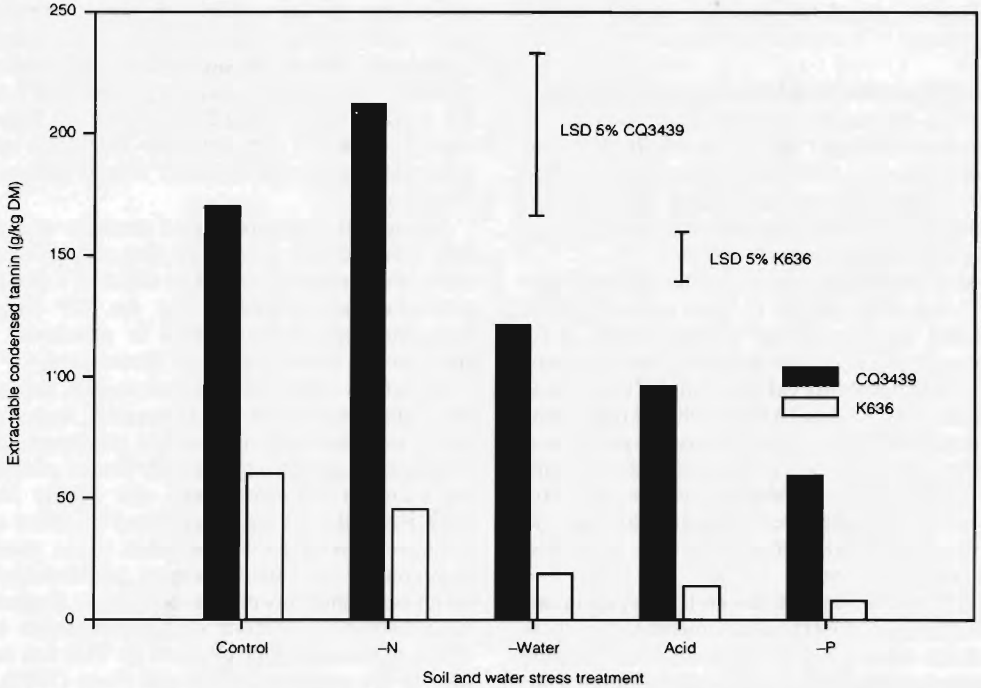

Figure 2. The effect of nitrogen (–N) and phosphorus (–P) deficiencies, and acid soil (acid) and water (–water) stress on the extractable condensed tannin content of the YFEL of *L. leucocephala* subsp. *glabrata* (K636) and *L. pallida* (CQ3439).

In another experiment at the University of Queensland, the application of phytotoxic insecticides also altered the CT status of *Leucaena* spp.. Severely phytotoxic insecticides caused leaflet necrosis and abscission, and reduced CT concentrations by 55% compared to healthy control plants (S. Dalzell unpublished data). Interactions with cotton CT status and the application of agricultural chemicals have also been observed (Bell et al. 1992).

Thus a wide range of different environmental stresses have suppressed the CT status of *Leucaena* spp.. These findings contrast with popular plant defence and carbon allocation theories developed from reports that phenolic concentrations increase when plants are grown under adverse climatic and edaphic conditions. A number of hypotheses regarding the effect of environmental factors on CT synthesis are being investigated at the University of Queensland.

Many other forage quality parameters are affected by environmental stress. The mineral composition of *Leucaena* spp. also varies with environmental conditions, particularly soil fertility. Ash contents generally increase during dry seasons, while individual element concentrations fluctuate independently based upon their phloem mobility and plant growth rate, which determine the extent of essential element dilution (Kabaija and Smith 1989; Faria-Marmol et al. 1996). Msangi and Hardesty (1993) observed seasonal increases in CP and IVDMD in *L. leucocephala* leaves at the break of the wet season in Tanzania, and attributed this to a flush of new growth. Mimosine concentrations in *Leucaena* spp. increase during active periods of plant growth (wet summers) (Hauad Marroquin and Foroughbakhch 1991; Gupta et al. 1992, Bray 1995) and decrease when plants were grown for prolonged periods under water-stress (Ponnammal and Gnanam 1984). Conversely, Bray and Hoekstra (1985) demonstrated that mimosine concentration increased with short-term moisture stress, highlighting the importance of stress duration on plant chemical composition response.

Thus multi-site evaluations are necessary to fully quantify genetic variation in forage quality and to understand environmental interactions with plant chemical composition.

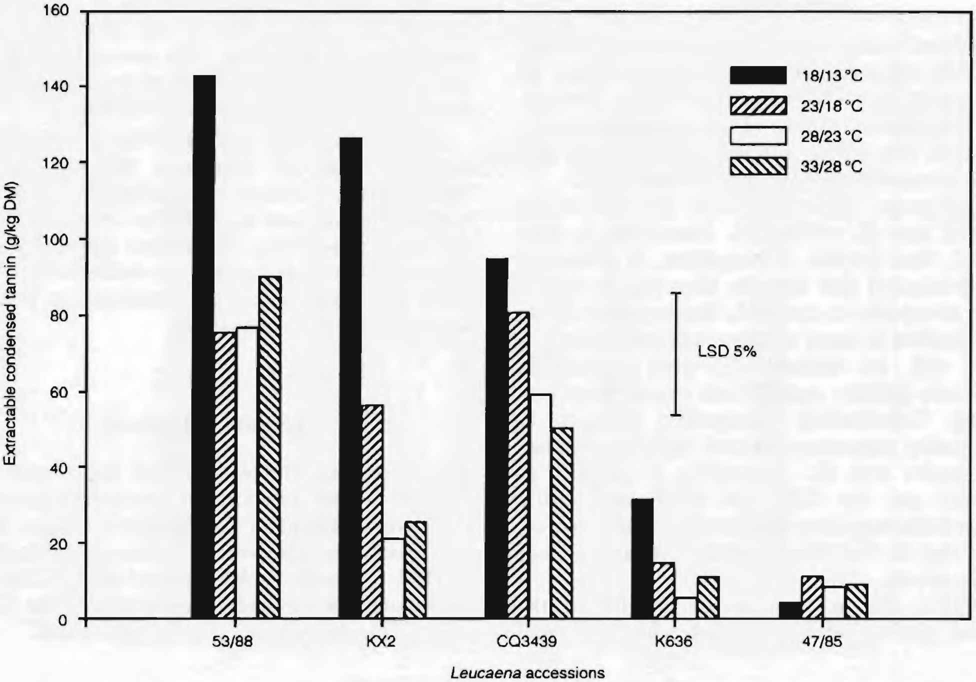

Figure 3. The effect of ambient temperature on extractable condensed tannin content of the YFEL of *L. trichandra* (OFI 53/88), *L. pallida* × *L. leucocephala* subsp. *glabrata* hybrid (KX2), *L. pallida* (CQ3439), *L. leucocephala* subsp. *glabrata* (K636) and *L. macrophylla* subsp. *istemensis* (OFI 47/85).

Future Research Priorities

The chemical composition and IVDMD data presented provide a preliminary evaluation of the forage quality of the *Leucaena* genus. Although chemical composition indications of forage quality need to be confirmed in animal trials, there remain some aspects of chemical composition that require further research to improve our understanding of the quality of *Leucaena* spp.:

1. The presence of CT in forages can adversely affect N utilisation in livestock. The biological activity of CT is a function of CT concentration and tannin-protein binding capacity. The environment in which plants grow has a dramatic effect on CT concentrations in *Leucaena* spp. forage; however, little is known about environmental and plant physiological effects on CT structure (composition of flavanol monomers and degree of polymerisation) and subsequent tannin-protein binding capacity. This requires elucidation.
2. Condensed tannins and mimosine are recognised as the most detrimental secondary plant metabolites present in *Leucaena* spp. for ruminant nutrition. However, the nutritional implications of other anti-nutritive compounds, particularly in the context of monogastric animals, are poorly understood and need to be addressed. Comprehensive screening to quantify mimosine, saponins, alkaloids, hydrolysable tannins and other phenolic compounds, and to understand their nutritional significance is required.
3. Although *L. leucocephala* has long been identified as an excellent source of protein for ruminant animals, very little is known about the non-structural carbohydrate fraction (sugar, starch and pectin) or non-protein N profile of the genus. Screening for these parameters may permit the selection/hybridisation of carbohydrate-rich accessions, with the aim of increasing the energy supply to the rumen (lower the CP/energy ratio) to improve the efficiency of microbial N utilisation. This information is also required to determine how sugar/pectin/starch rich supplements could be used to enhance animal performance from *Leucaena* based diets.

Conclusion

The chemical composition data presented enabled taxa within the *Leucaena* genus to be ranked on forage quality at one point in time in two environments. The absolute values of the parameters measured varied due to the different environments and with the laboratory methods used in both trials.

The parameter rankings indicate that there are a number of taxa (*L. collinsii*, *L. lanceolata*, *L. lempirana*, *L. macrophylla*. *L. magnifica*, *L. shannonii* and *L. trichodes*) that have in vitro forage quality equal to or superior to that of *L. leucocephala*. However, utilisation of many of these taxa for forage production will be limited by poor agronomic performance (Mullen and Shelton et al., these Proceedings). Considerable intraspecific variation in forage quality parameters existed within agronomically superior taxa (*L. diversifolia*, *L. pallida*, *L. trichandra* and the KX2 and KX3 interspecific hybrids), indicating there is potential to select accessions of high in vitro forage quality similar to that of *L. leucocephala*.

Generally, the in vitro forage quality of the *Leucaena* genus appears to be high when compared to other tropical forages, in terms of high IVDMD and CP, low levels of NDF and adequate levels of most minerals. However, high concentrations of CT will reduce the nutritive value of some accessions by interfering in CP digestion and IVDMD.

To complete our understanding of the in vivo nutritive value of *Leucaena* species, metabolic feeding trials and long term grazing/feeding trials are required to measure animal live weight gain, milk and wool production, and animal reproductive performance. Such trials could also indicate the productivity and resilience of the lesser-known *Leucaena* spp. in direct-grazing systems.

Acknowledgments

The Australian trial was carried out as part of an ACIAR-funded collaborative research program entitled 'New Leucaenas for Southeast Asian, Pacific and Australian Agriculture'. The technical assistance of Dr S. Islam, Mr M.A. Faint and Mr B.F. Mullen in laboratory analysis and data collation at the University of Queensland was greatly appreciated.

APPENDIX 1. Chemical composition and in vitro dry matter digestibility of YFEL of the *Leucaena* genus grown at Redland Bay, Australia.

Species	Subspecies/variety	Accession	Chemical composition (%DM)						
			IVDMD	ECT	BCT	TCT	CP	NDF	Ash
L. ? hybrid		K953	62	2.5	0.5	3.0	29.0	24.0	6.3
L. ? hybrid		OFI 52/87	65	1.8	0.6	2.4	30.6	17.4	6.0
L. collinsii	*collinsii*	OFI 51/88	68	0.0	0.1	0.1	37.7	19.1	7.9
L. collinsii	*collinsii*	OFI 52/88	70	0.0	0.1	0.1	36.4	18.6	7.8
L. collinsii	*zacapana*	OFI 18/84	67	0.0	0.2	0.2	34.4	21.3	6.9
L. collinsii	*zacapana*	OFI 56/88	65	0.0	0.2	0.2	33.2	26.7	7.4
L. collinsii	*zacapana*	OFI 57/88	67	0.0	0.1	0.1	–	23.0	8.6
L. confertiflora	var. *adenotheloidea*	OFI 87/94	42	15.2	1.6	16.8	17.6	22.8	5.6
L. confertiflora	var. *adenotheloidea*	OFI 88/94	42	23.5	2.7	26.2	17.8	22.8	6.0
L. cuspidata		OFI 83/94	43	29.1	1.5	30.6	14.7	26.7	5.8
L. diversifolia		CPI33820	56	11.8	1.9	13.7	32.0	20.2	6.3
L. diversifolia		K156	59	15.1	1.6	16.7	29.7	20.6	5.6
L. diversifolia		K778	57	16.6	1.8	18.5	26.0	27.9	6.1
L. diversifolia		K784	60	14.1	1.9	15.9	29.3	26.5	6.6
L. diversifolia		K802	60	5.2	2.0	7.2	29.0	18.1	6.8
L. diversifolia		OFI 104/94	60	10.1	2.3	12.4	26.0	24.5	6.2
L. diversifolia		OFI 105/94	61	4.0	1.8	5.7	26.3	20.4	6.8
L. diversifolia		OFI 106/94	58	8.9	3.2	12.1	29.3	18.5	6.3
L. diversifolia		OFI 126/92	57	10.3	1.5	11.8	25.1	24.1	5.9
L. diversifolia		OFI 45/87	60	13.1	1.8	14.9	27.1	19.1	5.8
L. diversifolia		OFI 46/87	58	12.5	2.5	15.0	29.2	21.5	5.9
L. diversifolia		OFI 82/92	58	6.2	3.8	10.0	27.9	22.2	6.4
L. diversifolia		OFI 83/92	61	11.5	1.1	12.6	24.7	17.2	5.9
L. diversifolia × *L. leucocephala* (KX3)[1]		91-13 F4	59	7.3	1.8	9.1	31.1	21.1	6.5
L. diversifolia × *L. leucocephala* (KX3)[1]		91-2 F4	63	6.4	1.3	7.7	36.3	22.9	6.2
L. diversifolia × *L. leucocephala* (KX3)[1]		91-6 F4	63	5.1	0.6	5.7	33.5	16.9	6.3
L. diversifolia × *L. leucocephala* (KX3)[1]		92-4 F4	62	2.7	1.5	4.2	28.7	20.4	7.0

APPENDIX 1. (cont.) Chemical composition and in vitro dry matter digestibility of YFEL of the *Leucaena* genus grown at Redland Bay, Australia.

Species	Subspecies/variety	Accession	Chemical composition (%DM)						
			IVDMD	ECT	BCT	TCT	CP	NDF	Ash
L. diversifolia × *L. leucocephala* (KX3)[1]		K156xK500 F2	62	2.5	1.7	4.2	30.2	19.4	7.6
L. diversifolia × *L. leucocephala* (KX3)[1]		K156xK636 F2	62	2.7	1.1	3.8	32.1	19.9	6.5
L. diversifolia × *L. leucocephala* (KX3)[1]		K156xK8 F2	62	6.4	1.5	7.9	29.2	19.0	6.7
L. esculenta		OFI 47/87	57	10.0	1.2	11.2	29.4	17.5	6.2
L. esculenta		OFI 48/87	58	12.3	1.4	13.7	31.2	19.7	6.3
L. greggii		OFI 82/87	47	18.4	1.3	19.7	19.4	22.6	5.5
L. involucrata		OFI 87/92	54	13.5	1.3	14.8	25.9	19.5	6.5
L. lanceolata	var. *lanceolata*	OFI 134/92	64	0.3	0.3	0.6	30.3	26.3	7.1
L. lanceolata	var. *lanceolata*	OFI 43/85	63	0.8	0.5	1.3	29.5	30.3	6.9
L. lanceolata	var. *lanceolata*	OFI 44/85	63	1.2	0.4	1.6	30.2	30.0	6.9
L. lanceolata	var. *lanceolata*	OFI 90/92	67	0.4	0.2	0.6	28.5	24.9	6.9
L. lanceolata	var. *sousae*	OFI 50/87	66	0.2	0.1	0.3	29.8	25.0	6.3
L. lanceolata	var. *sousae*	OFI 51/87	67	0.2	0.1	0.3	31.6	18.9	6.6
L. lempirana		OFI 5/91	66	0.2	0.1	0.3	31.1	23.3	6.4
L. lempirana		OFI 6/91	66	0.2	0.1	0.3	24.1	25.1	6.7
L. leucocephala	?	CPI58396	63	4.0	0.8	4.8	31.3	19.1	6.2
L. leucocephala	glabrata	CPI85176	63	1.5	1.0	2.5	26.6	20.1	7.4
L. leucocephala	glabrata	CPI90814	63	3.9	0.5	4.4	23.9	18.6	7.0
L. leucocephala	glabrata	cv. Cunningham	65	0.5	0.5	0.9	31.4	20.1	7.9
L. leucocephala	glabrata	K584	62	1.5	1.0	2.6	31.0	24.7	7.4
L. leucocephala	*glabrata*	K584xK636 F1	65	1.2	0.9	2.1	27.8	–	–
L. leucocephala	*glabrata*	K584xK636 F2	64	1.9	0.6	2.4	30.2	20.6	6.9
L. leucocephala	*glabrata*	cv. Tarramba	61	1.2	0.8	1.9	30.3	26.7	6.9
L. leucocephala	*glabrata*	K8	66	1.1	0.8	1.8	32.7	19.8	6.8
L. leucocephala	*glabrata*	K8	61	1.3	0.4	1.6	34.2	19.8	8.0
L. leucocephala	*glabrata*	OFI 102/94	65	3.2	0.5	3.7	27.8	21.2	6.4
L. leucocephala	*glabrata*	OFI 121/92	63	2.5	0.8	3.3	31.3	22.6	6.3
L. leucocephala	*glabrata*	OFI 136/92	65	1.5	0.7	2.2	32.5	16.4	8.4
L. leucocephala	*glabrata*	OFI 139/92	64	1.7	0.6	2.3	32.0	24.2	6.6
L. leucocephala	*glabrata*	OFI 145/91	61	1.9	1.3	3.2	26.9	25.4	6.5
L. leucocephala	*glabrata*	OFI 19/81	63	1.3	0.8	2.2	29.6	20.9	8.2
L. leucocephala	*glabrata*	OFI 30/93	62	1.5	0.4	2.0	30.0	23.0	7.2
L. leucocephala	*glabrata*	OFI 32/88	63	1.3	0.7	2.0	30.1	22.1	7.5
L. leucocephala	*glabrata*	OFI 45/88	65	0.8	0.7	1.4	30.1	17.4	7.6
L. leucocephala	*glabrata*	OFI 91/92	63	1.3	1.1	2.5	31.7	22.3	7.3
L. leucocephala	*glabrata*	OFI 94/92	65	3.0	0.9	3.9	28.5	21.3	6.8
L. leucocephala	*ixtahuacana*	OFI 117/92	61	4.1	0.9	5.0	39.6	38.1	6.7
L. leucocephala	*leucocephala*	CPI33821	65	3.2	0.5	3.7	32.5	18.0	8.0
L. leucocephala	*leucocephala*	CPI91953	61	1.6	1.2	2.7	24.8	23.1	5.5
L. leucocephala	*leucocephala*	K997	61	2.2	1.2	3.5	31.0	23.4	7.1
L. leucocephala	*leucocephala*	OFI 133/92	65	1.2	0.5	1.7	30.6	22.2	7.6
L. leucocephala	*leucocephala*	OFI 147/92	65	1.2	0.7	2.0	33.3	16.7	7.3
L. macrophylla	*istmensis*	OFI 39/89	69	1.0	0.2	1.2	37.6	18.2	6.5
L. macrophylla	*istmensis*	OFI 47/85	68	0.6	0.5	1.2	36.9	25.7	6.3
L. macrophylla	*macrophylla*	OFI 132/92	67	0.9	0.4	1.3	37.4	26.8	6.5
L. macrophylla	*macrophylla*	OFI 55/88	66	1.7	0.3	2.0	–	25.0	6.0
L. magnifica		OFI 19/84	68	0.0	0.1	0.1	37.9	23.8	7.2
L. magnifica		OFI 58/88	68	0.0	0.1	0.2	36.7	24.9	7.4
L. matudae		OFI 49/87	51	12.3	0.9	13.2	19.7	23.2	5.2
L. multicapitula		OFI 81/87	66	0.0	0.2	0.2	36.3	23.0	6.4
L. multicapitula		OFI 86/87	62	1.1	0.9	2.0	39.4	28.6	6.1
L. pallida		CPI91309	63	8.2	0.8	9.0	31.7	15.4	6.8
L. pallida		CQ3439	59	6.3	1.6	7.9	32.6	17.1	6.3
L. pallida		K376	61	4.2	0.8	4.9	29.5	22.2	6.4
L. pallida		OFI 44/87	56	15.9	1.3	17.1	27.5	17.6	5.7
L. pallida		OFI 78/92	64	8.3	0.8	9.2	35.1	19.3	6.1
L. pallida		OFI 79/92	61	4.2	1.2	5.3	31.0	19.8	6.7

APPENDIX 1. (cont.) Chemical composition and in vitro dry matter digestibility of YFEL of the *Leucaena* genus grown at Redland Bay, Australia.

Species	Subspecies/variety	Accession	Chemical composition (%DM)						
			IVDMD	ECT	BCT	TCT	CP	NDF	Ash
L. pallida		OFI 92/94	55	10.6	1.0	11.6	–	–	5.8
L. pallida × *L. leucocephala* (KX2)[1]		92-3 F5	65	2.4	0.5	3.0	35.1	14.6	6.7
L. pallida × *L. leucocephala* (KX2)[1]		92-3 SC	64	6.1	1.2	7.3	31.5	19.3	6.6
L. pallida × *L. leucocephala* (KX2)[1]		K748xK584 F1	64	5.5	1.2	6.7	26.8	17.2	6.4
L. pallida × *L. leucocephala* (KX2)[1]		K748xK636 F1	62	3.1	1.2	4.3	27.7	18.8	6.2
L. pallida × *L. leucocephala* (KX2)[1]		K748xK636 F1	62	4.1	1.2	5.3	34.6	18.8	6.2
L. pallida × *L. leucocephala* (KX2)[1]		K806xK636 F1	54	3.0	1.2	4.2	28.0	18.9	6.6
L. pueblana		OFI 125/92	52	9.3	0.6	9.9	28.4	26.0	4.9
L. pueblana		OFI 34/89	51	10.6	0.5	11.1	–	19.5	5.6
L. pulverulenta		OFI 22/86	52	11.8	1.2	13.0	24.3	23.2	5.7
L. pulverulenta		OFI 83/87	52	13.7	1.8	15.4	24.1	21.9	5.9
L. pulverulenta		OFI 84/87	53	18.3	1.0	19.4	26.8	16.3	6.0
L. retusa		OFI 23/86	63	2.3	1.2	3.5	21.7	22.1	6.4
L. salvadorensis		OFI 34/88	63	0.1	0.1	0.2	30.6	32.0	7.0
L. salvadorensis		OFI 36/88	64	0.0	0.1	0.1	26.9	29.8	7.2
L. salvadorensis		OFI 7/91	65	0.0	0.2	0.2	31.2	29.4	7.2
L. shannonii		OFI 135/92	67	0.0	0.5	0.5	35.5	22.0	7.0
L. shannonii		OFI 141/92	67	1.7	0.6	2.3	35.6	18.8	6.8
L. shannonii		OFI 26/84	66	0.6	0.4	1.0	32.2	24.0	6.5
L. shannonii		OFI 53/87	69	0.5	0.7	1.2	31.5	20.6	6.7
L. trichandra		CPI46568	58	16.4	2.5	18.9	25.1	21.0	6.2
L. trichandra		OFI 128/92	61	3.6	2.8	6.5	24.7	21.3	6.1
L. trichandra		OFI 131/92	62	2.9	2.8	5.7	32.6	23.4	5.5
L. trichandra		OFI 137/92	56	11.4	3.1	14.5	17.4	22.2	6.6
L. trichandra		OFI 138/92	68	0.3	0.5	0.8	26.9	22.9	–
L. trichandra		OFI 140/92	64	2.8	2.7	5.5	27.7	20.9	6.2
L. trichandra		OFI 3/91	64	14.1	2.7	16.9	24.7	20.5	5.9
L. trichandra		OFI 35/88	57	20.5	2.1	22.6	29.7	26.3	5.9
L. trichandra		OFI 4/91	67	0.2	0.2	0.4	33.0	26.7	6.5
L. trichandra		OFI 53/88	61	15.8	2.3	18.1	27.2	17.4	5.8
L. trichodes		OFI 2/86	67	0.1	0.1	0.2	40.0	24.6	7.2
L. trichodes		OFI 61/88	67	0.1	0.2	0.3	29.2	24.2	8.6
L. xspontanea		OFI 98/94	64	3.8	0.9	4.7	33.8	23.2	6.6
L. xspontanea		OFI 99/94	67	1.6	0.4	2.1	27.6	20.0	7.7

[1] KX2 and KX3 accessions are artificial interspecific hybrids generated at the University of Hawaii.

APPENDIX 2. Mineral composition of YFEL of the *Leucaena* genus grown at Redland Bay, Australia.

Species	Subspecies/bariety	Accession	Macronutrient (%DM)						Micronutrient (μg/g)					
			Ca	K	Mg	N	P	S	B	Cu	Fe	Mn	Na	Zn
L. ? hybrid		K953	0.4	2.2	0.14	4.6	0.37	0.53	39	7.3	97	50	242	38
L. ? hybrid		OFI 52/87	0.5	2.5	0.20	4.9	0.42	0.61	31	8.7	93	56	189	40
L. collinsii	*collinsii*	OFI 51/88	0.6	2.7	0.20	6.0	0.45	0.94	43	7.5	99	36	375	35
L. collinsii	*collinsii*	OFI 52/88	0.6	2.6	0.17	5.8	0.44	1.07	43	6.2	86	40	276	32
L. collinsii	*zacapana*	OFI 18/84	0.7	2.3	0.16	5.5	0.39	0.77	38	5.5	85	34	227	32
L. collinsii	*zacapana*	OFI 56/88	1.6	1.9	0.24	5.3	0.35	0.88	51	4.7	380	61	254	38
L. confertiflora	var. *adenotheloidea*	OFI 87/94	1.1	0.8	0.28	2.8	0.25	0.22	55	2.4	196	38	214	30
L. confertiflora	var. *adenotheloidea*	OFI 88/94	1.6	1.2	0.26	2.8	0.35	0.31	77	4.1	139	85	265	40
L. cuspidata		OFI 83/94	1.1	0.7	0.27	2.3	0.11	0.18	53	1.5	117	75	270	22
L. diversifolia		CPI33820	0.7	2.1	0.18	5.1	0.36	0.39	46	7.3	92	36	561	31
L. diversifolia		K156	1.1	2.0	0.28	4.7	0.36	0.39	87	7.3	115	65	295	39
L. diversifolia		K778	1.9	1.4	0.27	4.2	0.28	0.38	100	6.1	108	111	373	41
L. diversifolia		K784	1.0	2.1	0.19	4.7	0.35	0.33	67	5.5	137	67	256	35
L. diversifolia		K802	0.5	1.9	0.17	4.6	0.37	0.35	44	5.1	86	43	421	27
L. diversifolia		OFI 104/94	1.2	1.6	0.24	4.2	0.31	0.43	72	4.7	107	77	472	33
L. diversifolia		OFI 105/94	1.5	1.6	0.30	4.2	0.38	0.46	98	6.2	114	58	234	42
L. diversifolia		OFI 106/94	0.8	1.9	0.20	4.7	0.35	0.43	67	5.9	110	42	499	31
L. diversifolia		OFI 126/92	2.0	1.2	0.25	4.0	0.21	0.26	91	4.0	102	76	401	39
L. diversifolia		OFI 45/87	0.5	2.0	0.19	4.3	0.35	0.39	46	6.6	81	35	655	28
L. diversifolia		OFI 46/87	0.5	2.1	0.18	4.7	0.38	0.39	45	5.1	83	37	682	27
L. diversifolia		OFI 82/92	0.8	1.9	0.22	4.5	0.35	0.45	45	6.5	102	46	516	38
L. diversifolia		OFI 83/92	1.5	1.4	0.26	4.0	0.27	0.35	117	6.6	96	63	172	41
L. diversifolia × *L. leucocephala* (KX3)[1]		91-13 F4	0.7	2.3	0.19	5.0	0.40	0.48	32	7.0	92	56	226	33
L. diversifolia × *L. leucocephala* (KX3)[1]		91-2 F4	0.4	2.4	0.22	5.8	0.55	0.67	26	7.4	114	54	303	38
L. diversifolia × *L. leucocephala* (KX3)[1]		91-6 F4	0.4	2.2	0.23	5.4	0.46	0.55	30	6.9	104	49	230	32
L. diversifolia × *L. leucocephala* (KX3)[1]		92-4 F4	0.8	2.1	0.24	4.6	0.36	0.43	30	5.2	97	63	196	29
L. diversifolia × *L. leucocephala* (KX3)[1]		K156xK500 F2	0.7	2.4	0.20	4.8	0.40	0.50	41	5.9	83	51	104	34
L. diversifolia × *L. leucocephala* (KX3)[1]		K156xK636 F2	0.5	2.3	0.22	5.1	0.44	0.53	39	7.4	103	41	309	39
L. diversifolia × *L. leucocephala* (KX3)[1]		K156xK8 F2	0.5	2.1	0.20	4.7	0.42	0.47	36	8.4	91	37	343	27
L. esculenta		OFI 47/87	0.5	2.0	0.20	4.7	0.47	0.78	41	4.4	76	53	303	37
L. esculenta		OFI 48/87	0.5	1.9	0.27	5.0	0.52	0.94	62	8.2	80	48	206	43
L. greggii		OFI 82/87	0.2	1.5	0.20	3.1	0.33	0.63	19	2.6	72	23	571	30
L. involucrata		OFI 87/92	0.4	2.2	0.14	4.1	0.41	0.45	28	4.6	92	41	442	36
L. lanceolata	var. *lanceolata*	OFI 134/92	0.4	2.6	0.19	4.8	0.54	0.99	35	7.3	88	33	407	38
L. lanceolata	var. *lanceolata*	OFI 43/85	0.8	2.7	0.20	4.7	0.44	0.82	38	6.1	87	40	228	40
L. lanceolata	var. *lanceolata*	OFI 44/85	0.4	2.6	0.17	4.8	0.53	0.51	29	8.8	95	31	332	39
L. lanceolata	var. *lanceolata*	OFI 90/92	0.5	2.9	0.22	4.6	0.52	0.52	38	8.1	86	43	385	50
L. lanceolata	var. *sousae*	OFI 50/87	0.7	2.5	0.15	4.8	0.44	0.66	42	4.9	84	38	297	36
L. lanceolata	var. *sousae*	OFI 51/87	0.6	3.0	0.17	5.1	0.51	0.79	39	6.0	79	33	280	36
L. lempirana		OFI 5/91	1.0	2.0	0.18	5.0	0.42	0.45	41	6.4	94	38	410	41
L. lempirana		OFI 6/91	2.1	1.6	0.26	3.9	0.32	0.37	64	5.1	113	76	295	41
L. leucocephala	?	CPI58396	0.6	2.8	0.22	5.0	0.42	0.51	35	6.5	104	93	392	36
L. leucocephala	*glabrata*	CPI85176	0.4	2.0	0.19	4.3	0.40	0.46	31	5.6	77	49	299	34
L. leucocephala	*glabrata*	CPI90814	1.3	2.2	0.28	3.8	0.32	0.48	53	7.1	133	117	359	43
L. leucocephala	*glabrata*	cv. Cunningham	0.8	2.9	0.29	5.0	0.42	0.63	36	7.5	91	74	297	43
L. leucocephala	*glabrata*	K584	0.5	2.7	0.25	5.0	0.49	0.59	26	6.7	108	67	329	38
L. leucocephala	*glabrata*	K584xK636 F1	0.6	2.5	0.26	4.9	0.39	0.49	23	6.7	88	63	285	33
L. leucocephala	*glabrata*	K584xK636 F2	0.4	2.4	0.27	5.4	0.46	0.58	32	7.3	114	48	264	36
L. leucocephala	*glabrata*	cv. Tarramba	0.9	2.3	0.28	4.4	0.38	0.52	37	6.0	106	87	342	37
L. leucocephala	*glabrata*	K8	0.5	2.3	0.22	4.8	0.47	0.58	20	8.0	114	43	262	38
L. leucocephala	*glabrata*	OFI 102/94	0.7	2.7	0.24	4.4	0.39	0.47	27	6.1	128	72	355	35
L. leucocephala	*glabrata*	OFI 121/92	0.6	2.4	0.25	5.0	0.42	0.57	29	6.0	120	82	309	36
L. leucocephala	*glabrata*	OFI 136/92	0.7	2.3	0.20	5.2	0.42	0.57	31	7.0	104	52	245	37
L. leucocephala	*glabrata*	OFI 139/92	0.4	2.4	0.20	5.1	0.50	0.57	23	7.3	104	38	309	39
L. leucocephala	*glabrata*	OFI 145/91	0.5	2.6	0.24	4.3	0.41	0.53	30	7.1	92	70	453	36
L. leucocephala	*glabrata*	OFI 19/81	0.6	2.6	0.22	4.7	0.44	0.52	26	7.7	158	50	396	34
L. leucocephala	*glabrata*	OFI 30/93	0.9	2.0	0.27	4.8	0.36	0.43	48	5.5	128	63	328	37
L. leucocephala	*glabrata*	OFI 32/88	0.7	2.3	0.25	4.8	0.39	0.48	25	6.5	104	66	301	34

APPENDIX 2. (cont.) Mineral composition of YFEL of the *Leucaena* genus grown at Redland Bay, Australia.

Species	Subspecies/bariety	Accession	Macronutrient (%DM)						Micronutrient (μg/g)					
			Ca	K	Mg	N	P	S	B	Cu	Fe	Mn	Na	Zn
L. leucocephala	*glabrata*	OFI 45/88	0.6	2.8	0.23	4.8	0.44	0.63	25	6.5	107	48	391	35
L. leucocephala	*glabrata*	OFI 91/92	0.7	2.5	0.26	5.1	0.40	0.65	34	7.0	117	55	309	37
L. leucocephala	*glabrata*	OFI 94/92	0.8	2.6	0.23	4.6	0.37	0.49	31	6.4	101	66	345	36
L. leucocephala	*ixtahuacana*	OFI 117/92	0.6	2.1	0.24	6.3	0.39	0.47	31	6.1	93	60	259	34
L. leucocephala	*leucocephala*	CPI33821	0.7	2.0	0.23	5.2	0.39	0.39	38	6.0	110	73	281	31
L. leucocephala	*leucocephala*	CPI91953	0.3	2.1	0.19	4.0	0.34	0.45	25	5.8	89	42	359	28
L. leucocephala	*leucocephala*	K997	0.9	2.0	0.28	5.0	0.37	0.43	53	5.5	120	69	328	35
L. leucocephala	*leucocephala*	OFI 133/92	0.4	2.4	0.26	4.9	0.50	0.58	32	6.6	103	54	323	40
L. leucocephala	*leucocephala*	OFI 147/92	0.5	2.5	0.19	5.3	0.38	0.55	29	5.7	116	38	407	33
L. macrophylla	*istmensis*	OFI 39/89	0.5	2.6	0.16	6.0	0.52	0.40	34	6.0	95	49	280	38
L. macrophylla	*istmensis*	OFI 47/85	0.3	2.5	0.17	5.9	0.63	0.48	40	8.3	90	40	323	42
L. macrophylla	*macrophylla*	OFI 132/92	0.3	3.0	0.15	6.0	0.65	0.40	28	7.6	88	39	247	40
L. macrophylla	*macrophylla*	OFI 55/88	0.6	2.3	0.19	–	0.55	0.45	46	9.4	107	54	289	46
L. magnifica		OFI 19/84	0.5	2.9	0.18	6.1	0.50	0.70	39	5.4	105	40	375	33
L. magnifica		OFI 58/88	0.7	2.6	0.19	5.9	0.45	0.68	59	5.0	101	41	290	34
L. matudae		OFI 49/87	1.2	1.3	0.19	3.2	0.25	0.34	37	2.4	120	70	258	33
L. multicapitula		OFI 81/87	0.4	2.5	0.17	5.8	0.47	0.34	28	6.7	110	52	445	39
L. multicapitula		OFI 86/87	0.3	2.3	0.18	6.3	0.51	0.42	28	8.4	114	37	343	34
L. pallida		CPI91309	0.8	2.6	0.18	5.1	0.51	0.76	41	9.6	116	47	253	51
L. pallida		CQ3439	0.5	2.1	0.20	5.2	0.51	0.73	32	9.1	119	50	292	43
L. pallida		K376	0.6	2.2	0.21	4.7	0.37	0.48	41	7.8	89	51	195	39
L. pallida		OFI 44/87	1.1	1.6	0.32	4.4	0.38	0.54	111	4.0	102	90	680	44
L. pallida		OFI 78/92	0.3	2.3	0.19	5.6	0.56	0.91	32	10.1	117	55	266	48
L. pallida		OFI 79/92	0.7	2.2	0.23	5.0	0.45	0.66	56	7.7	105	55	313	44
L. pallida × *L. leucocephala* (KX2)[1]		92-3 F5	0.5	2.4	0.23	5.6	0.50	0.63	31	6.4	101	55	364	39
L. pallida × *L. leucocephala* (KX2)[1]		92-3 SC	0.6	2.2	0.20	5.0	0.37	0.40	29	4.5	99	42	288	37
L. pallida × *L. leucocephala* (KX2)[1]		K748xK584 F1	0.5	2.3	0.21	4.3	0.38	0.48	28	5.9	77	45	295	33
L. pallida × *L. leucocephala* (KX2)[1]		K748xK636 F1	0.4	2.4	0.21	5.0	0.41	0.51	25	6.2	85	46	340	33
L. pallida × *L. leucocephala* (KX2)[1]		K806xK636 F1	0.4	2.4	0.23	4.5	0.52	0.68	25	7.0	115	56	233	42
L. pueblana		OFI 125/92	0.6	1.4	0.20	4.5	0.34	0.54	29	5.4	98	33	165	36
L. pueblana		OFI 34/89	0.5	1.6	0.18	–	0.43	0.52	29	5.5	95	45	259	37
L. pulverulenta		OFI 22/86	0.7	1.8	0.28	3.9	0.32	0.32	37	4.8	104	43	536	32
L. pulverulenta		OFI 83/87	0.6	2.0	0.22	3.9	0.31	0.31	31	3.8	71	36	607	29
L. pulverulenta		OFI 84/87	0.8	1.9	0.25	4.3	0.35	0.40	26	5.5	100	26	465	41
L. retusa		OFI 23/86	1.3	1.2	0.24	3.5	0.25	0.36	38	2.4	90	36	287	36
L. salvadorensis		OFI 34/88	1.2	2.5	0.19	4.9	0.45	0.51	48	9.2	86	42	188	41
L. salvadorensis		OFI 36/88	1.3	1.9	0.17	4.3	0.37	0.43	55	7.6	113	50	267	34
L. salvadorensis		OFI 7/91	0.6	2.5	0.15	5.0	0.46	0.46	31	8.1	78	40	372	34
L. shannonii		OFI 135/92	0.7	2.7	0.17	5.7	0.48	0.55	37	7.3	97	32	282	39
L. shannonii		OFI 141/92	0.7	2.7	0.21	5.7	0.48	0.52	35	9.5	117	49	302	44
L. shannonii		OFI 26/84	1.2	2.2	0.22	5.2	0.35	0.45	39	6.5	98	36	216	39
L. shannonii		OFI 53/87	0.5	2.4	0.19	5.0	0.43	0.47	29	8.6	118	45	380	39
L. trichandra		CPI46568	1.8	1.2	0.23	4.0	0.27	0.29	92	4.3	91	128	223	47
L. trichandra		OFI 128/92	1.7	1.3	0.17	3.9	0.27	0.36	151	5.1	133	84	297	41
L. trichandra		OFI 131/92	0.6	2.1	0.14	5.2	0.44	0.35	45	7.3	87	76	417	42
L. trichandra		OFI 137/92	2.0	0.9	0.21	2.8	0.35	0.32	103	2.5	158	72	433	39
L. trichandra		OFI 138/92	1.1	1.5	0.19	4.3	0.31	0.33	83	4.4	114	172	893	40
L. trichandra		OFI 140/92	1.2	1.8	0.21	4.4	0.32	0.33	74	6.9	120	78	440	40
L. trichandra		OFI 3/91	1.5	1.4	0.16	4.0	0.24	0.31	94	2.6	124	64	305	41
L. trichandra		OFI 35/88	0.9	1.8	0.17	4.8	0.42	0.41	67	8.0	101	61	273	47
L. trichandra		OFI 4/91	0.6	2.2	0.16	5.3	0.52	0.58	71	9.9	113	58	299	45
L. trichandra		OFI 53/88	1.3	1.5	0.19	4.3	0.29	0.34	89	4.6	93	55	639	37
L. trichodes		OFI 2/86	0.4	3.1	0.17	6.4	0.56	0.63	28	8.1	101	49	433	44
L. trichodes		OFI 61/88	0.9	2.9	0.21	4.7	0.43	0.54	31	6.5	99	51	461	35
L. xspontanea		OFI 98/94	0.4	2.4	0.19	5.4	0.47	0.58	35	7.9	93	34	329	34
L. xspontanea		OFI 99/94	1.4	1.9	0.27	4.4	0.33	0.45	76	6.1	109	82	328	37

[1] KX2 and KX3 accessions are artificial interspecific hybrids generated at the University of Hawaii.

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Animal Production from Five Species of *Leucaena*

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Abstract

Relatively few studies have compared the animal production potential from different cultivars of *Leucaena leucocephala* or from browse species other than *L. leucocephala*. This paper presents early results from experiments established for this purpose in Australia, Papua New Guinea and the Philippines where psyllid-tolerant accessions of *L. pallida, L. diversifolia, L. trichandra* and *L. collinsii* were compared with psyllid-susceptible *L. leucocephala* cultivars. At three sites, where comparisons were made with a grass only treatment, the planting of shrubs resulted in increased steer gains. This occurred despite low edible shrub dry matter yields of <600 kg/ha. *L. leucocephala* cv. Tarramba was the control at all sites and steer gains on this cultivar ranged from 397–664 g/d. Only at two sites were gains greater on any other accession — at Lansdown (Australia) where steers on cv. Cunningham gained 10% higher and at Munum (PNG) where steers on *L. collinsii* OFI 51/88 gained 19% higher. Gains on *L. pallida* CQ 3439 ranged from 253–423 g/d at the different sites with low acceptability, especially in the dry season. Steer performance and acceptability was intermediate between *L. leucocephala* and *L. pallida* on *L. diversifolia* CPI 33820 and *L. trichandra* CPI 46568 and OFI 53/88. Overall, steer gains were not significantly (P>0.05) related to edible shrub yield, indicating the importance of shrub quality as opposed to quantity. Psyllid damage only occurred at one site (Lansdown) so the value of psyllid-tolerance was not fully assessed. However, even at Lansdown, the psyllid-susceptible cv. Cunningham gave highest steer gains. The experimental sites were all in the 'lowland' tropics. Different results may well occur at higher altitudes and higher latitudes, where cool tolerant material such as *L. diversifolia, L. trichandra* and *L. pallida* and their crosses with *L. leucocephala* may perform better.

LEUCAENA leucocephala is now widely acknowledged as having excellent yield and forage quality characteristics and consequently as giving high cattle liveweight gains (Jones 1994). Unfortunately, the advent of the psyllid insect *Heteropsylla cubana* to most tropical countries during the 1980s and 1990s has resulted in lower yield and therefore lower animal production potential from *L. leucocephala* cultivars. The evaluation of new *Leucaena* germplasm (Shelton and Brewbaker 1994) has identified material with superior psyllid tolerance to the very susceptible *L. leucocephala* cvv. Cunningham and Peru, and some accessions and the hybrids can outyield standard cultivars in environments with high psyllid challenge (see other papers in these Proceedings).

The animal production potential of this material is only now being assessed in grazing trials. Since most leucaena is planted for animal feed, it is imperative that this potential be assessed before widespread use is recommended. Compared with other forage legumes, leucaena is often more difficult and more expensive to establish. To offset this cost, the material needs to be persistent and capable of giving high animal production. The key characteristics required are: good yield, ready acceptability to animals, especially in the dry season, high digestibility, high intake and tolerance of browsing damage. These attributes should combine to give high liveweight gains and good reproductive performance in domestic ruminants.

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Materials and Methods

Four grazing experiments were established over a latitude range of 19°S to 12°N. Details of the sites are given in Table 1. The accessions sown or planted at each site are given in Table 2. At three sites, grass only control paddocks were established and managed as for the shrub paddocks. Seed supply limited the accessions that could be compared and also the size of the paddocks. However, the accessions chosen had given good yields in small plot trials and, except for the *L. leucocephala* accessions, had good psyllid tolerance (Mullen, Castillo et al.; Mullen, Gabunada et al., these Proceedings). Three of the sites were considered to have reasonable or excellent fertility. The site at Masbate, Philippines, had the lowest pH and the lowest soil P level. P fertiliser was applied at all sites, except for the PNG site, as P was assessed to be the most limiting plant nutrient other than N.

At Kununurra, a fully cultivated seedbed was prepared prior to sowing seed of the *Leucaena* cultivars. The pangola grass was established from stolons planted between the rows of leucaena. At the other three sites, seed was either drilled into an existing stand of grass that had been killed with herbicide and lightly cultivated (Lansdown) or else shrub seedlings were planted into killed strips of the existing pasture (Munum and Masbate). Seed of all *Leucaena* accessions was inoculated with a known effective strain of *Bradyrhizobium* prior to sowing.

For the experiment at Kununurra, several sowing treatments of 1, 2 or 4 rows of *Leucaena* per 1.8 m wide bed were compared. However, for the purpose

Table 1. Site characteristics for the four grazing experiments.

	Lansdown NQ Australia	Kununurra WA Australia	Munum PNG	Masbate Philippines
Latitude	19°40'S	15°39'S	6°33'S	12°22'N
Longitude	146°51'E	128°42'E	147°48'E	123°37'E
Elevation (m)	61	37	86	200
MAR(mm)	860	772 (+irrigation)	1800	1920
Soil type	Kandosol (Red Earth)	Vertisol	Vertisol	Ultisol
Soil texture	Sandy loam	Cracking clay	Clay	Clay loam — clay
pH (1:5 water)	6.3	8.1	7.2	6.1
P(Colwell) mg/kg	14	19	>200	5
Soil fertility	Good	Very good	Excellent	Poor/Medium
Slope	Level	Level	Level	Undulating
Row spacing	4 m	(variable)	5 m	4 m
Established from:	Seed	Seed	Seedlings	Seedlings
Sown or planted:	Jan 1994	Sept 1994	Sept–Oct 1996	June 1996
Paddock size	1.5 ha	0.52 ha	1.0 ha	1.0 ha
Pasture replicates	1	3	2	2
Grazing days	192	360	90	144

Table 2. Accessions planted/sown at each of the four sites and the associate grass species.

Lansdown NQ Australia	Kununurra WA Australia	Munum PNG	Masbate Philippines
Legume			
L. leucocephala cv. Cunningham	*L. leucocephala* cv. Cunningham	*L. leucocephala* cv. Tarramba	*L. leucocephala* cv. Tarramba
L. leucocephala cv. Tarramba	*L. leucocephala* cv. Tarramba	*L. trichandra* CPI 46568	*L. trichandra* OFI 53/88
L. diversifolia CPI 33820		*L. pallida* CQ 3439	*L. pallida* CQ 3439
L. pallida CQ 3439		*L. collinsii* OFI 51/88	*L. collinsii* OFI 52/88
Grass			
Urochloa mosambicensis+ cv. Nixon	*Digitaria eriantha* Pangola	*Brachiaria decumbens*+ cv. Basilisk	*Imperata cylindrica*

+ At these sites paddocks of the associate grass only were also established for comparison.

of this paper, only the mean values for these treatments will be considered. Pastures at this site were flood irrigated on a regular basis to provide optimum growth conditions. At Lansdown, drip irrigation along the rows was used to establish the shrub species due to exceptionally dry seasons in 1994/96. However, this supplemented irrigation ceased in June 1996.

At all sites, paddocks were fenced and each had a watering point for the cattle. Experimental grazing commenced when the trees were considered to be well established and had reached a height of 1.5–2.0 m or more. Pre-grazing yield estimates were made on every paddock prior to each grazing.

At Lansdown, these estimates were made by cutting edible shrub material from nine randomly located 3 m lengths of row in each paddock. Understorey yields were estimated by the BOTANAL method (Tothill et al. 1992). At Kununurra, a combination of cutting and visual yield estimation was used, and at Munum and Masbate, a separate ranking method for yield estimation of both the shrub and understorey yields was used.

Grazing management

All paddocks in each experiment received some form of rotational grazing. At Lansdown, 5 Droughtmaster steers were allocated at random to the paddocks after weighing. They were weighed directly off the paddocks about one week later and returned to the paddock again until all legume leaf was eaten off any one of the paddocks. This was usually the Cunningham leucaena paddock. Steers were again weighed and returned to the paddocks until most leaf was eaten off the shrubs in all paddocks. Steers were then removed and the rows of *Leucaena* were rotary slashed to about 50 cm. The difference between weighings 2 and 3 was taken as the weight gain for the various treatments. Weighing 2 was thought to be a better starting weight than the initial weighing as differences in gut fill between treatments should have stabilised by this time. Paddocks were then rested until adequate regrowth had occurred. The same procedure was then followed. Because of drought, there were only four experimental grazing periods: Jan 13–Mar 18 1996; July 24–Sept 16 1996; Jan 13–Mar 10 1997; July 21–Aug 8 1997 a total of 192 grazing days.

At Kununurra, steers stocked at 6.5/ha were rotated through the 3 paddocks of each cultivar on a 10-day graze/24 day rest cycle by using a fourth, mainly grass paddock, for 4 days following the grazing of the three leucaena paddocks. Steers were weighed directly off pasture every 28 days over the period July 3, 1996–June 27, 1997 (360 days).

At Munum, 6 Brahman steers and at Masbate 6 Brahman bulls (later reduced to 5) were allocated to each one hectare paddock in Replicate 1, and then moved to the same treatment in Replicate 2 when the shrubs were eaten down. Drought affected the trial at Munum, and so gains over 90 days only, from August 11, 1997, are presented, whereas, for Masbate, data are available for 144 days of grazing, from July 1, 1997. At these two sites, cattle were fasted overnight before weighing. Cattle were provided with salt blocks except at Kununurra.

Psyllid damage assessment

Psyllid damage on the various shrubs was assessed on a scale of 1 to 9. No psyllid damage was rated as 1. Shoots that had lost all new leaves leaving blackened stems were rated as 9 as proposed by Wheeler (1988).

Results

Pasture yields

The mean pre-grazing yields over all sampling times for both edible shrub and understorey pasture yields over all sites are presented in Table 3. Yields of edible shrubs were generally low (<600 kg/ha) at all sites except for the more closely spaced leucaena at the irrigated Kununurra site (700–800 kg/ha). In contrast, understorey yields were very high (>3000 kg/ha) at all sites except at Kununurra.

Masbate, the site with lowest soil fertility, and with strong competition from associated *Imperata cylindrica*, gave lower edible shrub yields than the other sites. At this site, *L. collinsii* OFI 52/88 gave very low yields (Table 3).

At the Australian sites, cv. Cunningham outyielded cv. Tarramba at Kununurra, but gave lower yields than Tarramba at Lansdown. Tarramba was the highest yielding *Leucaena* accession at Lansdown and Munum, but was lower yielding than *L. trichandra* at Masbate (Table 3).

Cattle gains

These have been expressed as g/day because of the different grazing periods at each site (Table 4). Gains at Lansdown (420–720 g/d) were higher than at the other sites where gains did not attain 500 g/day (Table 4). In general, the *L. leucocephala* cultivars gave the highest gains. Tarramba was planted at all sites and gave good gains. Only *L. collinsii* OFI 51/88 at Munum and cv. Cunningham at Lansdown gave higher gains than cv. Tarramba. *L. pallida* (CQ 3439) gave low gains at all sites. Other accessions gave gains intermediate between *L. pallida* and Tarramba.

Table 3. Mean presentation yields (kg/ha) of shrub and understorey species at the four sites.

Pasture treatment	Lansdown	Kununurra	Munum	Masbate
Grass control				
edible shrub	0	—	0	0
understorey	3130	—	13900	10560
L. leucocephala cv. Cunningham				
edible shrub	398	814	—	—
understorey	3530	2000	—	—
L. leucocephala cv. Tarramba				
edible shrub	532	695	594	235
understorey	3480	2000	7470	6320
L. pailida CQ 3439				
edible shrub	395	—	485	256
understorey	3610	—	6570	5190
L. diversifolia CPI 33820				
edible shrub	446	—	—	—
understorey	3610	—	—	—
L. trichandra CPI 46568				
edible shrub	—	—	522	—
understorey	—	—	10140	—
L. trichandra OFI 53/88				
edible shrub	—	—	—	398
understorey	—	—	—	5920
L. collinsii OFI 51/88				
edible shrub	—	—	390	—
understorey	—	—	7250	—
L. collinsii OFI 52/88				
edible shrub	—	—	—	89
understorey	—	—	—	6780

Table 4. Mean liveweight gain (g/day) of cattle grazing various shrub-legume/grass pastures at the four sites.

Pasture	Lansdown (192 d)*	Kununurra (360 d)	Munum (90 d)	Masbate (144 d)
Grass control	381 (25)+	—	202 (20)	139 (27)
L. leucocephala cv. Cunningham	723 (15)	400 (16)	—	—
L. leucocephala cv. Tarramba	664 (60	419 (18)	397 (23)	415 (40)
L. pallida CQ 3439	423 (41)	—	324 (92)	253 (28)
L. diversifolia CPI 33820	532 (59)	—	—	—
L. trichandra CPI 46568	—	—	309 (41)	—
L. trichandra OFI 53/88	—	—	—	328 (62)
L. collinsii OFI 51/88	—	—	473 (44)	—
L. collinsii OFI 52/88	—	—	—	353 (26)

* Number of grazing days.
— Accession not planted at the site.
( )+ S.E of the mean.

Pastures containing shrubs generally gave much higher cattle gains than the control treatment, where no shrub legumes were planted. The differences were particularly large at Masbate where the grass control gave only 33% of the gains made on Tarramba. At Lansdown, the grass-only control paddock gave higher gains than the control treatments at the other sites and similar gains to *L. pallida* CQ 3439 (Table 4).

Shrub yields and cattle gains

Cattle gains (g/day) were not significantly (P>0.05) related to edible shrub yield (kg/ha) at the three major sites.

Psyllid damage

There were no psyllids present at the Kununurra site. At all other sites, psyllids were present at times but only at Lansdown was there some damage and only the *L. leucocephala* cultivars were attacked. In July 1996, Cunningham had a psyllid damage score of 4 and Tarramba a score of 2. In July 1997, the respective scores were 5 and 3.

Discussion

The results presented were collected over a fairly short period for most sites so care needs to be taken when the implications are discussed. However, certain trends are emerging which need to be confirmed as more data come to hand.

Firstly, the impact of even modest yields of shrub legumes can have a large effect on steer gains. This is apparent at all three sites where comparisons with a grass control treatment were made. The very large effect at Masbate, where *Imperata cylindrica* is the associate grass, is perhaps understandable in view of the well-documented, low nutritive value of this species.

At Munum and Lansdown, the grass species in the control treatment are known to be of potentially good nutritive value, and at Lansdown, *Stylosanthes hamata* cv. Verano invaded the control treatment by the fourth grazing, so enhancing its nutritive value.

Although the relationship between liveweight gains and edible shrub yields was not significant, the absence of any positive relationship indicates that quality is a factor that cannot simply be compensated for by additional yield. This aspect is clear from another study of three tree legumes where Tarramba gave lower yields but higher steer gains than *Tipuana tipu* or *Albizia chinensis* (Gutteridge 1997).

Although *L. pallida* gave reasonable shrub yields, overall gains were low on this species. The relatively poor performance of *L. pallida* CQ 3439 supports the findings in southeast Queensland where this accession, despite having higher dry matter yield and being grazed at a lower stocking pressure, produced lower steer gains than cv. Tarramba (Gutteridge, unpublished data).

Unfortunately, psyllid damage only occurred at Lansdown, and so the advantage of psyllid-tolerance of the new material was not fully tested. However, at Lansdown, Cunningham gave higher steer gains than the psyllid-resistant material and the more psyllid-tolerant cv. Tarramba. Nevertheless, the magnitude of the superior steer performance on cv. Cunningham was greater in the absence of any psyllid damage (separate data not presented).

It is interesting to note that the species giving better steer gains — *L. leucocephala* and *L. collinsii* — have given higher in vitro DM digestibility and lower condensed tannin levels (nil in *L. collinsii*) than *L. pallida*, *L. diversifolia* and *L. trichandra* (Austin et al. 1995; Castillo et al. 1997, other papers in these Proceedings).

In addition, it was observed that the *L. leucocephala* cultivars and *L. collinsii* were very palatable to the steers and readily eaten compared with *L. pallida, L. diversifolia* and *L. trichandra* at the different sites. At Lansdown, these differences were most marked in the dry season, where leaf remained on *L. pallida* at the end of the experimental grazing period. On occasions, these accessions were readily accepted when steers first entered the paddocks, but later they appeared to be poorly accepted. Reasons for this are not known. Nutritionally, the legume leaf would appear to be higher than the understorey grasses, so some other factor must have reduced their acceptability. One possibility is that tannin levels increased in the plants that had been browsed — a response to herbivory noted in South Africa (Furstenburg and Van Hoven 1994). This elevated tannin level may then have increased their astringency and decreased their palatability.

Overall, the daily liveweight gains were lower than may have been expected. In central Queensland, steer gains of about 1 kg/day are reported on commercial pastures (Wildin 1994). Under these conditions, the density of plants and the yields of *L. leucocephala* may well have been higher than in the trials at Munum and Masbate. The liveweight gains are, however, within the ranges reported in the review by Jones (1994). As the trees become older, production should increase as should steer gains.

The data available thus far indicate that a more productive species to replace *L. leucocephala* as a feed for cattle will not be readily found, at least in the absence of heavy psyllid challenge. The very good steer gains on *L. collinsii* (19% higher than for Tarramba) at Munum is encouraging. However, across all sites, and especially at the drier sites, *L. collinsii* has not been as productive as the best *L. leucocephala* cultivars (other papers in this Proceedings). The psyllid-tolerant species used may perform better than the *L. leucocephala* cultivars at higher altitudes and higher latitudes since they have better cold tolerance (Austin et al. 1997).

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Poster Papers
Forage quality assessment

Forage Productivity and Quality of *Leucaena* as Influenced by Tree Density and Cutting Interval in the Humid Tropics

J. Cobbina

Abstract

Leucaena leucocephala has potential as a forage tree legume but data on management practices that maximise productivity under intensive cut-and-carry are wanting. This paper studied the effect of different tree densities (20 000, 26 600, 40 000, and 80 000 trees/ha) in combination with 4, 5, 6, or 8 cuttings per year on leaf dry matter (DM) yield and N, P, and Zn concentrations in the leaves of cv. K28 over a 3-year period. Increasing tree density increased DM yield, but shorter cutting intervals decreased yield. Leaf DM production declined with time. Infrequently cut and less-densely planted trees had bigger stumps and suffered least mortality. Frequent cutting resulted in higher N and P concentrations in the leaves. However, the concentrations of N and Zn in leaves decreased with time. Maximum production was obtained at a plant density of 80 000 trees/ha cut 4 times a year.

LEUCAENA (*Leucaena leucocephala* [Lam.] de Wit) has many uses including fodder, fuelwood and soil improvement (Pound and Martinez Cairo 1983). Leucaena can be used as a cut-and-carry forage to supplement poor quality feed for more intensive livestock operations such as stall-fed beef or dairy units or small ruminants (sheep, goats) in confinement. When intended for cut-and-carry forage, leucaena can be grown in pure stands at narrow spacing as intensive feed gardens or protein banks (Atta-Krah et al. 1986; Reynolds and Cobbina 1992). The plant management issues to be considered in such forage production systems would include planting density, cutting intervals and cutting height.

Although some studies have been conducted on cutting height (Duguma et al. 1988) and intra-row spacing and cutting regime (Guevarra et al. 1978), there are still gaps in available knowledge. For example, the recommended intra-row spacing of 0.15 (Guevarra et al. 1978) will induce severe intraspecific competition for water, nutrients and light, and hence higher tree mortality (Atta-Krah and Sumberg 1988). However, from an economic viewpoint, long-term persistence of the trees would be advantageous. Therefore, this study was undertaken to determine the best combination of tree density and cutting interval to maximise forage production from leucaena under humid tropical conditions. It is expected that the optimum tree density and number of cuttings would also guarantee persistence of the trees over many years.

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Materials and Methods

Site

The experiment was conducted at a site on the main campus of the International Institute of Tropical Agriculture in Ibadan, Nigeria (7°30'N, 3°54'E; 240 m above sea level) between May 1985 and September 1988. Annual rainfall for the period ranged from 1233 to 1694 mm (mean 1530 mm) and was bimodally distributed. The mean monthly temperature range was 22.5–30.8 °C. The soil was a sandy loam with pH of 6.2. The soil has been classified as Oxic Paleustalf by Moorman et al. (1975).

Experimental procedures

The experimental design was a randomised block split-plot design with three replications, with four plant densities (20 000, 26 600, 40 000, and 80 000 trees/ha) as main plots, and four cutting frequencies (4, 5, 6, and 8 cuttings per year) as subplots. The various tree densities were achieved by using 0.25 m intra-row spacing and inter-row spacings of 2.0, 1.5, 1.0 and 0.6 m.

Seeds of leucaena (K28) were scarified and sown in May 1985. There were four rows 4 m long in each subplot. Four months after sowing all the trees in the experimental plots were cut back to a uniform height of 0.5 m above ground level. Subsequently the trees were cut back regularly to 0.5 m every 6, 8, 10, and 12 weeks corresponding to 8, 6, 5, and 4 cuts per year. At each harvest, leaves were stripped off the stems and total leaf and wood dry matter (DM) yields estimated from subsamples dried in an oven at 70 °C for 72 hours. Dried leaves were ground and analysed for nitrogen (N), phosphorus (P) and zinc (Zn) concentrations using procedures described by Juo (1979).

Results

There were no tree density × cutting frequency interactions for any of the variables measured. Therefore the results presented are the tree density and cutting frequency main effects on leaf DM yield, stump girth and elemental concentrations in leaf tissues.

Leaf DM production

As cutting frequencies were increased from 4 to 8 times per year, leaf DM yields decreased in every year over the trial period (Table 1). The leaf DM yield of the less frequently cut trees showed 40% reduction while that of the more frequently cut trees declined by 30%. This difference may be due to physical loss of leaves through shedding by the mature coppice regrowth of infrequently cut trees.

Leaf DM production during each of the three years after the establishment year increased as plant density increased (Table 1). However, in all treatments there was a decline in leaf DM yield over time with the greatest reduction (over 40%) associated with the highest planting density. The highest leaf DM yield of 38 t/ha (1st year), 18 t/ha (2nd year) and 15 t/ha (3rd year) were obtained from trees in treatment plots which had 80 000 trees/ha and cut 4 times per year.

Stump girth and perenniality

As early as the first year after establishment, the infrequently cut trees had significantly ($P<0.05$) larger stump girths than those pruned more frequently (Table 1). The adverse effect of frequent cutting on stump size continued into the third year after establishment. There was also an early effect of tree density on stump girth, and at the end of the third year, the densest planting (80 000 trees/ha) had the smallest stump girth. In general, those stumps with the smallest girth and cut most frequently (80 000 trees/ha cut 8 times/yr) suffered greater mortality than those with the largest stump girth and less frequent cutting.

Forage quality

The frequency of cutting had some effect on nutrient concentrations in the leaves. Trees which were cut more frequently had significantly ($P<0.05$) higher N and P concentrations in the leaves than those which were cut infrequently (Table 2). There was significant reduction in the concentrations of nutrients with time, being most marked for N and Zn in the third year after establishment. This observed reduction in N and Zn concentrations did not appear to be due to a dilution effect since the quantity of DM produced decreased with advancing age. It is possible that the

Table 1. Effect of cutting frequency and planting density on leaf dry matter (DM) yield and stump girth of leucaena. Means within each group of four followed by the same letter are not significantly different ($P>0.05$).

Treatments	Leaf DM yield (t/ha)			Stump girth (cm)	
	Year 1	Year 2	Year 3	Year 1	Year 3
Number of cuttings (per year)					
4	23.8a	14.5a	13.5a	2.4a	11.2a
5	16.8b	13.6a	13.5a	2.4a	9.4b
6	13.4c	11.4b	10.4b	2.2b	9.4b
8	9.7d	6.8c	7.1c	1.9c	8.2c
Planting density (trees/ha)					
20 000	10.6c	9.7c	8.9b	2.4a	10.4a
26 000	12.5c	10.4c	10.1b	2.4a	10.2a
40 000	16.5b	12.2b	12.0a	2.3a	9.5b
80 000	23.9a	13.8a	13.5a	1.8b	8.1c
Total annual rainfall (mm)	1348	1495	1537		

Table 2. Effect of cutting frequency on nitrogen, phosphorus, and zinc concentrations in leaf tissue of leucaena during the first and third years after establishment. Means within each group of four followed by the same letter are not significantly different (P>0.05).

Number of cuttings (per year)	Nitrogen (%)		Phosphorus (%)		Zinc (ppm)	
	Year 1	Year 3	Year 1	Year 3	Year 1	Year 3
4	4.1b	3.4b	0.19a	0.17b	30.0b	14.4ab
5	4.1b	3.6b	0.20a	0.16b	28.9b	16.3a
6	4.6ab	3.5b	0.22a	0.24a	44.0a	12.7bc
8	4.8a	3.9a	0.26a	0.23a	30.2b	11.4c

reduction in leaf DM yield with time was triggered by a drop in nutrient uptake.

Discussion and Conclusion

The increase in leaf DM with less frequent cutting agrees with the results of Guevarra et al. (1978) and Ferraris (1979). Leucaena produces few basal buds before either the main stem or coppice stem is cut. Therefore, at the very short cutting intervals, the post-defoliation recovery would be slower, resulting in a lower rate of DM production.

The finding that the highest tree density produced the greatest leaf DM yields is also in accord with the data of Guevarra et al. (1978), Ferraris (1979) and Pathak et al. (1980). It seems that leucaena, unlike most plants that tiller, is unable to produce more stems to compensate for the wider spacing under low tree density. It is doubtful whether a density above the highest one used would have further increased the DM yield. Even at the highest density used in this study, plants developed thin stumps and suffered mortality thus corroborating the results obtained with *Gliricidia* (Atta-Krah and Sumberg 1988).

The N and Zn concentrations in the leaves of trees subjected to the various cutting treatments during the third year after establishment were lower than the collated averages of Kleinjans (1984). In fact, Zn concentrations for the third year after establishment fall within the deficiency range of most crops (Boehle and Lindsay 1969), and could have inhibited protein formation since Zn is closely involved in plant N metabolism (Mengel and Kirkby 1982). The sharp decline in leaf DM yield, particularly during the third year after establishment, could be due to the lower N and Zn uptake. The concentrations of nutrients in the leaves of plants cut 4 or 5 times a year were also lower than the reported values of Kleinjans (1984). However, the lower concentrations may be attributed to a dilution effect of the greater DM yield and the advanced age of the tissues. It may be inferred from the results on nutrient uptake that under this system of intensive forage production for cut-and-carry feeding, some fertilisation would be needed to replace the mined nutrients. In fact, some manure from animal pens or inorganic fertiliser could be applied to replenish depleted nutrients.

The observation that the less frequently cut trees developed bigger stumps and also produced the greatest DM is important. It would appear that, under a lenient cutting regime, leucaena trees would be able to produce high yields of both leaf and wood and still persist longer.

Less frequent cutting produced forage of lower N and P concentrations. Osman (1980) reported similar results for leucaena. It seems that the larger amount of DM produced by the infrequently cut trees resulted in a greater dilution effect than in the frequently cut trees with a smaller DM production (Ferraris 1979). The N and P yields per unit area in the infrequently cut trees were still high because of the greater DM yields. This is an indication that forage quality is not sacrificed at higher levels of DM yields.

In conclusion the data presented suggest that cutting frequency and tree density both had an effect on forage yield, quality, and tree persistence. Planting at a density of 80 000 trees/ha and cutting four times per year maximised DM yields at 38 t DM/ha in the first year after establishment and 18 t and 15 t DM/ha in subsequent years.

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Comparison of *Leucaena leucocephala* with *Calliandra calothyrsus* in Napier (*Pennisetum purpureum*) Fodder Banks

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Abstract

An experiment was conducted at Embu, in the central highlands of Kenya, to determine the optimum ratio for intercropping napier grass with *Leucaena leucocephala* and *Calliandra calothyrsus*, for fodder production. The treatments consisted of pure stands of napier, *L. leucocephala* and *C. calothyrsus*, together with intercrops of napier with each of the two shrub species at 1:1 and 4:1 ratios. The yield of napier grass in pure stands dropped dramatically over the four years of the study, and also when grown in combination with the tree legumes. The tree legume yields did not decrease over time, but were greatly reduced by the presence of napier, especially at the 4:1 combination. *L. leucocephala* appeared to have a lesser effect on the grass yields than *C. calothyrsus*, probably reflecting less competitive ability. Total grass yields when grown in combination with the legumes were similar to those of pure grass alone, but the 1:1 combinations produced less grass but more legume than the 4:1. The recommended napier — tree legume combination is different for the two species. For *L. leucocephala*, the best combination would be one or two rows of trees to one row of napier. For *C. calothyrsus*, this would be one row of trees to two or three rows of napier, but the nutritive value of this species needs to be considered also.

IN THE central highlands of Kenya, small-scale dairy production plays a significant role for both food production and income generation (Minae and Nyamai 1988; Murithi et al. 1994). The high genetic potential of the grazing animals is, however, rarely attained mainly because of inadequate nutrition (Wachira 1982). Napier grass (*Pennisetum purpureum*) forms the basal diet of cattle in most smallholdings.

Leguminous fodder trees with deep root systems remain green throughout the dry period and produce protein rich foliage which could be used to supplement poor basal diets of napier. *Leucaena leucocephala* has been a popular fodder tree among farmers until the pest *Heteropsylla cubana* broke out (Reynolds and Bimbuzi 1993).

Another promising fodder tree species is *Calliandra calothyrsus*, although its digestibility of dried fodder is lower than that of *L. leucocephala* (Kaitho et al. 1993).

The objective of this study was to assess fodder yields of grass and trees when napier was intercropped with either *Leucaena leucocephala* or *Calliandra calothyrsus*, at different spatial arrangements.

Shrub/grass associations have been found to be mutually advantageous in dry matter production when grown in linear arrangements on soil conservation structures in Maseno, western Kenya, under similar environmental conditions (ICRAF 1992).

Materials and methods

The experiment was conducted at Embu, 0° 30′ S and 37° 27′ E, in the central highlands of Kenya at an altitude of 1490 m. The soil was humic Nitisol (FAO-UNESCO 1977), a deep, well-weathered soil with moderate to high inherent fertility (Jaetzold and Schmidt 1983). Total annual rainfall was 1252, 1600, 1417, and 908 mm during 1993 through 1996, respectively.

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Rooted splits of napier, variety Bana and six months old *L. leucocephala* and *C. calothyrsus* seedlings were raised in polythene bags, and transplanted into the field in October 1992. There were seven treatments: sole plots of napier (nap), *L. leucocephala* (leuc) and *C. calothyrsus* (call); and the combination of napier with each of the shrub species in 1:1 and 4:1 ratios (nap1-leuc1, nap1-call1, nap4-leuc1, and nap4-call1). A population of 20 000 plants or stools per hectare was maintained in all plots. The design was a randomised complete block with three replicates. Each plot measured 10 × 8 m. A distance of 1.0 m between and 0.5 m within rows was used for legumes and grass.

The psyllid on *L. leucocephala* was controlled during the experimental period by weekly spraying with Dimethoate. At the beginning of every season, each plot was root pruned by digging a trench about 30 cm wide and 60 cm deep around the plot and thereafter covered. A two-split application of 8 t/ha (dry weight) of cattle manure per year was used as maintenance fertiliser.

Plots were harvested after eight weeks in the wet seasons and 12 weeks during the dry seasons. In shrubs, tender shoots <6 mm diameter and leaves were grouped together as edible foliage while in grass the green leaf sheath and the unopened shoots formed the edible fodder. Weights of fresh samples were taken immediately after harvesting and dried at 65 °C to constant weight to determine dry matter and crude protein contents.

Results

The average crude protein contents of napier grass, *C. calothyrsus* and *L. leucocephala* were 8.9%, 21.8% and 21.9% respectively. Dry matter yield per hectare for individual components and total production are presented in Table 1. The data shown are absolute values, and have not been corrected to allow for the different proportions of land area occupied by the crops in different combinations.

Grass fodder production

C. calothyrsus and *L. leucocephala* intercrops had similar understorey grass production in the first two years of the trial but thereafter more grass yields were obtained from the *L. leucocephala* intercrops. Lower grass yields were realised from the nap1-call1 plots compared with pure plots of napier during all four years of experimentation. This effect was not apparent in the nap4-call1 treatments. In the first three years, grass production from nap4-leuc1 and nap4-call1 plots was significantly ($p<0.05$) more than nap1-leuc1 and nap1-call1 plots while in the fourth year the two combinations had no grass yield differences.

Tree fodder production

L. leucocephala and *C. calothyrsus* production were adversely affected by intercropping with napier in all four years of the trial. Pure *L. leucocephala* and *C. calothyrsus* did not differ in tree fodder production in the first two years but in the third and fourth years, *C. calothyrsus* outyielded *L. leucocephala* significantly ($p<0.05$). Over the four years of the experiment, legume yields were greater in the 1:1 treatments than the 4:1 (*L. leucocephala*, 17.9 and 9.6 t/ha, *C. calothyrsus* 30.5 and 16.6 t/ha).

Total fodder production

Total fodder produced in both monoculture and mixtures decreased during successive years throughout the experiment. Yield reductions were greatest in pure plots of napier (73%) and the nap4:call1 plots. In the first two years, pure napier yielded as much as most of the intercrops with *L. leucocephala* or *C. calothyrsus* but in the fourth year pure napier was outyielded significantly ($p<0.05$) by all the intercrop combinations.

Discussion

Results show that, when intercropped, napier was more competitive than the leguminous trees. Napier depressed tree growth in all cases but conversely the trees had a positive effect on napier growth in all combinations. For example, the presence of *L. leucocephala* with napier almost doubled grass production of the napier rows in the first two years. Thus although land area under napier was reduced by 50% in the 1:1 combination, absolute grass production was reduced only slightly so that production per unit area was almost doubled. This effect can probably be attributed to the vigorous napier plants growing more strongly at the lower density due to reduced inter-plant competition. There may also have been some transfer of nitrogen from decomposing *L. leucocephala* litter and roots to napier. In sole stands, *C. calothyrsus* produced more tree fodder than *L. leucocephala*. For both tree species, increased napier populations decreased tree yields presumably due to competition effects.

When DM yields of intercrops are the same as sole napier, as demonstrated during the first three years, intercrops still had an advantage of yielding more crude protein. The 1:1 combination of *L. leucocephala* provided an average of 19.7% legume DM and 80.3% napier DM, after one establishment year for 1994, 1995 and 1996.

Table 1. Total edible dry matter yield (t/ha) in different years.

Treatments	Total DM yield in 1993			Total DM yield in 1994		
	Grass	Legume	Total	Grass	Legume	Total
Napier	43.1	—	43.1	32.6	—	32.6
L. leucocephala	—	19.3	19.3	—	15.9	15.9
C. calothyrsus	—	16.3	16.3	—	15.1	15.1
Napier + *L. leucocephala* 1:1	36.1	4.6	40.7	24.4	6.3	30.7
Napier + *C. calothyrsus* 1:1	32.5	5.4	38.0	18.9	7.7	26.6
Napier + *L. leucocephala* 4:1	42.4	2.3	46.0	31.7	3.0	34.7
Napier + *C. calothyrsus* 4:1	48.5	3.4	51.9	27.5	4.1	31.6
SED	2.8	2.6	3.4	3.8	3.8	3.8
Treatments	**Total DM yield in 1995**			**Total DM yield in 1996**		
	Grass	Legume	Total	Grass	Legume	Total
Napier	11.1	—	11.1	11.5	—	11.5
L. leucocephala	—	8.2	8.2	—	11.3	11.3
C. calothyrsus	—	15.7	15.7	—	16.7	16.7
Napier + *L. leucocephala* 1:1	13.5	2.7	16.2	15.3	4.3	19.6
Napier + *C. calothyrsus* 1:1	8.1	8.7	16.8	8.9	8.7	17.5
Napier + *L. leucocephala* 4:1	14.0	1.5	15.3	14.3	2.8	17.1
Napier + *C. calothyrsus* 4:1	12.9	4.1	17.1	12.6	5.0	17.6
SED	1.1	1.0	1.3	1.6	1.6	2.0

Dairy cows producing 15 kg milk per day need about 13% CP in their diet, which can be obtained through a ration of 30% legume and 70% napier. Two rows of *L. leucocephala* to one row of napier might produce that desired ration. For *C. calothyrsus*, the 1:1 combination provided 43.5% legume DM and the 4:1 combination 21.7% legume, DM after the first year. For this tree/grass combination, one row of *C. calothyrsus* to two or three rows of napier might produce the desired ration. However, the high tannin content of *C. calothyrsus* needs to be considered in any feeding system.

In this experiment, napier yields decreased over the experimental period, but there was a greater reduction in annual dry matter yield from pure stands of napier than in combination. Intercropping of napier with leguminous shrubs could effectively lengthen the economic life of napier stands, thus reducing the cost of frequent replanting and problems associated with fodder shortages prior to harvesting new stands.

Conclusions

The yield of napier grass in pure stands dropped dramatically over the four years of the study, and also when grown in combination with the tree legumes. The tree legume yields did not decrease over time, but were greatly reduced by the presence of napier, especially at the 4:1 combination. Over the experimental period, total grass yields when grown in nap4:leuc1 and nap4:call1 combinations were similar to those of pure grass alone, but the nap1:leuc1 and nap1:call1 combinations produced less grass but more legume. *L. leucocephala* appeared to have a lesser effect on the grass yields than *C. calothyrsus*, probably reflecting less competitive ability.

For the dairy farmer, the optimum grass and tree legume combination is different for the two tree species. For *L. leucocephala,* the best combination would be one or two rows of trees to one row of napier. As *C. calothyrsus* was more productive, an optimum arrangement would be one row of trees to two or three rows of napier. Other factors, such as nutritive value, which is higher for *L. leucocephala*, or pest resistance, which is higher in *C. calothyrsus*, will determine the choice of tree species to be cultivated with napier on farm.

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Nutritive Evaluation of *Leucaena leucocephala*, *L. diversifolia* and *L. pallida* in Awassa, Southern Ethiopia

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Abstract

The nutritive value of *Leucaena leucocephala*, *L. diversifolia* and *L. pallida* foliage was assessed on the basis of chemical composition, in vitro gas production and in sacco dry matter (DM) degradability. *L. leucocephala* had the lowest fibre content, but *L. pallida* had the highest crude protein content, and the lowest extractable and total proanthocyanidins contents. *L. diversifolia* had a lower rate of gas production than the other two species ($p<0.05$) and tended to produce relatively less volume of gas after 12 and 24 h of incubation. The other gas production constants and the potential gas production of the three species were not significantly different. *L. leucocephala* had higher ($p<0.05$) DM degradability than *L. diversifolia* at 4, 8, 16 and 48 h of incubation and higher degradability than *L. pallida* at 8 and 16 h of incubation. However, there was no significant difference ($p>0.05$) in overall DM degradation characteristics of the three species, except that *L. pallida* had a lower washing loss ($p<0.05$) than *L. diversifolia*.

LEUCAENA leucocephala is widely known throughout the tropics and subtropics because of its high nutritional value and other multiple uses. However, the species is susceptible to psyllid (*Heteropsylla cubana*) pest attack and performs poorly on acidic and water-logged soils and in frost-prone areas (Shelton and Brewbaker 1994). This has led to evaluation of alternative species that could replace *L. leucocephala* in agroforestry systems (Wheeler et al. 1994). This paper reports on the comparative nutritive value of three *Leucaena* species on the basis of chemical composition, in vitro gas production and in sacco DM degradability values.

Materials and Methods

L. leucocephala, *L. diversifolia* and *L. pallida* grown at Awassa, southern Ethiopia (7°04'N and 38°31'E; altitude 1650 m) were harvested during the dry season of 1997 at the age of 5.5, 5.5 and 4.5 years, respectively. Edible material was chopped and then dried in a forced-draft oven at 50 °C for 72 h. Dry matter (DM), ash and crude protein (CP) were determined using standard procedures. Neutral-detergent fibre (NDF), acid-detergent fibre (ADF) and acid-detergent lignin (ADL) were determined according to Goering and Van Soest (1970). Extractable and total proanthocyanidins were determined using the method of Porter et al. (1986). In vitro gas production and in sacco DM degradability were determined as described by Tolera et al. (1997).

Results and Discussion

Chemical composition

L. leucocephala had lower NDF, ADF, lignin and cellulose than the other two species while *L. pallida* had the highest NDF, ADF, lignin and cellulose and the lowest ash content (Table 1). The low fibre content of *L. leucocephala* and the high fibre content of *L. pallida* are in agreement with the results of Wheeler et al. (1994), Jones et al. (1995) and Hove et al. (1996). The CP content was highest in *L. pallida* and lowest in *L. diversifolia*. The lower CP content of *L. leucocephala* compared to *L. pallida* could be due to the effect of the prolonged dry season when the samples were taken and the differing age and regrowth stage of the plants.

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Table 1. Chemical composition (g/kg DM), and extractable and total proanthocyanidins concentration (absorbance at 550 nm/g DM) of *L. diversifolia*, *L. leucocephala* and *L. pallida* foliage

Chemical component	*L. diversifolia*	*L. leucocephala*	*L. pallida*
Dry matter (%)	46.2	37.7	44.0
Ash	122	125	92
Crude protein	145	166	193
Neutral detergent fibre	457	409	491
Acid detergent fibre	339	277	379
Acid detergent lignin	157	122	190
Total extractable proanthocyanidins	71	66	24
Total proanthocyanidins	135	131	87

The concentrations of extractable and total proanthocyanidins were similar in *L. diversifolia* and in *L. leucocephala* whereas *L. pallida* unexpectedly had the lowest concentration of these phenolic components. Previous studies (Hove et al. 1996; Jones et al. 1995) showed higher content of condensed tannin (CT) in *L. diversifolia* than in *L. pallida*, which in turn had higher CT content than *L. leucocephala*. On the other hand, Wheeler et al. (1994) found significantly higher CT values in *L. pallida* than in *L. diversifolia*, which also had significantly higher CT than *L. leucocephala*.

In vitro gas production

L. diversifolia had a lower rate of gas production than the other two species ($p<0.05$, Table 2) and tended to produce relatively less volume of gas after 12 and 24 h of incubation (Figure 1a). The other gas production constants and the potential gas production of the three species were not significantly different. The lower rate of gas production from *L. diversifolia* after 12 and 24 h of incubation could be attributed to the relatively higher concentration of phenolic compounds found in this species. In a previous study (Tolera et al. 1997), high concentrations of phenolic compounds depressed in vitro gas production.

In sacco DM degradability

L. leucocephala tended to have higher in sacco DM degradability than the other two species although the difference was only significant at 4, 8, 16 and 48 h of incubation for *L. pallida* and at 8 and 16 h of incubation for *L. diversifolia* (Figure 1b). These results are in agreement with Jones et al. (1995) who reported higher nylon bag degradability after 48 h of

Table 2. In vitro gas production and in sacco DM degradation characteristics of the three *Leucaena* species.

Parameter	*Leucaena diversifolia*	*Leucaena leucocephala*	*Leucaena pallida*	SE
Gas production characteristics				
a (intercept)	8.9	8.1	7.1	0.97
b (gas prod. curve, extent)	22.7	23.4	24.4	1.90
a+b (potential gas prod.)	31.6	31.5	31.5	2.12
c (rate of gas production)	0.051^{b}	0.070^{a}	0.067^{ab}	0.005
Residual standard deviation	0.94	0.66	0.87	
DM degradation characteristics				
A (washing loss; %)	31.4^{a}	29.2^{ab}	25.1^{b}	0.00
B (insoluble but slowly degradable; %)	42.1	43.5	47.6	1.93
A+B (potential degradability; %)	73.5	72.7	72.7	1.93
c (degradation rate; fraction/h)	0.038	0.084	0.048	0.023
L (lag time; h)	0.43	0.47	0.00	0.36
Effective degradability (%)*	46.6	50.5	46.2	2.90
Residual standard deviation	1.80	1.47	1.68	

* Calculated at rumen outflow rate of 0.05/h.

Means with similar or no superscripts within a row are not significantly different ($p>0.05$).

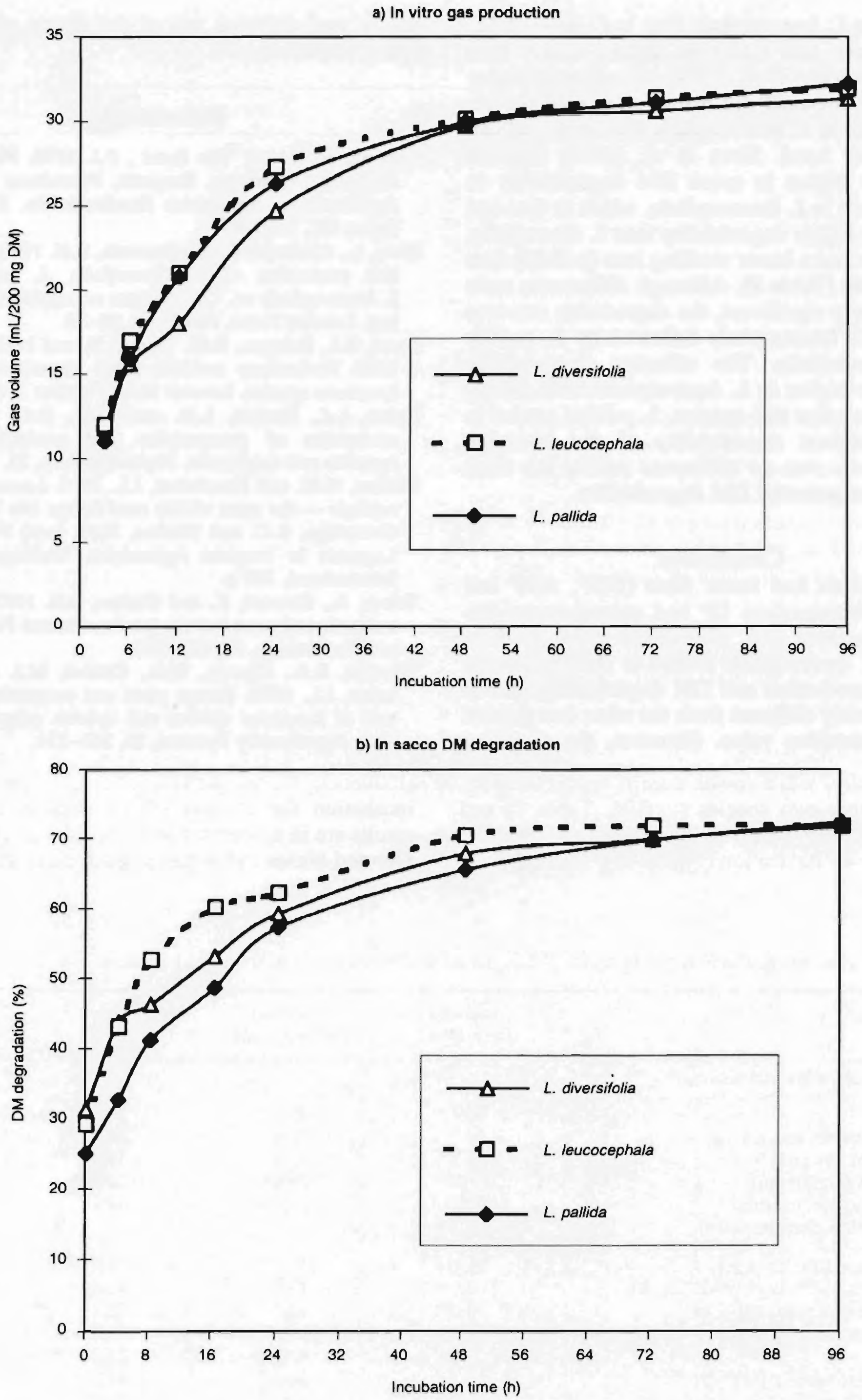

Figure 1. In vitro gas production and in sacco DM degradation of three *Leucaena* species from Awassa, Ethiopia.

incubation in *L. leucocephala* than in *L. diversifolia*, which in turn had relatively higher values than *L. pallida*. Wheeler et al. (1994) also reported higher ruminal and intestinal dry matter and crude protein disappearance in *L. leucocephala* than in *L. pallida*. On the other hand, Hove et al. (1996) reported significantly higher in sacco DM degradability in *L. pallida* than in *L. leucocephala*, which in turn had significantly higher degradability than *L. diversifolia*.

L. pallida had a lower washing loss ($p<0.05$) than *L. diversifolia* (Table 2). Although differences were not statistically significant, the degradation rate was highest in *L. leucocephala* followed by *L. pallida* and *L. diversifolia*. The effective degradability tended to be higher in *L. leucocephala* with similar values in the other two species. *L. pallida* tended to have the highest degradability of the insoluble fraction. There was no difference among the three species in the potential DM degradability.

Conclusion

L. leucocephala had lower fibre (NDF, ADF and ADL) and intermediate CP and proanthocyanidins contents compared to *L. diversifolia* and *L. pallida*. Although *L. leucocephala* tended to show relatively higher gas production and DM degradability, it was not significantly different from the other two species in overall nutritive value. However, the sampling season and differing age of the plants might have influenced the results.

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Anaerobic Degradation of Hydroxypyridines from *Leucaena leucocephala* by Rumen Bacteria

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Abstract

Some rumen bacteria degrade toxic compounds from *Leucaena leucocephala*, avoiding intoxication problems occurring in non-ruminants after ingestion of the plant. Degradation activity by one rumen strain, *Synergistes jonesii* was found to be non-constitutive. The substrate 3,4 dihydroxypyridine (DHP) induced degradation of both 3,4 and 2,3 DHP isomers, while 2,3 DHP induced only degradation of 2,3 DHP. Activity of degradation was inhibited by high substrate concentration. The enzyme cocktail had a high hydrogenase activity and degraded 2,3 DHP anaerobically either in the presence of methyl viologen/H_2 or in the presence of alpha-ketoacids (under H_2 or N_2). Specific activity of 2,3 DHP degradation was increased when FAD+ or CoA were present. The 2,3 DHP was found to be an intermediate of the degradation of 3,4 DHP by cultures. An unidentified non-polar amino compound appeared in TLC as 2,3 DHP was degraded.

RUMEN bacteria capable of degrading mimosine metabolites are dihydroxypyridine (DHP) responsible for the tolerance of ruminants to consumption of *Leucaena leucocephala* (Jones and Megarrity 1986; Dominguez-Bello and Stewart 1991; Allison et al. 1990). *Synergistes jonesii* (Allison et al. 1990) is a rumen bacterium active in degrading the isomers 3,4 and 2,3 DHP. This work presents results of the characterisation of the enzymatic anaerobic degradation of the mimosine-derived pyridines by cell free extracts of *Synergistes jonesii.*

Materials and Methods

Anaerobic cultures *Synergistes jonesii* (strain 78-1) were grown on medium 98-5 (Bryant and Robinson 1961) without carbohydrates and containing phytone (3% w/v) and 2,3 dihydroxypyridine (Aldrich, 2 mM or 4.5 mM).

Degradation of 2,3 DHP was assessed by the colorimetric method of Matsumoto and Sherman (1951) or by HPLC. Cell free extracts of the cultures were obtained by lysing the cells in a french press. Hydrogenase activity was determined in the extracts by measuring colorimetrically (601 nm) the reduction of methyl viologen under hydrogen.

Degradation of 2,3 DHP by cell free extracts was determined in the presence of pyruvate or alpha-keto glutarate or in the presence of 0.5 mM methyl viologen, under H_2 atmosphere. Thin layer chromatography (TLC) of the reaction mixture during degradation of 2,3 DHP was performed in TLC silica plates and spots were developed under UV light (254 nm) with fluorescamine.

Results

Activity of degradation of 2,3 DHP in cultures was induced by low substrate concentrations and was inhibited by high substrate concentrations (Figure 1). Activity decreased in rate and extent as cultures were grown and maintained without the substrate (Figure 2). Cultures of *S. jonesii* were active in degrading each DHP isomer. However, stationary phase cells grown on 2,3 DHP showed good 2,3 DHP but negligible 3,4 DHP-degrading activities. On the other hand, cells induced by 3,4 DHP degraded both isomers.

The 3,4 DHP is isomerised to 2,3 DHP before reduction of the ring. The 2,6 dihydroxypyridine and dihydroxyphenylalanine inhibited degradation of 2,3 DHP by about 53% and 36% respectively.

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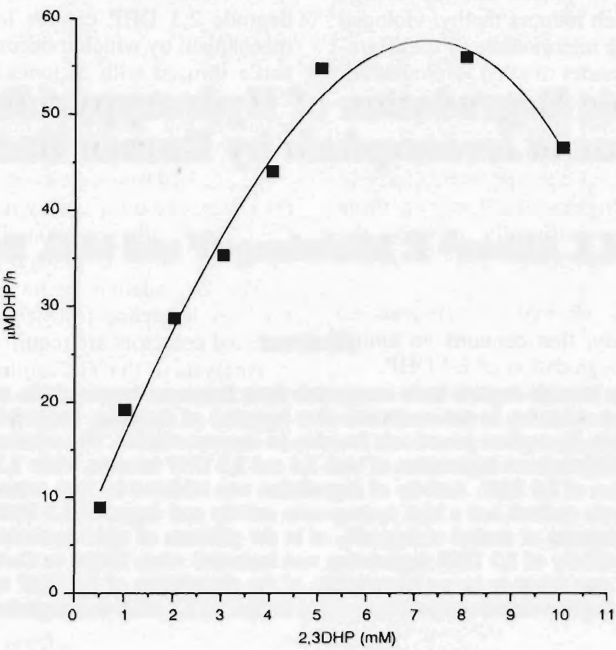

Figure 1. Velocity of 2,3 DHP degradation by a culture of *S. jonesii* at increasing substrate concentrations. N=2 replicates.

Figure 2. Loss of 2,3 DHP degradation activity in cultures of *S. jonesii* as they were exposed to lack of 2,3 DHP in the medium for 0 (■), 2 (●), 6 (▲) and 10 (▼) days. N=4 replicates.

Protein extracts from *S. jonesii* showed a high hydrogenase activity which reduces methyl viologen that can act as a reducing intermediate in the degradation of 2,3 DHP. Besides methyl viologen/H_2, the system for degradation of dihydroxypyridines required alpha-ketoacids and anaerobiosis.

The cell free extracts showed NAD+ and especially NADP+ reducing activity, particularly in the presence of alphaketoglutarate. However, these two cofactors did not significantly increase the specific 2,3 DHP-degrading activity, as did FAD and CoA (Table 1).

TLC chromatography showed an unidentified compound of low polarity, that contains an amino group, produced during degradation of 2,3 DHP.

Table 1. Specific activity of the cell-free extract of *Synergistes jonesii* in the presence of reduced cofactor. Superscript letters indicate significant differences ($p<0.05$; N=3).

Cofactor	Specific activity nmoles 2,3 DHP/min/mg protein
Methyl viologen	10.03^{a} + 0 97
Hydrogen	0.00^{b} + 0 O0
Cytochrome c	0.01^{b} + 0 10
Methyl viologen + Cytochrome c	10.15^{a} + 0 87
NAD+	0.06^{b} + 0 04
Methyl viologen + NAD+	11.93^{a} + 0 94
NADP+	0.06^{b} + 0 10
Methyl viologen + NADP+	11.50^{a} + 0.90
Pyruvate	9.69^{a} + 0.11
Pyruvate + NAD+	10.53^{a} + 0.52
Pyruvate + NADP+	8.84^{c} + 0.96
Pyruvate + FAD	13.45^{d} + 0.35
Pyruvate + CoA	18.22^{e} + 0.29

Discussion and Conclusions

The enzymatic degradation of pyridinediols by *Synergistes jonesii* responded to substrate induction. The bacterium did not degrade mimosine, but 3,4 DHP was degraded after isomerisation to 2,3 DHP, which is then further degraded. The enzyme system loses activity when exposed to lack of substrate.

Previous work has shown that capability to degrade 2,3 DHP can be irreversibly lost and the mechanism by which it occurs is not clear. However, cattle infused with *S. jonesii* when consuming leucaena and then grazed on leucaena-free pasture retained the ability to degrade DHP even after 9 months (R.J. Jones, pers. comm.).

The 2,3 DHP-induced enzyme system of *S. jonesii* also degraded other dihydroxylated pyridines such as 2,6 DHP. In other bacteria, dihydroxylation of pyridines in a diol precedes degradation of pyridines.

The degradation pathway of 2,3 DHP is still unclear. Evidence from these results suggests that reduced cofactors are required for ring reduction.

Analysis of the TLC amino-containing product of 2,3 DHP by GCMS will be useful to separate and to identify this compound in further studies.

Acknowledgments

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The Effect of *Leucaena*, *Calliandra* and *Gliricidia* Tannins on Dry Matter and Protein Digestibility in Ruminants

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Abstract

The use of multipurpose trees (MPTs) as fodder for ruminants is increasing in the smallholder mixed farms in Kenya. Most of the MPTs contain tannins that are known to depress feed digestibility. A study was therefore undertaken to assess the effect of common forage tannins on total tract digestibility of dry matter (DM) and crude protein (CP) in ruminants. The effect of tannins from *Leucaena leucocephala*, *Calliandra calothyrsus*, and *Gliricidia sepium* on the total tract digestibility of the DM and CP was determined using ruminally and duodenally cannulated Holstein cows. Prior to digestion, half of the samples were treated with polyethylene glycol (PEG) to suppress the effect of tannin. Feed samples in nylon bags were suspended in the rumen for 0, 6, 12, 24, 48 and 96 hours, one pair for each time. In addition, bags that had been incubated for 12 and 24 hours were introduced into the small intestine through a duodenal cannula and subsequently recovered from faeces. In the three fodder species, PEG increased effective degradation of DM and CP in the rumen, reduced the DM and CP reaching and subsequently digested in the intestine. Addition of PEG also increased the total tract digestibility of DM and CP. However, the increase was significantly more pronounced in *Calliandra* than in *Leucaena* and *Gliricidia*. *Gliricidia* was the least affected. *Leucaena* and *Gliricidia* can therefore be fed to ruminants without treatment.

THE escalating costs of commercial feed concentrates and relatively low milk prices in Kenya have made the smallholder dairy farmers turn to multipurpose trees (MPTs) as inexpensive alternative sources of nutrients for their lactating cows.

Most MPTs, though rich in protein, have high levels of tannin, which affect the dry matter (DM) and crude protein (CP) digestibility in ruminants. Tannin binds with protein to form a tannin-protein complex that is lowly degraded in the rumen but digestible in the lower gut (Jones and Mangan 1977). Binding with tannin results in increased bypass protein. However, it also results in higher faecal nitrogen than in tannin free feed (Donnelly and Anthony 1969).

Thus although MPTs are included in ruminant diets as protein sources, tannin levels also need consideration. A study was therefore undertaken to assess the contribution of tannins from the common MPTs, viz., *Leucaena leucocephala*, *Calliandra calothyrsus* and *Gliricidia sepium* to total tract digestibility of DM and CP in ruminants.

Materials and Methods

Samples of the three MPTs, viz., *Leucaena*, *Calliandra* and *Gliricidia*, were collected in Embu, Kenya in June 1991, oven dried and ground to pass through 5 mm sieve in a Wiley mill. The digestibility study was done at the University of British Columbia (UBC), Canada.

Each sample was divided into two portions. One portion was treated with polyethylene glycol (PEG) at the rate of 40 mg/g tannin as used by Jones and Mangan (1977) to suppress tannin effect and the other sample was not treated. Approximately 1 g of dried sample of each species was weighed into a pre-weighed, labelled nylon bag (3.5 x 5.5 cm, pore size 40 mm) and heat sealed. Bags of this size flow easily in the intestine without obstruction.

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Incubation

In September 1992, sample bags were incubated in four Holstein cows maintained on orchard grass and alfalfa hay and fitted with both rumen and duodenal cannulas, using the mobile bag technique of Arieli et al. (1988).

The PEG-treated samples were placed in different animals from the untreated samples and incubated in the rumen for 0, 6, 12, 24, 48 and 96 hours in duplicate. The time 0 hour samples were incubated at 37 °C in a borate-phosphate buffer (pH 6.8) on a shaker for 30 minutes. At the end of rumen incubation, the bags were removed and washed in cold tap water for 15 minutes. Except for one of the pair for the 24 and 12-hour times, all samples were oven dried at 60 °C for 3 days and weighed to determine the DM of the remains.

Intestinal digestion

Two additional bags that had been incubated for 24 and 12 hours were further incubated at 37 °C for 2 hours in a pepsin solution (2 g pepsin per litre in 0.1 N HCl), rinsed in water and inserted into the intestine through duodenal cannula. The bags were recovered from the faeces and treated the same way as the bags removed from the rumen.

The trial was repeated again three months latter with treatments switched such that animals that had previously had PEG forages got untreated samples.

Analysis and calculations

Tannin content was determined using a gravimetric method (Reed et al. 1985). The results were reported as *Ytterbium* precipitated phenolics as percentage of the DM (Yb-ppt). The residue N was also determined using the wet oxidation method.

The results of these calculations were fitted to the non-linear regression equation $P = a + b(1-e^{-ct})$ (Orskov and McDonald 1979). The parameters *a*, *b*, and *c*, were estimated using a SAS program procedure developed by Agriculture Canada, Research Centre, Lethbridge. The effective degradability was also estimated with the same Lethbridge SAS procedure using the equation $p = a + \frac{bc^{\;ct_0}}{c+k} e^{(-(c+k)t_0}$ where k is the assumed rumen flow rate and t_0 is the lag.

The intestinal DM and CP disappearance were taken as the difference between the total tract digestion obtained from the intestinally introduced pair, 12 and 24 hour, and the rumen disappearance.

The statistical analyses were done using the general linear model of SAS package, release 6.04 (SAS/STAT software, 1985). This was analysed as a 4 x 3 x 2 x 2 factorial experiment.

Results and Discussion

Tannin and protein levels

The mean tannin and protein contents of the three species are presented in Table 1. Tannin is presented as the Yb-ppt which is an estimate of total phenolics in the DM. Tannin and protein were significantly ($P<0.05$) lower in *Gliricidia* than in *Leucaena* and *Calliandra*.

Dry matter and crude protein rumen degradation

The results indicated varying but low DM and CP degradation in the rumen for untreated samples (Tables 2 and 3). Thus, varying quantities of the dietary DM and CP escaped the rumen undegraded depending on the plant species, which therefore means increased dietary DM and N flow into the intestine when animals consume these forages. Similar low degradation results were reported by Jones et al. (1992) for *Leucaena* and *Calliandra*. Such low CP degradability values in forages might lead to shortage of rumen degradable nitrogen (RDN) for optimum microbial activity if animals consume this diet wholly as suggested by Chiquette et al. (1988)

The addition of PEG markedly increased the effective degradability of the DM especially for *Calliandra* from 13.8% to 41.5% of the DM, an increase of 200%. CP degradation also increased significantly ($P<0.05$) over the untreated.

Table 1. Variation of Yb-precipitated phenolics and crude protein among species. Values within a column followed by a similar superscript are not significantly different ($P> 0.05$)

Species	Yb-ppt %DM (s.e.m)		CP %DM (s.e.m)	
Leucaena leucocephala	24.16[b]	(1.88)	25.86[b]	(0.99)
Calliandra calothyrsus	25.96[b]	(1.88)	23.42[ab]	(1.11)
Gliricidia sepium	16.08[a]	(1.39)	20.69[a]	(1.36)

Table 2. Effect of addition of PEG on mean effective degradability of DM, at assumed rumen outflow rates of k = 0.04 and 0.06. Values within a row with different superscripts are significantly different (P<0.05).

Species	Without PEG (S.E.M) % of initial DM	with PEG (S.E.M) % of initial DM	% increase over untreated
k=0.04			
Leucaena	$38.5^{a} \pm 1.53$	$63.7^{b} \pm 1.53$	65
Calliandra	$13.8^{a} \pm 1.53$	$41.5^{b} \pm 1.53$	200
Gliricidia	$46.5^{a} \pm 1.54$	$65.4^{b} \pm 1.53$	40
k = 0.06			
Leucaena	$30.7^{a} \pm 1.53$	$59.0^{b} \pm 1.54$	92
Calliandra	$9.9^{a} \pm 1.54$	$37.8^{b} \pm 1.54$	281
Gliricidia	$39.8^{a} \pm 1.56$	$60.4^{b} \pm 1.54$	52

Table 3. The effect of PEG on effective degradability of the CP at assumed rumen outflow rate k = 0.04 and 0.06 respectively. Values within a row with different superscripts are significantly different (P<0.05).

Species	Without PEG (S.E.M) % of initial CP	with PEG (S.E.M) % of initial CP	% increase over untreated
k=0.04			
Leucaena	71.7a ± 2.00	82.6b ± 2.00	15
Calliandra	50.0 a ± 2.00	64.3 b ± 2.35	28
Gliricidia	75.1 a ± 2.36	86.4 b ± 2.35	15
k=0.06			
Leucaena	65.7 a ± 2.10	78.5 b ± 2.10	12
Calliandra	45.5 a ± 2.10	60.6 b ± 2.47	33
Gliricidia	69.8 a ± 2.47	82.8 b ± 2.10	19

Table 4. The effect of tannin on total tract DMD and DCP. Values within a row with similar superscripts are not significantly different (P > 0.05)

Species	Without PEG (S.E.M) % of initial	With PEG(S.E.M) % of initial	% increase over untreated
	DMD		
Leucaena	$54.3^{a} \pm 1.70$	$75.0^{b} \pm 1.82$	38
Calliandra	$25.4^{a} \pm 1.70$	$51.8^{b} \pm 1.82$	104
Gliricidia	$67.0^{a} \pm 1.70$	$80.7^{b} \pm 1.76$	20
	DCP		
Leucaena	$86.6^{a} \pm 1.44$	$95.8^{b} \pm 1.54$	10
Calliandra	$60.4^{a} \pm 1.44$	$86.8^{b} \pm 1.54$	43
Gliricidia	95.9a ± 1.44	98.8a ± 1.54	3

Total tract and intestinal digestibility of DM and CP

The total tract digestibilities of the DM and CP calculated from hours 12 and 24 rumen incubated bags, introduced into the intestine and recovered in the faeces, are presented in Table 4.

The total tract digestibilities of both DM and CP were lower in untreated than the PEG treated forages. This implied that tannins reduced the apparent digestibility of both DM and CP. Except in the case of *Calliandra*, a significantly (P<0.05) larger proportion of the escaped DM and CP was digested in the intestines (Table 5). The results support findings by Barry et al. (1986) that increasing the dietary tannin concentration increases the duodenal N flow, but decreases the apparent digestibility of organic matter. This also confirms findings by Jones and Mangan (1977) that PEG is an effective suppressor of tannin effects on digestibility.

Some recent work by Palmer and Schlink (1992) and Palmer and Ibrahim (1996) indicate that *in sacco* digestibility of fresh *Calliandra* forage was higher than the dried or wilted *Calliandra*. Forages used in this study were oven-dried and this is probably the reason for such a low digestibility. However, the importance of these findings cannot be ruled out because most farmers in the smallholdings cut and carry fodder to the animals in stall and are not fed immediately. More often forages are wilted by the time they are fed to animals.

Table 5. The effect of tannins on IDMD. Values within a row with similar superscripts are not significantly different (P > 0.05)

Species	Without PEG (S.E.M)	With PEG (S.E.M)
Leucaena	$18.9^{b} \pm 1.92$	$10.5^{a} \pm 2.00$
Calliandra	$13.6^{a} \pm 1.92$	$10.8^{a} \pm 2.05$
Gliricidia	$22.6^{b} \pm 1.92$	$12.5^{a} \pm 1.99$

Values with similar superscripts in a row are not significantly different (P<0.05).

Conclusion

Forages with less than 55% DMD and less than 70% DCP such as the *Calliandra* in this study require treatment to enhance the nutrient availability for better animal performance. *Leucaena* and *Gliricidia* forages had over 55% DMD and 70% DCP and could therefore be fed without treatment.

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The Production Potential of *Leucaena* spp. and *Calliandra calothyrsus* under Acid Soil Conditions and their Intake by Goats and Rabbits

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Abstract

In trials of *Leucaena leucocephala* hedgerows at eight sites in Vietnam, edible green matter production was closely related to soil pH, with problems identified due to aluminium toxicity and phosphorus deficiency. In a detailed study of 23 *Leucaena* accessions at the Bavi site where soil pH is <4.5, results showed that *L. esculenta* subsp. *paniculata* (137/94) and *L. pallida* composite appeared to have tolerance to the acidic soil conditions. *Calliandra calothyrsus* also performed well at this site. Foliage from several of the *Leucaena* spp. and *C. calothyrsus* was fed as a high quality protein supplement to goats and rabbits. The *Leucaena* spp. were all eaten more than *C. calothyrsus*. There is a need for further evaluation both of accessions suitable for acid soils and of the feeding value of these species.

THE use of *Leucaena leucocephala* foliage as a protein source or as a protein supplement has been studied widely in many countries, for both cattle and small ruminant production. Under favourable conditions of fertile soils and good moisture regimes, dry matter yields of up to 20–25 t/ha/yr have been recorded, containing about 200 g/kg of crude protein. There is thus considerable scope for the use of *L. leucocephala* in the supplementation of diets of the various small animals raised for food in Vietnam. However, past results show that the high leaf yields obtained elsewhere have not been attained in Vietnam, with about 11 t/ha/yr being the maximum observed. Clearly, there is a need for further evaluation of the genus, and of alternative genera.

This paper reports data from three series of experiments: evaluation of *L. leucocephala* at eight sites in Vietnam; evaluation of 23 accessions of various *Leucaena* spp. and *C. calothyrsus* at Bavi in Hatay province; and feeding trials of goats and rabbits with selected *Leucaena* spp. and calliandra.

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Multisite Evaluation of *L. leucocephala*

Experiments were carried out in eight different climatic zones of Vietnam with *L. leucocephala* established as hedgerows spaced 3–6 m apart, with plants 50 cm apart in the hedgerow. Generally, harvests were carried out twice in the rainy season (May to September) and once in the dry season. The pruned material was used as green manure for alley crops. The edible green matter yields obtained are shown in Table 1, together with some soil characteristics of the eight sites.

There is clearly a good relationship between increasing soil pH and green matter production. It is probable that the low soil pH increased phytotoxic aluminium and reduced phosphorus availability. Thus aluminium toxicity and phosphorus deficiency are probably the main reasons for the lower yields obtained. There is clearly a need to apply both lime and phosphorus when growing *L. leucocephala* in tropical acid soils. However, there is also a need to evaluate a wider range of genetic material for growth on acid soils.

Evaluation of 23 Accessions of Various *Leucaena* Spp. at Bavi in Hatay Province

The experiment was conducted at Bavi, adjacent to the Goat and Rabbit Research Centre in Sontay, Hatay province of Vietnam. The 24 accessions

Table 1. Some chemical characteristics of soil at eight sites in Vietnam, and yield of *Leucaena leucocephala* as double hedgerows.

Site	Soil type	Edible green matter (t/ha/yr)	pH	Al^{+++}	P_2O_5 Total (%)	P_2O_5 Available mg/100 g
Bac can Phu Luong Dist	Ferralic Acrisols	5.61	5.3	5.2	0.08	8.0
Thai Nguyen Agroforestry College	Haplic Acrisol	5.80	4.9	19.0	0.07	6.0
Ha Tay, Bavi Commune	Haplic Acrisols	3.20	4.3	67.5	0.08	12.7
Hoa Binh Mai Chau commune	Luvic Calcisols	7.41	6.1	—	0.21	11.7
Thanh Hoa, Ngoc Lac commune	Rhodic Ferrasols	4.70	5.2	8.4	0.10	3.6
Nghe An, Phu quy Research Centre	Rhodic Ferrasols	4.20	4.6	13.4	0.19	5.0
Daklak Coffee Plantation	Rhodic Ferrasols	6.23	5.6	0.4	0.2	9.5

(23 *Leucaena* spp. plus *C. calothyrsus*) were set out in an experimental area of 2000 m^2. Plants were established in rows, 3 m apart. Each plot consisted of 10 plants, 0.5 m apart within the row. Because of the acid soil conditions, there were two fertiliser treatments: unfertilised, and with 5 t $CaCO_3$/ha, 100 kg K_2SO_4/ha, 20 kg $MgSO_4$/ha and 200 kg superphosphate/ha added. There were two replications. Total yields and fresh weight of the edible fraction were recorded. Samples of foliage were taken at harvest for analysis of dry matter and protein content. Results are shown in Table 2.

Table 2. Forage production of *Leucaena* accessions at the Bavi site.

Entry	Dry matter production (kg/m^2)	
	Total	Edible
L. collinsii subsp. *collinsii* 52/88	1.32	0.51
L. collinsii subsp. *zacapana* 56/88	1.66	0.57
L. diversifolia subsp. *diversifolia* 82/92	0.36	0.16
L. diversifolia subsp. *stenocarpa* 4/91	0.58	0.30
L. diversifolia subsp. *diversifolia* 83/92	1.43	0.63
L. diversifolia subsp. *stenocarpa* 53/88	1.10	0.53
L. diversifolia CPI46568	0.55	0.28
L. diversifolia K156	0.68	0.30
L. esculenta subsp. *esculenta* 47/87	2.18	0.93
L. esculenta subsp. *paniculata* 137/94	4.10	1.70
L. esculenta subsp. *paniculata* 79/92	2.60	1.15
L. involucrata subsp. *involucrata* 87/92	1.14	0.54
L. lanceolata subsp. *lanceolata* 43/85	0.84	0.41
L. lempirana 6/91	1.02	0.48
L. macrophylla subsp. *nelsonii* 47/85	2.55	1.08
L. pulverulenta 83/87	0.51	0.30
L. salvadorensis 36/88	2.78	1.28
L. shannonii subsp. *magnifica* 19/84	0.69	0.28
L. leucocephala cv. Tarramba	0.70	0.35
L. leucocephala cv. Cunningham	0.68	0.43
L. leucocephala × *L. diversifolia* KX3	0.78	0.36
L. leucocephala × *L. pallida* KX2	1.00	0.50
L. pallida composite	3.53	1.60
Calliandra calothyrsus	2.88	1.2
SE of mean	0.41	0.17

There were significant differences among yields of the entries in Table 2 ($P<0.001$) both for total and edible dry matter. The eight highest yielding entries were *L. esculenta* subsp. *paniculata* (137/94), *L. pallida* composite, *C. calothyrsus*, *L. salvadorensis* (36/88), *L. esculenta* subsp. *paniculata* (79/92), *L. macrophylla* subsp. *nelsonii* (47/85), *L. esculenta* subsp. *esculenta* (47/87) and *L. collinsii* subsp. *zacapana* (56/88). In general, the edible fraction was between 35% and 42% of total yield.

The application of fertiliser significantly increased the average total yield by 40%, from 1.23 kg/m^2 to 1.74 kg/m^2, and the average edible yield by 49% from 0.53 kg/m^2 to 0.79 kg/m^2.

Feed Intake Studies

The eight highest yielding entries in the forage evaluation experiment were used in feeding trials with goats and rabbits at the Goat and Rabbit Research Centre, Sontay. In the first trial, 40 lactating goats of the India and Bachthao breeds were divided into eight groups, and each group was fed one type of feed. The diet consisted of 2.5 kg foliage (including leaf and stem to 6 mm diameter) plus 2.5 kg guinea grass and 300 g concentrate fed each day over a 5-day period. In the second trial, 40 breeding rabbits were divided into four groups for assessing four different feeds.

The intake of goats and rabbits of the different feed varieties are summarised in Tables 3 and 4.

There were only minor differences among the *Leucaena* accessions for dry matter and protein intake, but intake was always lowest for *C. calothyrsus*. There was no difference between two goat breeds (Bachthao and India) in the amount of DM (714 and 770 g/doe/day) or protein intake (148 and 158 g/doe/day) (Figure 1).

When the four feeds were fed to rabbits (Table 4), *L. esculenta* subsp. *paniculata* (137/94) had the highest intake, and *Calliandra calothyrsus* the lowest.

Table 3. Dry matter and protein intake (g/doe/day) of eight supplementary feeds by lactating goats.

Supplementary feed	Dry matter		Protein	
	Total	Supp. feed	Total	Supp. feed
L. collinsii subsp. *zacapana* (56/88)	1351	745	263	195
L. esculenta subsp. *esculenta* (47/87)	1464	822	233	162
L. esculenta subsp. *paniculata* (137/94)	1341	748	223	156
L. esculenta subsp. *paniculata* (79/92)	1467	832	239	168
L. macrophylla subsp. *nelsonii* (47/85)	1489	894	221	154
L. salvadorensis (36/88)	1443	843	246	178
L. pallida composite	1266	649	200	131
Calliandra calothyrsus	1063	443	158	92
SE of mean	66	58	13	12

Table 4. Intake of dry matter and protein (g/doe/day) of four supplementary feeds by rabbits.

Supplementary feed	Dry matter		Protein	
L. esculenta subsp. *paniculata* (137/94)	310	151	50	32
L. esculenta subsp. *paniculata* (79/92)	266	116	41	24
L. pallida composite	261	107	39	22
Calliandra calothyrsus	221	83	32	16
SE of mean	16	11	3	2

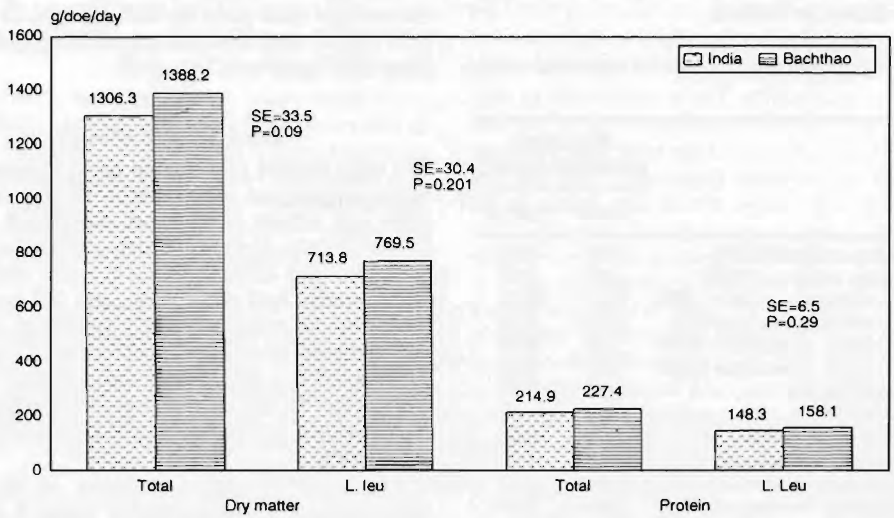

Figure 1. Relative dry matter intake and protein between India and Bachthao goat.

General Conclusions and Recommendations

It is clear that growth of *Leucaena* spp. is generally reduced by acid soil conditions, and that application of fertiliser is needed to obtain even moderate yields. Highest yields at an acid-soil site were obtained from *L. esculenta* subsp. *paniculata* (137/94), *L. pallida* composite, and *C. calothyrsus*. These should be evaluated further in other acid-soil situations. Foliage from several *Leucaena* spp. was well eaten by both goats and rabbits. *C. calothyrsus* was not eaten as much. Because these trials were only of short duration, further work is needed to evaluate the feeding values more extensively.

The Effects of Supplementing Roughage Diets with *Leucaena leucocephala* on Intake, Digestion and Animal Performance of Goats and Cattle in Kenya

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Abstract

Studies conducted using cattle (experiment 1) and goats (experiment 2) to evaluate the effects of *Leucaena leucocephala* (leucaena) forage on intake, digestion and animal performance are reported. In experiment 1, 20 crossbred steers were used to describe the responses when supplementing napier grass (*Pennisetum purpureum*) with 0, 7.5, 15, 22.5 or 30.0 g DM/kg$W^{0.75}$ leucaena forage. Supplementation increased the total dry matter intake, but not that of napier grass. Diet digestibility was lowest in the control group, and the average live weight gains were increased significantly by supplementation. In experiment 2, six dairy goats were fed leucaena and *Gliricidia sepium* in compounded rations, in contrast to commercial concentrate. Voluntary food intake, milk yield and composition were measured. There was no significant effect of the supplements on voluntary food intake or milk yield, but the commercial concentrate produced the highest level of crude protein and lactose. It is concluded that *L. leucocephala* improves intake and animal performance and that it can replace expensive commercial protein sources in a diet for ruminants.

TREE legume forages offer a cheap alternative to concentrate diets in ruminant nutrition. One of the tree legumes that is used as supplementary feed in Kenya is *Leucaena leucocephala* (leucaena). This tree has multiple uses: it is used as windbreaks, fences in the form of hedges, and the provision of forage for livestock. Due to its high crude protein (CP) content, the forage can replace commercial protein feed sources in compounded rations or be used as a supplementary diet. This paper discusses some of the responses obtained in cattle and goats when offered forage of *L. leucocephala* (leucaena) as a supplementary diet or as a compounded ration respectively.

Material and Methods

Twenty crossbred steers were used in an experiment to describe the response of voluntary intake and animal performance when leucaena forage was used as a supplementary diet to napier grass. The animals were offered a basal diet of napier grass (*Pennisetum purpureum*) alone or supplemented with incremental levels (7.5, 15, 22.5, 30 g DM/kg $W^{0.75}$) of leucaena forage in a randomised block design for 49 days. The basal diets were offered at least twice daily to ensure the feeding trough was not empty. Leucaena was offered twice daily at 0800 h and 1500 h.

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In experiment 2, the nitrogen contribution of *L. leucocephala* and *Gliricidia sepium* (gliricidia) was examined using 6 dairy goats at 178 days of lactation, in a double 3 × 3 latin square design, with 14 days of data collection and a 10-day adaptation period. The goats were offered *ad libitum* Rhodes grass (*Chloris gayana*) hay diet supplemented with equal portions by weight (·55 kg/day) of one of three supplements. Leucaena and gliricidia forage was used to replace the nitrogen source in a commercial concentrate. Dry poultry waste was prepared by collecting poultry waste from caged layer hens, deep stacked for 20 days then sun-dried. Leucaena and gliricidia leaves from mature stands were harvested, chopped and then sun-dried to produce dry meals. The leucaena and gliricidia meals, cotton seed cake and poultry waste were milled through a 3.5 mm screen and mixed with other ingredients, namely maize germ meal, maize bran, crushed maize grain, fish meal and mineral mix. Maize germ meal, maize bran, cotton seed cake and mineral mix were mixed with the legume fodder meals to formulate the leucaena-based (L) and gliricidia-based (G) diets respectively. A concentrate was constituted by mixing crushed maize grain, maize germ meal, maize bran, cotton seed cake, mineral mix and fish meal so as to be representative of a commercial concentrate (C). The three supplements were constituted to contain 16% CP.

Total daily faecal output was collected, weighed and a 10% sample taken, dried at 60 °C for 24 h and stored for chemical analysis. All animals were confined in well-ventilated individual feeding stalls and weighed weekly. Water and mineral mix was on offer at all times.

Dry matter of food and faeces was determined by drying the sample in an oven at 105 °C for 24 h, ash by ashing at 550 °C for 4 h, CP, milk composition (solids-not fat, SNF), butterfat, total solids (TS), and lactose by the official methods of the Association of Official Analytical Chemists (AOAC 1984). Experimental data were subjected to analysis of covariance using GLM procedures of Statistical Analysis Systems, (SAS 1987). Significantly different means at 95% confidence were separated by Duncan's new multiple range test (Steel and Torrie 1980).

Results and Discussion

In experiment 1, supplementation with leucaena maintained the intake of the napier grass and resulted in a significant ($P<0.05$) increase in total dry matter intake (DMI). The apparent digestibility of the diet and the average daily gain were significantly improved with supplementation (Table 1). The increase in total nutrients and diet digestibility resulted in better performance in supplemented animals.

In experiment 2, there was no significant difference between the three supplements for hay intake, total DMI, Crude Protein digestibility or total milk yield. The only significant differences in milk composition were in crude protein and lactose content, where the commercial concentrate had the highest values (Table 2).

It is concluded that *L. leucocephala* forage, used at up to the 30% level as supplementary feed, improves intake and live weight in ruminants. It can also substitute for more expensive protein sources in commercial concentrate for dairy goats offered a roughage diet, without any detrimental effect.

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Table 1. Mean dry matter intake (DMI), average daily gain (ADG) and organic matter digestibility (OMD) in steers offered napier grass supplemented with 0, 7.5, 15, 22.5 or 30 g/kg DM $W^{0.75}$ leucaena forage.

	Level of supplementation						
	0	7.5	15	22.5	30	SED	sig.
DMI (kg/d)							
Napier grass	5.2	5.3	5.3	5.3	5.0	0.21	NS
Leucaena	0.0	0.5	0.9	1.3	1.7		
Total	5.2	5.8	6.2	6.6	6.7	0.31	***
OMD (g/kg)	657	695	650	657	712	51.5	NS
ADG (g/day)	538	711	719	789	850	76.5	*

Table 2. Mean dry matter intake (DMI), diet digestibility, milk yield, and composition in dairy goats offered hay supplemented with leucaena-based diet (L), gliricidia-based diet (G) and commercial concentrate (C).

	L	G	C	SE
DMI (kg/day)				
Hay	0.79	0.83	0.78	0.18
Supplement	0.55	0.55	0.55	
Total	1.34	1.38	1.33	0.44
CP digestibility (%)	71.4	73.2	75.6	5.10
Total milk yield (kg)	7.9	6.9	8.0	0.49
Daily average milk yield (kg/d)	0.6	0.5	0.6	0.04
Milk composition (%)				
Butterfat	5.8	4.9	5.5	0.40
Crude protein	23.6^{b}	24.1^{ab}	26.4^{a}	0.94
Total Solids	3.3	2.9	3.0	0.18
Solid not fat	9.6	9.2	8.4	0.51
Ash	5.4	5.8	8.8	0.18
Lactose	38.1^{ab}	37.7^{b}	43.7^{a}	1.86

Means within the same row with different superscripts are significantly different ($P<0.05$).

Effect of *Sesbania grandiflora* or *Leucaena leucocephala* on Rumen Environment and Production of Goats Fed a Basal Diet of Maize Stover

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Abstract

Preliminary results are reported from an experiment where immature green maize stover was used as a basal diet for goats supplemented with foliage from the leguminous trees *Leucaena leucocephala* and *Sesbania grandiflora*. Total feed intake was increased by supplementation with both types of legume foliage but liveweight gain was best with *Leucaena*. Intake and growth rate were reduced when the maize stover was ensiled. It was more productive of farmers' time to harvest foliage from *Sesbania grandiflora* than from *Leucaena leucocephala*.

A LARGE area has been planted with maize recently in the Mekong Delta for production of immature cobs for industrial processing. After harvesting the young maize cobs, the maize stover which is still green could be used to feed ruminants such as cattle, buffalo, goats and sheep. Of these species, goats are especially interesting because of their capacity to select the more nutritious components of plants. Immature maize stover does not require any processing although ensiling is a common practice when whole plant maize is used as animal feed on the farm. The stover is relatively low in nitrogen and it is to be expected that it would benefit by being supplemented with a protein-rich leguminous forage. Two leguminous trees available in the Mekong Delta and which have potential as supplements for goats are *Sesbania grandiflora* (sesbania) and *Leucaena leucocephala* (leucaena).

The time taken to cut and collect feed by hand is an important factor in 'cut and carry' systems for livestock managed in confinement, as is the case in most situations in Vietnam. This characteristic of a feed is rarely reported but is said to be the reason in Colombia for using leucaena in a grazing system and *Gliricidia sepium* for 'cutting and carrying' as practical observations showed that the harvest rate (kg foliage/unit time) was much higher for gliricidia than for leucaena (Molina, C. 1998, pers. comm.).

An experiment was undertaken using growing goats to obtain preliminary results on the use of immature maize stover as a basal feed supplemented with the foliage of leucaena and sesbania. The time required to harvest the foliages from the two legume trees was also determined.

Materials and Methods

Feeding trial

Four female goats (4–5 months of age) weighing from 9 to 12 kg were placed in individual cages made from bamboo. They were fed four diets according to a 4 × 4 Latin square arrangement:

- MS: maize stover;
- EMS: ensiled maize stover (with 10% molasses fresh basis);
- MSSG: maize stover and sesbania (50% of each in the ration based on dry matter);
- MSLL: maize stover and leucaena (50% of each in the ration based on dry matter).

Each experimental period was for 25 days and consisted of 5 days adjustment followed by 20 days for collection of data. Feed intake was recorded by weighing the amounts offered and the residue. The goats were weighed at the beginning and the end of each period before feeding in the morning. On the last day of each period, rumen fluid (about 50 mL) was obtained with a stomach tube before and 4 hours after feeding. Measurements were made of pH,

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ammonia concentration (Kjeldahl distillation) and populations of protozoa (direct counting under microscope).

Harvesting rate of legume foliage

Measurements were made during May, June and September of the quantities and the time taken to harvest the foliage of leucaena and sesbania.

Results and Discussion

Rumen environment parameters

The mean values for pH, rumen ammonia and protozoal population are shown in Table 1. In accordance with expectations, the rumen ammonia levels were lowest in the diets that were not supplemented with the legume forage. However, the concentrations in all diets were close to or above the minimum values considered to be necessary for efficient utilisation of fibrous diets.

Values for pH were all in the range considered to be optimum for rumen function. There were no differences between diets.

The protozoa normally account for about 5%–10% of the rumen microbial biomass. There was a tendency for the protozoa to be less numerous when the feed was ensiled maize stover, perhaps reflecting the fact that soluble sugars present in the maize are fermented to organic acids in the ensiling process; and protozoa are stimulated by the presence of sugars in the diet.

Feed intake and weight change

Feed intake was highest for the diets supplemented with the legume foliage and lowest for the unsupplemented, ensiled maize stover (Table 2). The acid smell and taste of the ensiled maize stover and the relatively short time to adapt to this feed may have been factors leading to the low intake. Weight gain was highest when leucaena was used as the supplement and least on the ensiled maize stover, reflecting the low level of intake. Addition of foliage of sesbania to the maize stover increased the dry matter intake but not the weight gain.

Harvesting rate

The data in Figure 1 show that it took a significantly longer time to harvest a given amount of leucaena than of sesbania.

Table 1. The effect of ration and time on rumen ammonia-N, pH, and protozoa numbers in goats fed immature maize stover. Means within rows with different superscripts differ significantly at the probability level shown.

Parameter	Time	Ration				SE[1]	Probability
		Maize stover	Ensiled maize stover	Maize stover + sesbania	Maize stover + leucaena		
Ammonia-N (mg/L)	0h	157.9[a]	195.0[b]	261.1[c]	265.2[c]	19.9	0.01
	4h	286.3[a]	224.5[b]	448.6[c]	397.0[d]	24.4	0.01
PH	0h	6.75	6.72	6.59	6.68	0.16	0.90
	4h	6.26	6.58	6.26	6.30	0.10	0.14
Protozoa (× 10^6/mL)	0h	3.5	3.0	3.4	3.6	0.17	0.14
	4h	3.8[a]	3.4[b]	3.7[a]	4.1[c]	0.14	0.03

1: SE: standard error of difference between treatment means.

Table 2. Feed intake and liveweight changes in goats fed immature maize stover. Means within rows with different superscripts differ significantly at the probability level shown.

Parameter	Ration				SE[1]	Probability
	Maize stover	Ensiled maize stover	Maize stover + sesbania	Maize stover + leucaena		
Feed intake (g/day)	304[a]	199[b]	443[c]	478[d]	20.8	0.001
Body gain (g/day)	42[a]	3[b]	43[a]	73[c]	15.3	0.05

1: SE: standard error of difference between treatment means.

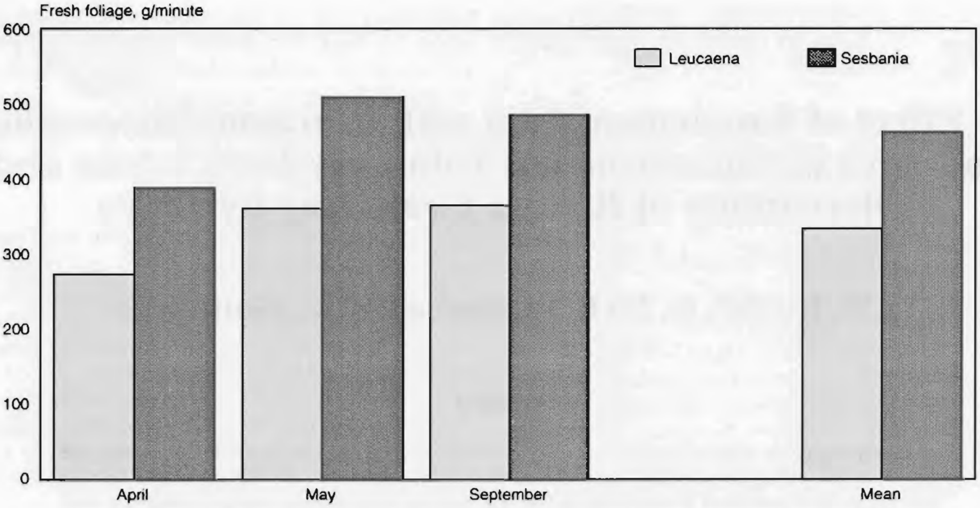

Figure 1. Rate of harvesting foliage from leucaena and sesbania in Mekong Delta in Vietnam (SE ± 19 P=0.001 for differences between means).

Conclusions

The preliminary results from using immature green maize stover as the basal diet of goats are encouraging, especially when this feed is supplemented with foliage of leucaena. The lack of response in liveweight change to supplementation with sesbania is surprising especially as intake was stimulated to the same level as with leucaena.

The use of ensiled maize stover may require longer periods of adaptation, as this is a novel feed for goats.

It was easier to harvest foliage from sesbania than from leucaena.

The Effect of Supplementation with *Leucaena leucocephala* and Urea or Sucrose on the Voluntary Feed Intake and Digestibility of Rhodes Grass Hay by Sheep

I.W. Karda[1], G. McL. Dryden[1] and R.C. Gutteridge[2]

Abstract

To determine the effect of supplementation on voluntary intake and digestibility of rhodes grass hay by sheep, 200 g of *Leucaena leucocephala* (leucaena) either with or without urea or sucrose was fed for four periods of 15 days. During the last five days, digestibility was determined by total collection. There was no effect of supplementation on hay intake or total intake. Nitrogen digestibility was improved by supplementation with leucaena and urea. However, N balance was improved by leucaena supplementation, and addition of urea further improved this parameter. In contrast, supplementation with leucaena plus sucrose depressed the digestibility of NDF compared to the control and leucaena supplemented diet.

NUMEROUS trials have been conducted to test the value of *Leucaena leucocephala* (leucaena) leaf for ruminants as a protein supplement to low and moderate quality roughages (Bamualim et al. 1984; Elliott et al. 1985; van Eys et al. 1986). In these trials, cultivars Peru, Cunningham, Hawaii and accession ILCA 71 were used. Drying the leaf may enhance the formation of by-pass protein which is thought to be due to protein insolubilisation (Leng and Devendra 1995). Moreover, supplements from tree foliage generally have lower metabolisable energy contents compared to concentrate supplements (Richards et al. 1994).

We therefore, undertook an experiment to study the voluntary feed intake and digestibility of rhodes grass hay when supplemented with *Leucaena leucocephala* cv. Tarramba either alone or with urea or sucrose.

Materials and Methods

Four rumen-fistulated sheep, body weight (38 ± 0.5 kg) were used to compare four dietary treatments in a latin square design. The four dietary treatments were rhodes grass hay alone ad lib. (Diet 1), grass hay ad lib. supplemented with daily amounts of 200 g dreid leucaena leaf (Diet 2) or supplemented with 200 g dried leucaena plus 8 g urea (Diet 3) or with 200 g leucaena plus 150 g sucrose (Diet 4).

Water and multimineral blocks were also provided *ad lib.* Four experimental periods were used with 10 days of adaptation followed by five days in which total feed, refusals and faeces were collected to study feed intake and in vivo organic matter (OM), nitrogen (N) and neutral detergent fibre (NDF) digestibilities.

Results and Discussion

Rhodes grass hay contained 0.95% N and 73.0% NDF in its dry matter, leucaena contained 2.77% N, 31.3% NDF and 7% condensed tannin (dry matter basis). Intake and digestibility data are presented in Table 1.

Supplementation did not improve the voluntary feed intake or digestibility, except N digestibility. This might have been because the N content of the basal diet was close to 20 g N/kg DOM, the level at which a response to protein supplementation may not be expected to increase the voluntary intake of low quality basal diets (Egan 1989). Alternatively, the level of supplement was below the optimal level of supplementation for tree foliage as suggested by Norton et al. (1994) (16% vs. 30%–50% total DMI).

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Table 1. Intake (gDM/d), digestibility (g/kg DM) and N balance (g/day) of sheep fed grass hay ad lib. supplemented with leucaena or leucaena with urea or sucrose. Means within rows with similar superscripts are not significantly different (P>0.05).

Parameter	Diet				l.s.d. (P<0.05)
	Grass alone	Grass + leucaena	Grass + leucaena + urea	Grass + leucaena + sucrose	
Intake:					
Hay	924[a]	912[a]	899[a]	726[a]	203
Leucaena	—	186	186	186	—
Urea	—	—	8	—	—
sucrose	—	—	—	126	—
Total	924[a]	1098[a]	1093[a]	1062[a]	204
Digestibility:					
OM	532[a]	531[a]	529[a]	522[a]	35
NDF	540[a]	499[a]	486[a]	392[b]	58
N	537[a]	564[a]	670[b]	510[a]	65
N retained	3.7[a]	6.2[b]	8.9[c]	4.7[a]	1.6

However, N balance was improved by leucaena supplementation, and addition of urea further improved this parameter.

In contrast, supplementation with leucaena plus sucrose depressed the digestibility of NDF over control and leucaena alone diets.

In conclusion, because of the positive effect of urea, rumen degradable N may be limiting in sheep given low quality basal diets supplemented with dried leucaena leaf.

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The Role of Tree Legumes in Fattening Cattle in Bali

I. Ketut Rika

Abstract

Tree legumes are important sources of feed for Balinese cattle, particularly in the medium/high land area. Tree legumes provide 68% of the total tree forage in Bali of which gliricidia contributes 47%, followed by erythrina (11%), calliandra (9%) and *Leucaena leucocephala* (2%). Gliricidia is used mainly in the lowland areas, but calliandra and erythrina are significant in the medium/high land areas. The use of *Leucaena leucocephala* has declined since the advent of the *Leucaena leucocephala* psyllid. The introduction of new shade tolerant grasses and legumes has helped increase the weight gains attained under the cut and carry system.

ALTHOUGH Bali is famous as a tourist destination, 60%–70% of people are farmers. Land use in Bali consists of about 20 655 ha of sawah (rice fields) and 437 772 ha of dry land area, generally at middle and higher elevations. Forest covers about 125 513 ha. Rice is grown in the lowlands, and coffee, cocoa, coconuts, cloves, vanilla and fruits in the medium altitude and highland areas. Bali has a pronounced dry season of 4–5 months.

All farmers keep livestock as an integrated activity, generally on a small scale. There are about 500 000 cattle and 30 000 goats overall. The dry land farmers in the medium/high land areas have only small areas of land (average 2 ha) and grow many different sorts of tree crops (e.g., bananas, coffee, cocoa, fruit trees, cloves and coconut). Between or under the main trees they plant corn, sweet potato, cassava, peanuts, and forages. Vanilla is grown on supporting trees or shrubs.

The farmers generally do not have more than two head of cattle. These are regarded both as a source of income and as draught animals. They are kept in a small shade house and fed using a cut and carry system. In the rainy season, the farmers find it easy to obtain forage, with adequate amounts generally coming from their own land (grass and legumes from under trees, plus prunings from live fences).

However, in the dry season, forage supply is a problem, and it takes a lot of work to get an adequate supply from riverbanks, roadsides and common land. Feed resources consist of local grasses that are generally of low quality.

A number of species have been introduced to improve the productivity and quality of forage in the farming systems, including *Pennisetum purpureum* and various *Setaria* species.

Even when the supply of forage is adequate, the quality is generally low, and cattle generally do not gain more than 250 g/day. However, farmers try to overcome this problem at least in part by planting shrub legumes (*Calliandra calothyrsus* (calliandra), *Leucaena leucocephala*, *Gliricidia sepium* (gliricidia) and *Erythrina* spp. (erythrina)) as living fences or specifically for forage.

Tree forages represent only about 28% of total forage production in Bali. It has been estimated that the total annual production of tree forages in Bali is about 842 000 tonnes per year. Of this, the tree legumes gliricidia (47%), *Leucaena leucocephala* (2%), calliandra (9%) and erythrina (11%) contribute more than two-thirds. The remaining 31% is made up of banana leaf, coconut leaf, bamboo leaf plus other sources.

Some areas favour production of certain species. In the sub-region of Badung (mostly lowland and very dry), 75% of tree forage is gliricidia, but in the sub-region of Bangli (all medium-high land) 49% is calliandra.

The Principal Tree Legume Species

Leucaena leucocephala

Leucaena leucocephala has been used in Bali for a long time, but since 1985 its use has decreased due

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to the psyllid. *Leucaena leucocephala* was favoured as a shade tree because its small leaflets provided the right amount of shade. It regrows well after cutting, is highly palatable to animals, and also retains its leaves well in the dry season. In addition, it was strong enough to use as a support for vanilla.

The new psyllid tolerant cv. Tarramba appears to grow well and may help to restore confidence in *Leucaena leucocephala*. It has been included in trials with new accessions of calliandra and gliricidia in the Besakih area of Bali (800–900 m above sea level, 1500 mm rainfall). These trials provided plants to a number of local farmers for evaluation.

Calliandra

Calliandra has become popular because it can produce high yields of feed and fuel wood. Planting as live fencing produced 1.8–3.2 t/km in 10 months, but planting in a monospecific stand produced 7–10 t/ha. These yields would be lower in areas with less rainfall.

In the medium/high land areas, calliandra is cut together with *Pennisetum* to provide a high quality feed mixture. Calliandra is eaten by cattle when it is fresh, in contrast to gliricidia, which is not.

In the border forest areas, the government planted *Pinus* trees, but also planted calliandra and *Pennisetum* in the same area. In return for caring for the *Pinus* tress, the farmers were allowed to cut the calliandra and *Pennisetum* regularly for cattle feed. The calliandra branches were also used for fuelwood. This system means that while farmers have access to a feed source for their animals, they do not have to invade the forest area for fuel.

Gliricidia

Gliricidia is mostly planted in the lower areas, where it ideally needs more than 900 mm of rainfall. It is used mainly as live fencing, but also in vanilla plantations. Trees become well established in 18–24 months, and can then be harvested every 2–3 months during the rainy season and every 3–4 months during the dry season. Yields of about 3–4 kg DM per tree per harvest may be achieved.

Gliricidia has been used for forage in a three-tier forage system (Nitis et al. 1989). Most cattle in Bali will not eat gliricidia immediately after cutting. It must be wilted first before being fed. It has a reputation of dropping its leaves in the dry season.

The leaves of gliricidia have high nutritive value for ruminants (20%–30% protein, 60%–65% in vitro digestibility, low crude fibre and tannin levels) but are toxic to some monogastric animals. In some parts of the world (e.g., Somalia) the use of gliricidia for ruminants is limited by its unpalatability (Wiersum and Rika 1997).

Erythrina

Erythrina has long been used for shade, live fencing and mulch. In the cut and carry system, it is cut by farmers 2 or 3 times a year, and often mixed with other local forages such as grasses or other tree leaves. However, erythrina does not tolerate pruning well. Cutting it every 2 months resulted in 15% of trees dying in the first year. Cutting every six months produced 7.3 t of edible biomass per year, whereas cutting every 4 months only produced 3.4 t. The leaves had a crude protein content of 22%, and a digestibility of 60%. The trees of erythrina are not strong, and are easily cleared out when farmers do not need them any more, or wish to replant the area.

Improving Forage Quantity and Quality

In addition to the planting of shrub legumes, farmers now have access to new grasses (*Stenotaphrum secundatum* cvv. Floratam and Vanuatu) and legumes (*Arachis pintoi*) which tolerate shade under plantation trees such as coconuts. These species can provide good quantities of high quality feed in both the rainy and the dry season. This enables the farmer to keep more cattle, often up to 6–8 head, and obtain better daily weight gains of up to 500 g/day. It is anticipated that new accessions of *Leucaena* species and calliandra will further enhance these gains.

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Preliminary Study of *Leucaena leucocephala* as Feed for Livestock

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Abstract

The tender shoots and leaves of leucaena (*Leucaena leucocephala*) are high in protein and other nutrients but they also contain the amino acid mimosine which can be toxic to livestock if used inappropriately. Feeding experiments using leucaena showed that 5% leucaena leaf meal could be used in the feed ration for chickens and 10% for pigs, but there was no advantage and a suggestion of slightly reduced liveweight gains and toxicity in chickens. Feeding 30% tender shoots and leaves in fresh forage to cattle increased liveweight gains by 32%.

LEUCAENA (*Leucaena leucocephala*) is a valuable, high quality fodder tree for the tropics. It is capable of producing high yields and in Taiwan it produces 2500–4000 kg/ha dry matter of tender shoots and leaves each year. Leucaena leaf contains 55% total digestible nutrients (TDN), 2.42 Mcal/kg of digestible energy (DE), and 1.98 Mcal/kg of metabolisable energy.

However, leucaena does contain the non-protein amino acid mimosine and if fed in excess, particularly to monogastric animals, adverse effects and even death in serious cases can occur. It is therefore very important to have a good understanding of safe feeding rates. In this context, livestock feeding experiments with leucaena were conducted at Production Team #10, Experimental Farm, Chinese Academy of Tropical Agricultural Sciences (CATAS) during the period 1994 to 1997. Preliminary results are given in this paper.

1. Chicken Feeding Experiments with Leucaena Meal

Materials and methods

Four experiments were conducted over the following periods: April 27 to August 11, 1994; November 31 to December 20, 1994; September 14 to October 14, 1995; and January 23 to February 31, 1996. Treatments and ration formulae are given in Table 1.

The chicken breeds used for the experiments were Xingbuluo, Hongbuluo and Fujian for Experiments 1, 2 and 3 and 4 respectively.

Nutrient analysis of the leucaena meal used in the experiments is presented in Table 2 in comparison with alfalfa.

The chickens were housed in cages in all four experiments where they ate and drank freely under natural sunlight. All birds were drenched for ascarid and innoculated with Xinchengfang vaccine during the pre-experiment period.

Results

There was a suggestion of slightly lower weight gains in treatments containing leucaena compared to the controls (Table 3). Higher levels of leucaena feeding would be necessary to confirm this result.

Observations indicated that chickens fed rations containing 5% or 6.2% leucaena showed some rough feathers, feather shedding and/or pecking in some birds.

Dissection of birds at the end of the experiment showed a darker, yellow skin and flesh, a larger gall bladder and spleen and harder liver in birds fed leucaena. However, no birds died in any of the four experiments.

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Table 1. Chicken feed ration treatment and formulae.

Experiment/Treatments		Maize (%)	Cassava (%)	Rough rice (%)	Wheat bran (%)	Peanut cake (%)	Sesame cake (%)	Fish meal (%)	Rice Bran (%)	Leucaena (%)	ME (Mcal/kg)	Crude protein (%)
Experiment 1	Control	60	–	10	–	20	–	7	–		2.83	18.1
	3.8% treat.	55.8	10	5	–	17	–	7	–	3.8	2.76	17.3
	5% treat.	55.4	9.3	5	–	17	–	7	–	5	2.74	17.3
	6.2% treat.	53.5	10	5	–	17	–	7	–	6.2	2.70	17.6
Experiment 2	Control	56	–	10	–	20	–	12	–	–	2.82	21.8
	3% treat.	53	3	10	–	20	–	12	–	3	2.72	21.5
	6% treat.	53	–	10	–	18	–	12	–	6	2.64	21.4
Experiment 3	Control	58.5	20	–	–	15	–	5	–	–	3.10	15.6
	4.8% treat	5 kg of Leucaena per 100 kg of control feed									3.03	16.0
	6.5% treat.	7 kg of Leucaena per 100 kg of control feed									3.02	16.1
Experiment 4	Phase 1 Ctrl	39	23	–	6	11	12	6	3	–	2.85	18.3
	Phase 1 5%	39	23	–	1	11	12	6	3	5	2.79	18.7
	Phase 2 Ctrl	38	30	–	5	11	10	6	–	–	2.87	17.3
	Phase 2 5%	38	30	–	–	11	10	6	–	5	2.84	17.7

Table 2. Nutrient composition (%) of *Leucaena leucocephala.*

	Crude protein	Crude fat	Crude fibre	Crude ash	Extract without N	Ca	P	Mimosine
Leucaena	26.7	5.1	11.40	6.25	50.56	0.8	0.21	5.88
Alfalfa meal	22.5	1.3	28.3	9.0	27.1	1.26	0.25	–

* Source: Pig and Chicken Feed Component and Nutritional Value, compiled by China Society for Study of Animal Nutrition and Animal Husbandry Institute, Chinese Academy of Agricultural Sciences.

Table 3. Chicken weight gain (g).

			Weight gain (g)	Feed consumed (g)	Feed/Conversion ratio
Experiment 1	Control		880	–	–
	3.8% treat.		675	–	–
	5% treat.		843	–	–
	6.2% treat.		801	–	–
Experiment 2	Control		475	1970	4.2
	3% treat.		511	1933	3.8
	6% treat.		440	1910	4.4
Experiment 3	Control		425	1633	3.8
	4.8% treat.		411	1605	3.9
	6.5% treat.		381	1590	4.2
Experiment 4	Phase 1	Control	427		3.1
		5% treat.	405		
	Phase 2	Control	296		3.6
		5% treat.	299		3.6

2. Pig Feeding Experiment with Leucaena Leaf Meal

Materials and methods

Two experiments were undertaken between July 7 and October 8, 1996, and April 14 and November 12, 1997. Treatments and ration formulae are given in Table 4.

All pigs were the F1 generation of Subai × Lingao breeds. They were 75 days-old for Experiment 1 and about 90 days-old for Experiment 2.

They were all injected against swine pest, diamond disease and lung plague and drenched for ascarid in the pre-experiment period.

Results

There was no significant effects of treatment on weight gain of pigs in either experiment (Table 5).

3. Cattle Feeding Experiment with Fresh Leucaena Forage

Materials and methods

The experiment was conducted from August 11 to November 11, 1997 at the Production Team #10, Experimental Farm, CATAS.

There were two treatments, fresh grass forage alone or fresh grass plus 30% fresh leucaena leaf.

Local one-year-old cattle were used for the experiment with one bull and one cow in each treatment.

Results

Inclusion of 30% leucaena forage in the diet increased liveweight gain from 430 g/head/day to 569 g/head/day. There were no adverse effects of the leucaena on the cattle during this period.

Discussion

There was no change in liveweight gain with up to 5% leucaena included in the diet of chickens. At higher levels, toxicity symptoms appeared and there was a suggestion of reduced liveweight gain. There was no change in liveweight gain of pigs fed up to 10% leucaena in the diet. Leucaena fed as 30% of diet increased liveweight gain of cattle.

There would appear to be no value in including leucaena in the diet of chickens. There may be a small benefit in feeding leucaena to pigs and there was a definite advantage when it was fed to cattle.

Pelletisation or flavouring of leucaena feed may improve its palatability and reduce feed waste.

Table 4. Pig feed ration treatment and formulae.

		Maize (%)	Cassava (%)	Rough rice (%)	Wheat bran (%)	Peanut cake (%)	Fish meal (%)	Rice bran (%)	Leucaena (%)	ME (Mcal/kg)	Crude protein (%)
Experiment 1	Control	11	33	13	5	19	4	15	–	2.95	15.8
	5% treat.	11	33	13	5	19	4	10	5	2.96	16.8
	10% treat.	11	33	13	5	19	4	5	10	2.96	17.9
	15% treat.	11	33	13	5	19	4	–	15	2.97	18.9
Experiment 2	Control	–	50	5	5	25	5	10	–	2.85	18.3
	5% treat.	–	50	5	5	25	5	–	5	2.79	18.7

Table 5. Pig weight gain (kg).

		Weight gain	Feed consumed	Feed/pork ratio
Experiment 1	Control	165	619	3.8
	5% treat.	161	600	3.7
	10% treat.	166	603	3.6
	15% treat.	162	600	3.7
Experiment 2	Control	418	154	3.7
	5% treat.	422	153	3.6

Supplementation of dairy cows

Milk Production from Ruzi mixed with *Leucaena*, Ruzi Alone and Ruzi Supplemented with *Lablab purpureus*

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Abstract

Three groups of dairy cattle (n=8/group) were compared under different grazing managements, viz., strip-grazed on pure ruzi grass (*Brachiaria ruziziensis*), strip-grazed on a ruzi/leucaena pasture or strip-grazed on pure ruzi in the morning and on lablab (*Lablab purpureus*) in the afternoon. The animals that received the leucaena or lablab in combination with the grass produced higher daily milk yields (14.4 and 13.6 kg/cow) and fat percentages (4.5% and 4.2%) than those on pure grass alone (11.9 kg/cow for milk yield and 4.0% for fat). This advantage is likely to be due to the greater crude protein levels in the legume/grass mix compared with that of pure grass alone. It is concluded that growing tree legumes with grass or sowing of pure herbaceous legumes can be recommended as pasture for dairy cattle in Thailand.

GRASS/LEGUME pastures are not widely used to reduce the cost of milk production in Thailand due to the difficulty of maintaining legumes in mixtures with grasses. In order to overcome this problem, the use of tree legumes such as leucaena (*Leucaena leucocephala*) instead of herbaceous legumes is of practical significance. Sowing of pure legume in a small area and using this for special purposes has also been recommended by Wongsuwan and Watkin (1990). This paper reports a grazing trial in which milk production from ruzi grass (*Brachiaria ruziziensis*) mixed with leucaena and ruzi supplemented with lablab (*Lablab purpureus*) were compared to ruzi grass alone.

Materials and Methods

The experiment was conducted at the Dairy Promotion and Organisation of Thailand, located at Muaklek, Saraburi, 150 km northeast of Bangkok. The soil is a clay loam of moderate fertility with pH 6.5. Climatic conditions at the experimental site are monsoonal with the rainy season extending from May to October with peak precipitation in September and averaging 1012 mm annually. From November to April, the weather is relatively dry. Mean maximum and minimum temperatures are 34.1 °C and 18.7 °C respectively, with a relative humidity averaging 77%. The experiment was carried out for 14 weeks commencing on 7 June and terminating on 14 September 1995. A pre-experimental period of one week was allowed for the animals to adjust.

The experimental area was subdivided into six paddocks ranging in area from 0.80–0.96 ha. Two paddocks were used for each treatment. All paddocks were ploughed and cultivated to produce a fine and firm seedbed before sowing on 10 July 1994. A basal fertiliser (15N-15P-15K) was applied before sowing at the rate of 200 kg/ha. For the mixed pastures treatment (Ruzi/leucaena), leucaena was planted in rows (100 × 50 cm) on 15 July 1994 with approximately 20 000 plants per hectare and ruzi grass was grown between the rows of leucaena by drilling the seeds at the rate of 12 kg/ha. For the pure ruzi grass alone, seeds were drilled in rows (50 cm between rows) using a seeding rate of 24 kg/ha.

Lablab purpureus was sown on March 15, 1995 in rows (50 × 25 cm) at approximately 80 000 plants/ha for the supplementary treatment.

All paddocks, except the *Lablab purpureus* were cut to 15 cm for ruzi grass and 25 cm for leucaena on 28 April 1995 and fertilser (15N-15P-15K) was applied at the rate of 200 kg/ha.

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Twenty-four European crossbred cows in their first-to-third lactation and their first and second months of lactation period were selected. They were balanced for these factors and also the previous milk yield across the three treatments, viz.:

1. Strip-grazed on pure ruzi grass alone for 24 hours daily, apart from twice-daily milking.
2. Strip-grazed on a ruzi/leucaena mixed pastures for 24 hours daily as in group 1.
3. Strip-grazed on pure ruzi grass from 1.00 pm–5.00 am and strip-grazed on pure *Lablab purpureus* from 5.00 am–1.00 pm.

Rotational grazing was adopted, with an average grazing interval of 25–30 days such that there were three grazing cycles in the 98 days of the trial. Pasture was grazed down to 15–25 cm above ground. All cows were also fed with concentrate (14% CP) according to their individual milk production daily, at the rate of 1 kg per 3 kg of milk per day. Pasture production and chemical compositions were measured before and after grazing by using nine quadrats (100 × 100 cm) in each treatment. Pasture intake was calculated as the difference between pasture dry matter on offer at the beginning and end of each grazing period.

Results

Animal production

Animals grazing ruzi and supplemented with lablab achieved the highest average daily milk yield of 14.4 kg/cow, when compared to 13.6 and 11.9 kg/cow in the leucaena/ruzi mixed and pure ruzi pasture respectively (Table 1).

Milk production from the supplemented and mixed pasture treatments remained relatively high throughout the experimental period compared with the pure grass alone (Figure 1). Milk fat percentage showed a noticeable increase in the legume added treatments (2 and 3) compared with the ruzi grass only treatment.

At the end of the experiment, the cows grazing ruzi grass alone, grazing ruzi mixed with leucaena and supplemented with lablab showed weight gains of 99, 66 and 209 gm/head/day respectively (Table 1).

Pasture production and protein content

During the first cycle of grazing, all pasture treatments had 35–50 days regrowth (Table 2) but in the second and third grazing cycles the grazing interval was reduced to 25–30 days. As a result, the amount of pasture on offer was greater in the first cycle but with a lower crude protein content, compared with the lower pasture yield but much higher protein content in the later grazing cycles.

However, the pure ruzi grass alone was still noticeably superior in dry matter on offer to the rest. All legume yields in the mixed and supplemented treatments declined following the second and the third cycles of grazing, but maintained a consistently high crude protein percentage compared to that of the ruzi grass.

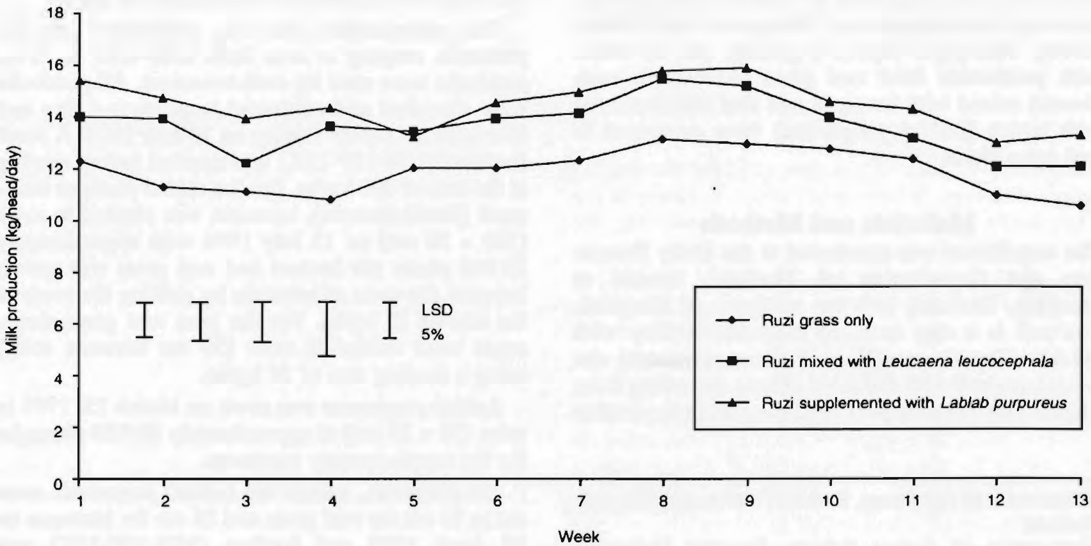

Figure 1. Milk production over 13 weeks at 4% fat.

Table 1. Effect of pasture management on dry matter on offer, on milk production (kg/head/day) and milk fat (%) over 13 weeks.

Treatment	Milk production (adjusted to 4% fat)	Milk fat (%)	Pasture dry matter intake (kg/head/day)	L.W.G. (g/head/day)
1. Ruzi grass alone	11.9 b	4.0 b	8.2	98.9 a
2. Ruzi/leucaena mix	13.6 ab	4.2 ab	10.8	65.9 a
3. Ruzi in the morning, lablab in the afternoon	14.4 a	4.5 a	11.2	208.8 a

Table 2. Pasture on offer before grazing of each grazing cycle (kg/ha) and their protein content.

Treatment		Grass		Legume		Total
		DM	% CP	DM	% CP	
	T1[1]	3056	6.40	—	—	3056
Cycle 1	T2	1831	5.90	688	25.6	2519
	T3	1538	6.30	438	23.4	1976
	T1	2463	12.25	—	—	2463
Cycle 2	T2	1156	12.38	356	27.4	1512
	T3	1088	12.64	744	24.9	1832
	T1	2006	12.73	—	—	2006
Cycle 3	T2	1100	11.51	175	23.4	1275
	T3	969	12.93	375	25.5	1344

[1] T1 Ruzi grass alone; T2 Ruzi mixed with Leucaena; T3 Ruzi supplemented with Lablab.

Dry matter intake of the cows grazing ruzi grass alone, grazing mixed leucaena and grazing ruzi and supplemented with lablab were 8.2, 10.8 and 11.2 kg/head/day respectively (Table 1).

Discussion

The results of this experiment indicate the importance of forage legume inclusions in pastures for dairy cattle production. The animals receiving the legumes through supplementation or mixed with the grass showed higher milk yield and fat levels than that of the pure grass alone.

This advantage was possibly due to the higher crude protein levels (Table 2) and higher forage intake (Table 1) compared with grass alone, as reported by Stobbs (1975) and Muinga et al. (1995). Similar results have been reported by Abdulrazak et al. (1996) in that supplementation with leucaena increased the total DM intake linearly without depressing the intake of napier grass.

The superior milking performance due to legume inclusion was particularly evident during the first four weeks of the experiment, probably due to the poor quality of the ruzi grass in that period. Therefore, the legume added through the mixed grass/legume or as a supplementary feed, is essential to the maintenance of elevated milk yields.

The results of this study also showed that sowing of pure legumes and feeding daily by grazing or cutting in order to provide the cow with high protein forage can be achieved without difficulty. This system also allows the farmer to add more urea and other fertiliser to the pure grass without any problem of suppression of the legume which commonly occurs in mixed grass/legume pastures (Whiteman 1980).

As a result, the supplementary system can achieve higher milk yield and fat percentage than conventional herbaceous mixed grass/legume systems. However, the use of a tree legume, such as leucaena, is of particular interest as it can better withstand grazing pressure and compete well with the grass. From observations, there appeared to be no death of leucaena plants as compared with the severe death of *Stylosanthes hamata* plants reported by Wongsuwan and Watkin (1990).

All treatments declined in milk yield especially under the pure ruzi grass treatments during the last three weeks of the experiment, due probably to the reduction in legume yield and hence forage quality of the legume-based treatments and due to the commencement of the reproductive phase in the grass-only treatment. The animals may have also reached the physiological stage of mid-lactation period (Bryant and Trigg, 1982).

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Comparison of *Leucaena leucocephala* and other Tree Fodders as Supplements for Lactating Dairy Cows

B.V. Maasdorp[1] and B.H. Dzowela[2]

Abstract

Two trials are summarised in which the forage value of four browse species was evaluated as dried conserved dry season feed for dairying, either as an improved source of forage, or as a cheaper source of homegrown protein substituting for cottonseed meal. Cows were on a basic diet of maize silage and maize grain, plus/minus cottonseed meal. In one trial, 1.5 kg of sundried *Acacia boliviana, Calliandra calothyrsus* or *Leucaena leucocephala* replaced an equal mass of poor quality grass hay, and in the other about 5 kg sundried *Acacia angustissima, Cajanus cajan, C. calothyrsus* or *Leucaena leucocephala* was substituted for 3.3 kg cottonseed meal isonitrogenously. All trial forages were fed together with 2–3 g/kg polyethylene glycol (PEG) or Browse Plus (a commercial PEG-containing digestive modifier). Milk yields (kg/cow/d) in the first trial were: grass hay 11.36, *Leucaena leucocephala* 13.19, *A. boliviana* 11.94 and *C. calothyrsus* 11.14 ($P<0.001$); and in the second trial: cottonseed meal 15.57, *Leucaena leucocephala* 14.36, *C. cajan* 12.79, *A. angustissima* 11.56 and *C. calothyrsus* 8.57 ($P<0.01$). Tree fodder polyphenolic characteristics were assessed in the first trial. Indications were that, despite the forages being fed together with PEG, anti-nutritional factors related to polyphenolic characteristics were still operative, particularly with *A. angustissima*/*A. boliviana* and *C. calothyrsus*. The potential for use of *C. calothyrsus* conserved as hay for dry season feed for dairying would appear to be limited and *A. boliviana* only moderate, whereas *Leucaena leucocephala* and *C. cajan* have good potential for this purpose with respect to forage value.

FEED supply is a major limiting factor for smallholder dairy production in Zimbabwe, particularly during the dry season. Fodder trees are seen as a cheaper source of protein than dairy concentrates and several introduced species have proved reasonably well adapted. However, many browse species have high levels of polyphenolic compounds, including condensed tannins (proanthocyanidins — PAs), which can have negative effects on protein availability, palatability and digestibility (Woodward and Reed 1989). It is therefore essential to conduct feeding trials for accurate nutritional evaluation of tree fodders.

Two studies were undertaken to evaluate the forage value of four species when used to supplement dairy diets, either as an improved source of forage (Maasdorp et al., in press), or as a homegrown substitute protein source (Dzowela et al., in press). The forage was cut at the end of the growing season and sun dried, a practice suggested by Dzowela et al. (1995) to avoid dry season leaf loss due to moisture stress and frost.

Materials and Methods

Trial 1: As improved forage

Fodder of *Acacia boliviana* (progeny of CPI 40175), *Calliandra calothyrsus* (OFI 9/89) and *Leucaena leucocephala* cv. Cunningham was used to replace, and compare with, 1.5 kg of poor quality roughage (Rhodes grass hay, *Chloris gayana*), given to Holstein-Friesian cows on a basic diet of maize silage (30 kg), cottonseed cake (2 kg), crushed maize (8 kg), with access to ad libitum grass hay after 12 noon.

The trial forages were all mixed with 5 g of Browse Plus, a digestive modifier containing polyethylene glycol (PEG), and fed mid-morning. There were three

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cows in each feeding group. Milk yield was recorded for two weeks following a 2-week adaptation period and using the 7-day pre-trial milk yield as a covariate. Forages underwent proximate analysis and were assessed for polyphenolic characteristics.

Trial 2: As a substitute for cottonseed meal

The species evaluated were *A. angustissima*, *C. cajan*, *C. calothyrsus* and *Leucaena leucocephala*. Friesian cows were fed maize silage (22 kg), maize meal (5 kg on average), and either 3.3 kg cottonseed meal or 5 kg (on average) tree fodder (amounts of maize meal and tree fodder adjusted so as to feed 10 kg of an approximately isonitrogenous mixture).

The cows were also dosed daily with 20 g PEG and had access to Star grass (*Cynodon nlemfuensis*) pasture. The experiment was conducted as a balanced latin square with groups of four cows, with 2-week adjustment and one week true response periods.

Pre-treatment average milk yield was used as a covariate for milk yield. Tree fodder crude protein (CP) content and in vitro organic matter (OM) digestibility (Tilly and Terry 1963) were determined.

Results and Discussion

Practically all of the test fodder was consumed. Browse Plus/PEG at the rate of about 2–3 g/kg fodder was therefore adequate to ensure good intake of these dried tanniferous forages.

Milk yields, OM digestibility and polyphenolic characteristics are presented in Tables 1 and 2.

Considering both trials, milk yield response was highest for *Leucaena leucocephala*, intermediate for the *Acacia* species, and lowest or nil for *C. calothyrsus*. Milk yield of cows supplemented with *Leucaena leucocephala* was not significantly different (NSD) from that of cows fed cottonseed meal, though it did result in a lower fat corrected milk (FCM) yield ($P<0.05$). The response to *C. cajan* as a cottonseed meal substitute was NSD from that

Table 1. Tree fodders used as a substitute for grass hay: milk yield and forage in vitro organic matter digestibilty and polyphenolic characteristics.

	Acacia boliviana	*Calliandra calothyrsus*	*Leucaena leucocephala*	Grass hay
Milk yield (kg/cow/day)	11.94b	11.14c	13.19a	11.36c
OM digestibility (g/kg)	572c	509d	879a	624b
Soluble phenolics (g/kg DM)	189.2b	232.4a	160.0c	6.99d
Soluble PAs (AU_{550}nm/g DM NDF)	113.5a	69.5b	63.5b	0.48b
Insoluble PAs (AU_{550}nm/g DM)	24.77b	29.20a	17.38c	0.37d
Polyphenolic PPC (mm^2/g DM)	697a	557b	339c	nd

Means in the same row followed by different letters are significantly different ($P \leq 0.05$). OM — organic matter; PAs — proanthocyanidins; PPC — protein precipitating capacity; AU — absorbance units at 550nm; nd — not determined. Source: Maasdorp *et al.* (in press).

Table 2. Tree fodders used as a replacement for cottonseed meal: milk yield and forage in vitro organic matter (OM) digestibility.

	Cottonseed meal	*Acacia angustissima*	*Cajanus cajan*	*Calliandra calothyrsus*	*Leucaena leucocephala*
Milk yield (kg/cow/d)	15.57a	11.56bc	12.79ab	8.57c	14.36ab
Fat corrected milk yield (kg/cow/d)	14.55a	9.93b	10.48b	6.89c	11.34b
OM digestibility (g/kg)	–	341	443	334	455

Milk yield means followed by different letters are significantly different ($P \leq 0.05$). Source: Dzowela et al. (in press).

of *Leucaena leucocephala*. OM digestibility was also similar. *C. calothyrsus* was of no benefit as a replacement for grass hay and depressed milk yield by 45% and FCM by 53% when substituted for cottonseed meal isonitrogenously.

In these trials, milk yield responses to *Leucaena leucocephala* and *C. cajan* were substantial, viz. 1.86 kg from 1.5 kg sundried *Leucaena leucocephala* instead of grass hay, and yield reductions NS when substituted isonitrogenously for 3.3 kg cottonseed meal. This supports the view of Muinga (1993) and Muinga et al. (1995) that favourable milk yield responses depend on the presence of adequate dietary energy.

The OM digestibility differences between the tree forages were not related to crude protein, neutral detergent fibre or acid detergent fibre, as *A. boliviana* and *C. calothyrsus* were not inferior with respect to these parameters. In these mature tree fodders (without PEG) soluble polyphenolic content and insoluble PA content (trial 1) were strongly negatively associated with both OM digestibility and milk yield. Polyphenolic PPC was also negatively related to these parameters. This would indicate that, despite the forages being fed together with PEG, anti-nutritional factors related to polyphenolic characteristics were still operative, particularly with *A. angustissima*/*A. boliviana* and *C. calothyrsus*.

The poor responses to dried *C. calothyrsus* in these trials contrast with positive results reported for the feeding of fresh *C. calothyrsus* foliage (Paterson et al. 1996; Palmer et al. 1995). Drying of *C. calothyrsus* and some other tanniferous tree forages has been associated with decreased intake and digestibility (Palmer and Schlink 1992) and decreased soluble tannin content (Ahn et al. 1989). This is thought to be related to increased tannin polymerisation and binding with proteins and cell wall carbohydrates (Reed 1986).

Conclusion

Sun dried *Leucaena leucocephala* and *C. cajan*, fed together with 2–3 g PEG/Browse Plus per kg and with adequate dietary energy, have good potential for dry season feeding of dairy cows, providing an improved source of forage and homegrown substitute for expensive dairy concentrates. *A. angustissima*/*A. boliviana* would appear to be of intermediate forage value for this purpose.

By contrast, the potential use of *C. calothyrsus* as a dried conserved dry season high protein feed for dairying is limited, apparently related to its high polyphenolic content. Further feeding trials are required to determine rate responses and to establish and quantify sygnergistic effects between these more promising tree fodders and affordable amounts of cottonseed meal.

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Use of *Leucaena* in Feeding Pigs

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Abstract

When leucaena leaf meal (LFM) was substituted for 10% or 20% of the normal corn-soybean ration of pigs, the digestibility of all components of the diet except fibre was reduced. The added LFM increased fibre content in the diet. Digestible energy was severely reduced by the addition of LFM. However, in a feeding trial comparing 0 and 20% LFM, there was no difference in feed consumption, daily weight gain or feed use efficiency. There was no pathological damage to visceral organs or carcasses of the pigs. Although these results indicate the potential usefulness of LFM in pig diets, there is a need to assess both the long-term effects of LFM on pigs and the economic aspects of feeding LFM. If LFM is to be used, it should be kept as free as possible from small stems, in order to reduce fibre content.

THE PIG sector in Venezuela has been hit by a number of difficulties in the past few years, particularly due to the high cost of concentrate foods. Protein is one of the more expensive components, and comes mainly from imported sources. Therefore, there is a need to study alternative protein sources that can be produced within the country with high yield and relatively low cost. *Leucaena leucocephala* (leucaena) is a versatile leguminous plant adapted to tropical conditions. It has been estimated (Shelton 1996) that there are between 2 and 5 million hectares of cultivated leucaena throughout the world.

Venezuela has large areas of acidic infertile soils, to which leucaena is not well adapted. However, annual yields of leucaena of 2500 kg dry matter per hectare (DM/ha) with a protein content of 20%–31% have been obtained (Espinoza et al. 1992). This species therefore presents an alternative not only for feeding ruminants but also non-ruminant species such as the pig. Leucaena may be able to partially substitute for soybean and corn in balanced diets. The present work was undertaken to determine, in pigs, the apparent digestibility of diets that included leucaena foliage meal (LFM) and to evaluate the acceptance of these diets in growing animals.

Materials and Methods

Two experiments were carried out in the swine unit of the Instituto de Investigaciones Zootécnicas, Centro Nacional de Investigaciones Agropecuarias (CENIAP). In the first experiment, 12 hybrid pigs, averaging 30 kg liveweight housed in individual metabolism cages, were assigned at random to either of three treatments: T1: control diet (corn and soybean); T2: substitution of the control diet by 10% of LFM; T3: substitution of the control diet by 20% LFM. All the diets were balanced to be isoproteic and isoenergetic to give 18% crude protein (CP) and 3800 kcal/kg (Table 1). After 10 days of adaptation to the cages and diets, total collections of faeces and urine were made daily at the same hour for six consecutive days.

Table 1. Chemical composition of the three feeds in the first experiment.

Component	Treatment		
	0% LFM	10% LFM	20% LFM
Moisture content	8.7	7.6	7.5
Crude protein	18.1	18.1	18.6
Crude fibre	1.9	4.1	6.1
Ether extract	2.1	6.8	8.8
Nitrogen free extract	74.8	65.7	60.2
Ash	4.2	5.40	6.1
Energy (kcal)	3544	3816	3931

In the second experiment, 12 hybrid pigs of 45 kg liveweight were assigned at random, 2 pigs per pen, to either of 2 treatments: T1: control diet (corn and soybean); and T2: substitution of control by 20% LFM. The experiment lasted 2 weeks, and feed

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intake, initial and final liveweight were recorded. At the end of the experiment, 2 pigs were killed and visceral organs and carcasses were investigated for pathologies in the Instituto de Investigaciones Veterinarias, CENIAP, Venezuela.

Results and Discussion

Table 2 shows the digestibility values for the different treatments in the first experiment. Highly significant differences were observed for all components except crude fibre (CF), with digestibility decreasing with increasing LFM content. The protein digestibility coefficients are similar to those reported by Guerrero and Castellanos (1984), with a decrease in digestibility as more LFM was added to the diet. Although there were no differences in fibre digestibility the diets containing LFM have a higher fibre content (Table 1) because the leaf meal used comprised the rachises as well as the pinnae. It is of some concern that the digestibility of energy greatly decreased with increased LFM content, leading to considerably less digestible energy in the LFM rations.

Table 2. Apparent digestibility coefficients (%) of chemical components of the three feeds. Within a row, means followed by different letters are significantly different (P<0.01).

Component	Treatment		
	0% LFM	10% LFM	20% LFM
Dry matter	96.4a	91.5a	80.2b
Crude protein	87.3a	77.6b	69.8c
Crude fibre	53.2	51.1	50.6
Ether extract	68.0a	65.3a	59.1b
Nitrogen free extract	96.1a	81.8b	68.3c
Energy	90.3a	63.0b	40.0c

In the second experiment, there was no significant difference in feed consumption either in per head (2.2 kg for 0% LFM, 2.1 kg for 20% LFM) or per pen (61.6 kg and 58.8 kg respectively). These values are similar to those reported by Rodriguez (1989) who observed consumption in fattening pigs of between 2.13 and 2.78 kg/day for diets which included LFM at levels of 20% and 5% respectively.

The average daily weight gains (795g for 0% LFM and 780g for 20% LFM) did not differ significantly. These figures are higher than those reported by Rodriguez (1989) for similar diets, and also higher than the results of Salas and Castellanos (1986) feeding 10% LFM.

Feed efficiency was the same for both treatments (0.36 and 0.37). These values are considered normal for this growing period (NAP 1988), but are higher than those implied by Rodriguez (1989).

There was no pathological damage to the visceral organs or carcasses of the pigs. However, the feeding period was only short and may not have been long enough to affect the animals physically. More research is needed over a longer time. As a positive sign, it was indicated that there was smaller fat content and more muscular mass from those pigs fed with 20% of LFM than the control (Rodriguez 1989).

Conclusions and Recommendations.

The values obtained in the first experiment indicate that to reach the nutritional requirements of the pig with these diets, a bigger food consumption will need to be stimulated possibly through low cost flavour enhancement or higher balanced protein and energy content. It is therefore important to examine the costs of various rations, in particular, the decrease in costs when higher proportions of LFM are included. It is also important to examine the use of very fine sieves so that only the less-fibrous pinnae are included in the diet, thus increasing the digestibility.

The second experiment suggests that LFM could be considered as an alternative resource to feed pigs, with daily weight gains and feed efficiencies similar to those obtained when feeding corn-soybean, and without risk to the animals' health. However, it is important to carry out experiments where LFM is provided at all stages of the animal's growth, possibly including higher proportions of LFM in the diet to obtain a more comprehensive understanding.

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The Effect of *Leucaena* Leaf Meal on Egg Quality and Growth of Broiler Chickens

Tu Quang Hien[1] and Nguyen Duc Hung

Abstract

The effect of leucaena leaf meal (LLM) on egg quality and chicken growth was studied by supplementing the mixed diet with LLM. Adding 4% of LLM into the diet of laying hens increased egg weight and quality and reduced the cost of chick production. Supplementing the ration of broiler chickens with LLM increased live weight gain and decreased the cost of production. It appears that 4% LLM could be close to the optimum level of LLM supplementation as there was some indication that higher levels were not as effective.

LEAF meal of legumes has often been used as a component of mixed feed fed to layer and broiler chickens. The quality of leucaena leaf is generally similar to that of other legume species, with good levels of protein and vitamins. Two experiments were conducted to assess the effect of feeding leucaena leaf meal (LLM) on egg quality and growth of broiler chickens.

Experiment 1

To identify the effect of LLM on egg quality
Three diets were compared: Control (mixed feed), mixed feed + 4% LLM in diet, and mixed feed + 6% LLM in diet. All diets were the same in terms of metabolisable energy (ME) (2837 Kcal/kg) and crude protein (19.4%). Each diet was fed to 50 laying chickens (breed HV35), with three replications (total 450 birds). Six hundred eggs were selected from each group for incubation, and assessment of embryos, hatching and chick quality. The results are shown in Table 1.

Chickens fed with LLM produced bigger eggs with a higher proportion of yolk than the control. Eggs from those fed 4% LLM were bigger but had a smaller proportion of yolk, than from those fed 6% LLM.

Diets containing LLM produced a higher proportion of eggs containing embryos than the control diet. The percentage of eggs hatching and the class I chicks were also higher. There was no difference between the two LLM diets.

Table 1. The effect of leucaena leaf meal (LLM) on egg quality and feed cost in laying chickens.

Variable	Diet		
	Control	4% LLM	6% LLM
Egg weight (g)	56.7	58.2	57.5
Yolk %	31.1	32.3	33.9
Incubated eggs with embryos (%)	89.2	91.5	93.3
Incubated eggs that hatched (%)	70.5	78.0	78.2
Class I chickens/total incubated eggs (%)	69.2	77.7	77.8
Feed cost/10 eggs (VND)	14208	12526	12516
Feed cost/class I chicken (VND)	2054	1613	1608

Thus the use of leucaena leaf meal has a good effect on egg production and quality. Feeding 4% LLM should result in a higher proportion of Class I chicks for sale.

If feeding LLM is to be practical, it must be economically efficient. A financial analysis of the feed cost to produce 10 eggs and one chicken is shown in Table 1. The cost of egg production was reduced by 12%, and as the proportions of hatching and class I chicks produced by layers fed LLM were higher than the control, the feed cost to produce one chicken reduced by 22%.

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Experiment 2

To identify the effect of LLM on the growth rate of broiler chickens

Again, three diets were compared: control (mixed feed), mixed feed + 3% LLM for the first 28 days and 5% thereafter, and mixed feed + 4% LLM for the first 28 days and 6% thereafter. All three diets were the same in terms of ME and CP: for the first 28 days, 3074 Kcal/kg and 23.6% CP, thereafter 3158 Kcal/kg and 21.4% CP.

The three diets were each fed to 100 broilers (breed HV35), replicated 3 times (total 900 birds). Liveweight gain was measured after 56 days, and the results are shown in Table 2.

The liveweight of chickens at 56 days was higher for those fed LLM than for the control group, but the lower proportion of LLM produced the greater gain. The feed efficiency of the group fed LLM was higher than that of the control group, leading to a reduction in production cost of 7% for the 3% and 4% LLM diet and 5% for the 4% and 6% LLM diet.

Conclusions

A mixture 4% of LLM into the diet of laying hens increased egg weight and quality and reduced the cost of chicken production. Supplementing the ration of broiler chickens with LLM produced increased LWG and decreased the cost of production. It appears that 4% LLM could be close to the optimum level of LLM supplementation as there was some indication that higher levels were not as effective.

Table 2. The effect of leucaena leaf meal (LLM) on live weight gain, feed use efficiency and cost of production in broiler chickens.

Variable	Diet		
	Control	3% and 5% LLM	4% and 6% LLM
Liveweight gain 56 days (g)	2062	2242	2122
Consumed feed/chicken (kg)	4.93	5.04	4.92
Feed intake (kg/kg gain)	2.39	2.25	2.31
Energy efficiency: Kcal/kg LWG	7,488	6,932	7140
Protein efficiency: g LWG/g protein	1.62	1.72	1.67
Feed cost/chicken (VND)	18720	18910	18350
Cost/kg LWG (VND)	9078	8434	8647

The Effect of Supplementing the Diet of Broiler Chickens with *Leucaena* Leaf Meal and $FeSO_4$

Tu Quang Hien[1] and Nguyen Thi Inh[2]

Abstract

Chickens fed 3% leucaena leaf meal (LLM) for 28 days and 4% from days 28 to 56 had higher weight gains, better feed intake efficiency and lower costs per kg LWG than control birds. Using a higher rate of LLM (5 and 6%) without $FeSO_4$ supplementation reduced LWG and decreased feed intake efficiency. Supplementation with $FeSO_4$ restored the LWG and feed intake efficiency to levels similar to those attained with the lower intake of LLM.

LEAF meal made from leucaena (*Leucaena leucocephala*) (LLM) is rich in proteins and vitamins and is often used as a component of mixed feeds for various forms of animal production. However, this material contains mimosine, a toxic amino acid which can have a detrimental effect on animal health, particularly in non-ruminants.

One way to negate the effect of mimosine is to supplement the ration with $FeSO_4$. This paper reports the results of an experiment where the diet of broiler chickens was supplemented with LLM and $FeSO_4$.

Materials and Methods

Four diets were compared. They were identical in terms of metabolisable energy and protein.

For the first 28 days:

Group 1: (control) — basal feeding only (BS I).
Group 2: 97% of BS I + 3% LLM.
Group 3: 95% BS I + 5% LLM.
Group 4: 95% BS I + 5% LLM + $FeSO_4$.

BS I contained 3100 Kcal ME/kg and 23% protein.

For days 29–56:

Group 1: (control) — basal feeding only (BS II).
Group 2: 96% of BS II + 4% LLM.
Group 3: 94% of BS II + 6% LLM
Group 4: 94% of BS II + 6% LLM + $FeSO_4$.

BS II contained 3200 Kcal ME/kg and 21% protein.

Each diet was fed to a group of 60 broiler chickens (breed BE88), with three replications. Over a 56-day period, the following observations/calculations were made:

- Health of the chickens.
- Liveweight gain (LWG)on a weekly basis.
- Feed consumption/chicken and feed intake/kg LWG.
- Economic efficiency: cost of feed/chicken and cost of feed/kg LWG.

Results

Health of the chickens

In all groups the health situation was good. There were no differences in death rates between the groups.

The LWG, feed intake and economic data are summarised in Table 1.

Liveweight gain

From the third week, the weight of chickens in Group 3 (fed 5% LLM) was lower than the weights of the chickens in the other three groups, suggesting a negative effect of the LLM.

After 8 weeks, Groups 2 and 4 were significantly different from Groups 1 and 3, having higher LWG. This indicates that supplementation with lower levels of LLM, or higher levels of LLM plus $FeSO_4$, is effective in increasing weight gain in chickens.

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Table 1. Liveweight gain (LWG), feed efficiency and economic efficiency when supplementing the diet of broiler chickens with leucaena leaf meal (LLM) and $FeSO_4$.

Variable	Diet			
	Group 1 Control	Group 2 3% and 4% LLM	Group 3 5% and 6% LLM	Group 4 5% and 6% LLM + $FeSO_4$
Chicken liveweight at 4 weeks (g)	918	927	852	930
Chicken liveweight at 8 weeks (g)	2299	2442	2242	2450
28-day feed consumption/chicken (g)	1516	1523	1500	1526
56-day feed consumption/chicken (g)	5474	5475	5393	5378
Feed intake/kg LWG (kg)	2.38	2.24	2.40	2.20
ME intake/kg LWG (Kcal)	7553	7112	7630	6962
LWG/protein intake	1.93	2.07	1.96	2.15
Food cost/chick (VND)	21886	21900	21930	21514
Food cost/kg LWG (VND)	9520	8968	9781	8781

Feed conversion efficiency
Up to 28 days, feed consumption was similar in all treatments. However, from 28 to 56 days the chickens from Groups 1 and 3 ate more feed than the others, to the extent of between 50 to 100 g/chicken. Groups 2 and 4 had lower intake/kg LWG and are therefore considered to be more efficient in feed conversion.

Energy and protein use efficiency
Again, Groups 2 and 4 (fed either smaller amount of LLM or larger amounts of LLM and $FeSO_4$) were more efficient in using both energy and protein, by about 8%, compared to Group 1 (control) and Group 3 (high LLM).

Cost of production
The total cost of food was similar for Groups 1, 2 and 3, but about 2% cheaper for Group 4. Based on the cost of producing 1 kg LWG, group 3 cost 103% of the control, group 2 cost 94% and group 4 cost 92%.

Conclusion

Chickens fed 3% LLM for 28 days and 4% from days 28 to 56 had higher weight gains, better feed intake efficiency and lower costs per kg LWG than control birds. There is no need to use $FeSO_4$ to reduce mimosine toxicity at this level of feeding.

Using a higher rate of LLM (5% and 6%) without $FeSO_4$ supplementation reduced LWG and decreased feed intake efficiency. Supplementation with $FeSO_4$ restored the LWG and feed intake efficiency to levels similar to those attained with the lower intake of LLM.

Farming Systems

Presented Papers

Leucaena in Smallholder Farming Systems in Asia: Challenges for Development

F.A. Moog[1], P. Bezkorowajnyj and I.M. Nitis

Abstract

The current use and scope for development of leucaena in smallholder farming systems in Asia are described and socio-economic constraints and challenges discussed. Psyllid infestation halted development activities in the region but renewed interest in the species is slowly increasing. The promotion of leucaena in the holistic context of farming systems should identify socio-economic constraints of farmers, and lead to discovery of practical and working alternatives that can be implemented by farmers themselves.

SMALLHOLDER crop and livestock production is a common feature of Southeast Asian agriculture. Farming families, either cultivating food crops or engaged in plantation crops, keep one or several species of animals (both ruminants and non-ruminants) which are integral parts of their farming systems. Land holdings in the region are small. Most farm families cultivate less than 1 ha and only a small proportion owns more than 3 ha. In Bali, Indonesia, 98% of farmers own areas of only 0.11–0.46 ha. In upland farms in Batangas (Philippines), farmers operate small parcels of land cultivating an area of less than 2 ha while 76% of farmers raising buffalo in rice-growing areas have 3 ha or less and only 24% have more than 3 ha (Alviar 1987). In Thailand, farming families cultivate less than 1 ha and only a small proportion owns more than 2 ha.

Livestock are an important component of the production system for many reasons. Draught animals, generally cattle and buffalo, and use of crop residues, weeds and cultivated fodder for supplementary feeding, are common features of the system.

Leucaena or Ipil-ipil *Leucaena leucocephala* (Lam.) de Wit has been the most popular fodder tree species in the region because of its multiple uses. It is generally used as a source of fodder and fuelwood. In the Philippines, it is used for poles, leaf meal and as living fences. Other Asian countries like Thailand, India, Sri Lanka and Vietnam use it in soil erosion control, alley crops and green manure, and the young shoots as a vegetable. In East Java (Indonesia), it is an important component of the 'taungya' silvicultural system for establishing teak plantations.

Leucaena's popularity was at its peak in the 1970s and early 1980s. No other tree legumes had been given as much attention as leucaena. However, with the psyllid infestations in the mid-1980s, most of the plantations were damaged and its popularity waned. This paper presents a brief review of current use and development perspectives for leucaena, based on the authors' observations and experiences and selected case studies in the region.

Current Use of Leucaena

In general, the multiple uses of leucaena in Southeast Asia remain. There has been a significant reduction in psyllid infestation but the use of leucaena has not been as intensive as in the 1970s. Throughout the region, thickets of leucaena plantations can be observed. These standing plantations, which seem unutilised, are occasionally harvested for timber and fuelwood, and stabilise the soil in hilly and mountainous areas.

In densely populated areas of Luzon, Philippines, where swine and poultry are concentrated, fresh leucaena leaves are harvested for feeding pigs in the villages. In upland farms and rainfed rice-growing

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areas, it is grown to establish land ownership boundaries and trees are harvested for poles and fuelwood. While intensive cattle fattening in Batangas province has significantly reduced due to industrialisation, leucaena remains a significant part of the cattle ration in upland and coastal villages of the province. In commercial feedlots, operators are buying fresh and dried leaves of leucaena from villagers. Some feed mills have resumed buying dried Ipil-ipil leaves for leaf meal and for incorporation in commercial poultry and swine feeds. Feed production reports in the Animal Feed Standard Division of the Bureau of Animal Industry showed that one of the feed mills in Cebu produced 232 and 180 tons in 1996 and 1997, respectively. However, a feed mill in San Carlos City, Negros Oriental, ceased operation in February 1997, because its buyers reduced or stopped incorporating leucaena in their feed formulations due to availability of cheaper substitutes.

In Indonesia, leucaena is commonly used for forage and fuelwood but has been planted for various distinctive roles in different provinces. In Timur and Flores, it is planted to stabilise eroded hill slopes and in Sulawesi, Sumatra and Nusa Tenggara Timur it is a common shade tree species in coffee and cocoa plantations (Toruan-Mathius et al. 1994).

In Vietnam, leucaena is extensively used as an intercrop with coffee, pepper, and oranges and when leaves of leucaena are used as a green manure and mulch, coffee bears fruit earlier and with higher yields (Khoa and Ha 1994). It is also a good source of village wood. Growing, harvesting and processing of leucaena employs women, youths and children. Planting and management of leucaena in Vietnam is a concerted effort of both the government and village communities.

In Thailand, leucaena is mainly used as source of leaf meal for poultry to colour egg yolks and broiler skins, and as living fences (Sampet et al. 1994). It is also grown for wood, soil erosion control, soil improvement on steep lands and other uses like turnery and parquet flooring.

In Laos, leucaena is commonly grown in home gardens with young shoots and seeds used as a vegetable by the villagers. Leucaena was extensively used in the Forest Development and the Watershed Management Project in the northern provinces in agroforestry (FAO 1991).

In Myanmar, leucaena is grown in the dry zone, particularly in Magway, mainly as a windbreak.

Leucaena was introduced to India in the 1950s to be used as a green manure and for soil reclamation, but it was not until the 1970s that the Indian Council of Agricultural Research (ICAR) promoted leucaena as a high quality fodder and fuelwood. In addition, social forestry programs began to encourage farmers to grow leucaena as a substitute to eucalyptus as a small timber, and later as a source of pulp for the paper industry (Hegde and Gupta 1994). Today it is found throughout India, and after a few set-backs including the psyllid (*Heteropsylla cubana*) infestation of the 1980s, is still used as a source of fodder, fuelwood and small timber.

A more detailed account of the use of leucaena in specific locations of the Philippines, Indonesia and India is outlined in Table 1.

Challenges and Constraints

There are two broad challenges facing leucaena development for smallholders in Asia: (1) the technical issues; and (2) the socio-economic issues. Both broad issues are important to consider but the focus of this paper is on the socio-economic issues.

Production challenges

The technical or production issues are covered in detail by other authors in these Proceedings. Psyllid infestation has been significantly reduced, yet most farmers still find that leucaena does not produce the biomass that it used to. Due to the psyllid, farmers reduced the number of animals raised or stopped raising cattle (Moog and Sison 1986)

Leucaena does not thrive in acidic soils and in regions subject to frosts.

Socio-economic challenges

Farmers' perception

In the Philippines, recent interviews with 71 coconut farmers in Quezon province indicated that both crops and livestock are important in their farming systems; crops provide a steady income throughout the year and livestock provide the 'bonus' income which comes in bulk when they sell animals. While 49 (69%) of the farmers interviewed have leucaena in their home gardens or farm lots, only 22 feed leucaena to their animals. They claimed to have enough feed and if shortages occur during the dry season, they use banana stems and coconut fronds or travel several kilometres to gather grasses and other tree leaves. Although those farmers consider livestock valuable in the farming system and even though a number of them claimed they knew from their parents or experiences that leucaena was a good feed, they are still passive about its use.

A participatory 3-year research project on fodder and fuelwood improvement conducted in the highly degraded tribal areas of southern Rajasthan where fodder and fuelwood are particularly scarce gave interesting results (Bezkorowajnyj 1998). The people in these remote villages had no previous experience with leucaena and participated in testing several

Table 1. Use of existing leucaena plantations in selected Asian countries.

Leucaena plantation	Country		
	Philippines	Indonesia	India
Home gardens	Leucaena is generally found in most homelots as fencing and support to trellises for viny vegetables. In Batangas, it is a valuable cut-and-carry fodder in smallholder farms.	As fencing around homelots only, other space devoted for vegetables and medicinal plants.	As hedges along boundaries and in backyards.
Hilly to mountainous areas	In Cebu, Leyte and Negros islands, leaves are harvested and sold by villagers to feedmillers and processed into leaf meals. In other areas, leucaena is harvested for fuelwood.	As guard row and cluster in sloping land not used for crop production.	
Roadsides/communal areas	In Masbate and General Santos City, harvested dried leaves are sold to feedlot operators as supplement to fattening animals. In most areas, leucaena is occasionally cut for fuelwood.	As fences to separate farm areas along roadsides and as cluster in communal grazing areas.	In the plains of Assam and along the irrigation canals of Rajasthan.
Upland and rainfed areas	To establish boundaries of landownership. In Tarlac and other provinces of Luzon and Visayas islands, leucaena is cut in summer months of February to May for fuelwood	As fences, guard rows and cluster for fodder and fuelwood in Kuta, Bali. For shade, soil protection, green manure and fodder in Petang, Bali.	Grown in conjunction with soil and water conservation measures for fodder and fuelwood productions.
In plantation crops	In coconut growing areas in Southern Luzon and Mindanao, leucaena is sparsely planted and used as living fences and as poles. Leaves are harvested as green feed.	As trellise for vanilla and pepper; as shade for coffee and clove; and, as intercrop with coconut. As fence-boundary in small plantations.	Use for fodder, fuelwood and pulpwood in South India and Andra Pradesh.
In alley cropping	Leucaena is one of the species used along with corn and other upland crops in Mindanao.	As alley crop for fodder and green manure in semi-intensive dryland farming in Amarasi, Flores.	
Forestry/fuelwood lots		As alley crop in taungya system; as shade in young forest; and, source of fuelwood.	

newly introduced species. Farmer group discussions (FGDs) conducted during the 3-year project revealed that farmers were very impressed by both the palatability of the leafy matter, and the rate of biomass regeneration, particularly after livestock had entered and browsed some of the patch plantations within the villages.

During the third year of the project, household interviews (H) were conducted to determine the quality of leucaena wood as a fuel for food preparation. Several opinions were expressed by household members, especially the women who are responsible for the gathering of fuelwood and cooking meals.

Results of the interviews showed that most of the household members believed that the wood burned longer than most other species presently used for cooking, resulting in the need for less fuelwood to cook the same amount of food. Other typical responses indicated that the wood was perceived as: producing a good taste to the food; producing less smoke and ash; and, burning in a similar manner to or better than teak wood.

While there were good qualities attributed to leucaena, the question of whether the farmers will continue to manage the newly introduced leucaena species still remains. Browsing by livestock in this area is one of the major problems associated with establishing leucaena and other trees which do not carry immediate cash value. Unlike seasonal crops, planting trees requires in most instances the introduction of a new practice — tree planting. The trees must be protected and managed not only during the monsoon, but also during winter and summer seasons when fodder is in short supply, which coincides with villagers migration to areas outside of the village to seek employment.

In order to promote utilisation of trees such as leucaena in these areas, ways to encourage people to stay in their villages, and to protect both private and common property resource areas that can be managed for fodder and fuelwood should be developed.

Time constraints

Limited time is generally available for other activities in rice growing areas during land preparation, planting and weeding as well as harvesting of the rice crop.

Access to credit and markets

Lack of capital and incentive to produce quality meat among farmers in remote or island towns and villages prohibit intensive livestock production. In Batangas province (Philippines), fattening of cattle with cut-and-carry leucaena became popular because local banks are extending loans to farmers for the purchase of stock. In addition, these towns have or are close to towns with regular weekly livestock markets where they could sell finished cattle (at a better price than other provinces) either to butchers or merchants catering to metropolitan Manila markets. These livestock markets also served as a source of feeder stocks to these farmers. Farmers close to the livestock markets bring their animals to and from the markets by driving them on-the-hoof. Commonly, farmers sell their animals after a 2 to 3-month fattening period.

Land conversion

Conversion of lands from agriculture to urban centres and for industrialisation are the main threats to existing leucaena plantations and other land uses. An example is the CALABARZON area, a classified industrial zone south of Manila where smallholder intensive cattle production using leucaena was common, but is now on the verge of extinction. Investors had raised the value of the land, offering farmers good prices for commercial or residential use, which the latter could not refuse.

Land tenure

In the Philippines, most of the areas where leucaena leaves are harvested are not owned by the gatherers themselves. These belong either to absentee property owners who have other businesses and the land effectively becomes communal, or to people who run a cattle fattening business and allow the harvesting of leucaena from their properties and then buy it. The roadsides are common areas to which everybody has access, unless owners of adjacent lands put stakes in them. Some areas are either forests or public lands which have become communal. In these cases, there are no incentives for those people, generally children and women who gather the leaves, to improve productivity of or to expand the plantations.

In Indonesia, Laos and Myanmar, free or communal grazing areas are extensive and common. Herds of cattle or buffalo with one or more owners are grazed freely on these areas without restriction. This means nobody cares about the improvement of grazing. Scope for leucaena in communal grazing is very limited unless farmers are organised and develop among themselves a controlled system of utilisation.

Scarcity of land

Scarcity of land is a threat to leucaena plantings in Southeast Asia because of its expanding human population which grows at the rate 2% to 3% annually. This increases the population density in a given area limiting the area for cultivation. This is particularly true in East Java, Indonesia, where landholding is down to less than 0.5 ha per family. Another case is one village in Batangas, Philippines, where the number of households has doubled in seven years. Years before, one family could survive on a single crop of upland rice, but now, both rice cultivation and draught cattle are gone (leucaena is gone too) and to be able to survive most farmers shifted to more intensive swine and poultry production that relies on imported commercial feeds. The situation differs in Laos, one of the least densely populated countries in the region with 4.1 million people and a land area of 23.7 million ha.

Under-utilised and un-utilised plantations

In some areas, leucaena plantations remain unutilised or under-utilised. Landowners prohibit gathering of herbage and fuelwood. These plantations, however, are generally found in hilly areas and road cliffs and thus serve as an excellent soil stabiliser.

Under-utilisation occurs in areas of low concentrations of people and livestock. There are cases where there is feed but a lack of animals to utilise it. This is not true in Bali, Indonesia, where the leaves of practically all trees (including leucaena) and shrubs are harvested as fodder.

Other species becoming more important

There is increasing popularity of other legume and tree species for fodder or timber. For example, *Sesbania grandiflora, Acacia leucophloa* and *Corypha utan* are good sources of fodder (Thajar and Mahyuddin 1993). The Sloping Agricultural Land Technology (SALT) of the Mindanao Baptist Rural Life Centre (MBRLC) in southern Philippines is not only promoting the use of leucaena but also the use of other species like *Leucaena diversifolia, Calliandra calothyrsus, Gliricidia sepium*, *Flemingia macrophylla* and *Desmodium rensonii* in combinations found suitable in respective farms (Laquihon and Pagbilao 1994).

In Bali, Indonesia, leucaena is replaced by *G. sepium* and *C. calothyrsus*, the latter in higher altitude situations because farmers are still afraid of the psyllid returning.

Cattle prefer leucaena over other species but sheep and goats have no particular preference for leucaena. Both sheep and goats feed on a wider range of tree species than cattle and buffalo.

Availability of cheaper substitutes (particularly imported varieties) to leucaena leaf meal is also a threat to the leaf meal industry that employs the rural villagers.

Extension methodologies

Despite all the advances that have already been made with leucaena, adoption is still very low. A big part of the problem has been the way researchers worked with farmers in the past. Leucaena was offered as a miracle species and planted everywhere. As a result, there were many failures. People remember a failure much longer than they remember successes. For example, a large (3 MGW) dendrothermal plant in Pangasinan province was installed, based on a 100 ha leucaena plantation maintained by a farmers association. The management found it difficult to run the plant because they ran out of wood supplies, because the farmers did not sell the leucaena wood to the plant. Farmers earned more income by selling charcoal from leucaena and there were also difficulties in synchronising harvest and transport with the capacity of the plant. Finally, when the plant did not pay the farmers, it stopped operation, and the farmers took everything they could sell from the plant. Some sectors thought that they may have succeeded had they opted for several smaller plants (10 KW). If the managers had involved farmers in the management, the project could have been a success.

The challenge facing development of leucaena in Southeast Asia in the future is changing the way researchers work with farmers. First, researchers should know the farmers well, understand their culture, needs, interests and resources and how to deal with them. These things are often unconsciously ignored. Dealing with farmers is an art, and open-ended. It cannot be taught and in general is not the domain of biological scientists.

Scope and Potential of Leucaena in the Region

In spite of the above constraints, which vary in magnitude in different countries of Southeast Asia, there is still a scope for leucaena in the region. Based on current use, leucaena still serves various roles in different farming systems. Further development of leucaena will depend on how it will provide direct economic benefits to farmers, i.e., employment, income and material needs for poles, timber and fuelwood for the immediate household needs in their respective areas.

Table 2 shows the scope for development of leucaena in different production systems. Leucaena would have very limited scope in intensive rice cultivation areas. Leucaena will play a major role in upland regions and rainfed crop production areas, but where land conversion to urban centres and industries is occurring, land use zoning should define specific long-term agriculture land use.

In general, smallholders consider livestock to be as important as their crops. This is a very important point to consider because this means that improvement of animal nutrition is a major concern of the farmers within the production system. This is the main reason why farmers integrate fodder trees like leucaena in their home gardens, lot boundaries and as an alley crop: A good example of this is the case in a Philippine village, which is outlined in the Appendix.

Intensive poultry and swine production propels the feed milling industry. Feed mills will remain an important market for leucaena leaves for leaf meal production.

According to FAO (1989), nearly three-quarters of the population of developing countries use wood as a fuel and more than 1000 million people in these developing countries are short of fuelwood. Therefore, it is not only the need for or scarcity of fodder but also that of fuelwood, which will provide better scope for leucaena, as in the case of Rajasthan, India, described above.

The fuel crisis alone will certainly need aggressive reforestation programs not only to provide fuelwood for energy needs but also to prevent more lands being cleared for agriculture due to expanding populations.

Though psyllid infestation has halted the development activities of leucaena for fodder, agroforestry and soil improvement, the identification and development of new hybrids and cultivars not only resistant to pests but also adapted to the infertile and acidic soil of the uplands, coupled with intensive promotional campaigns involving farmers, will renew interest in leucaena.

Table 2. Scope for development of leucaena in different production systems.

Area (District/Region/Province)	Reasons for adoption of leucaena	Constraints	Scope/strategies for development
Lowland regions where leucaena is used for ruminant production			
a. Pampanga, Philippines	Used as supplement to rice straw and source of fuelwood in the dry season	Intensive rice cultivation. Space limited.	Limited
b. Indonesia	Used as supplement to grass grown in the bunds of ricefields.	No space to grow leucaena	Fence boundary in bunds of rice field.
c. Gujarat, India	Supplement to cattle for production	Open grazing	Stall feeding
Upland regions where leucaena is used for ruminant production			
a. Batangas, Philippines	Accessible market and good price for finished beef.	Land conversion from agriculture to urban and industrial centers.	Land use zoning which defines specific long-term land use.
b. Petang, Bali, Indonesia	Good for shade, green manure and fodder.	Slow growth due to cool weather.	Agrisilvicultural system
Regions with no history of utilisation but promotion being done.			
a. Tarlac, Philippines (rainfed rice, sugarcane and vegetables)	On-farm trial set-up and credit in kind (sheep) extended to farmers. Higher LWG is obtained and cash income earned by farmers.	Farmers time and grazing areas limited during cropping season	Planting more leucaena in home gardens, alleys and roadsides.
b. Banswara District, Rajasthan, India	Introduction of farmer participatory experiments to address the need for fodder and fuelwood	Primary constraint if open grazing of livestock; secondary, is long periods of drought.	Participatory land use planning and management
Leucaena in alley cropping systems			
a. Mindanao, Southern Philippines	Promotional seminars and field trips on Sloping Agric. Land Technology (SALT) conducted by Mindanao Baptist Rural Life Centre	Farmer acceptance relatively poor. Requires higher initial labor inputs.	Use of new cultivars.
b. Indonesia	Increase soil fertility and fodder supply.	Food crop being shaded.	In Three Strata Forage System (TSFS).
c. Throughout India	Promotion by NGOs	Farmers unwilling to plant trees in their fields.	Allocate non-cropping areas for planting.

Table 2. Scope for development of leucaena in different production systems (continued).

Area (District/Region/Province)	Reasons for adoption of leucaena	Constraints	Scope/strategies for development
Leucaena for fuelwood			
a. Nueva Ecija, Northern Philippines	Good intermediate crop to timber species.	Accidental fire in the dry season	Limited
b. Indonesia	Leaves also available for fodder.	Fresh fodder available only during lopping	In TSFS
Special cases			Development of drying
a. Leaf meal (Masbate and General Santos City; Cebu and Negros Islands, Philippines)	Feedlot operators and feedmills buying dried leucaena leaves. Employs women and children.	Harvesting and drying limited only during dry season. Cheaper substitutes may be available.	facilities for wet season harvest to improve efficiency of production. Regulate importation of feed ingredients.
b. Support for vanilla and black pepper (Bali, Indonesia)	Vanilla and pepper have commercial value and leucaena leaves aveailable as fodder.	Limited land.	In TSFS.
Banswara District, Rajast, India	Using manure as a fuel source due to lack of fuelwood.	Availablity of protected areas for fuelwood production	Land use management

Conclusion and Recommendations

The promotion of leucaena in Southeast Asia should be viewed in the context of a holistic farming systems approach with concern for people rather than trees. This has been translated into a motto 'Look after the people, and the trees will look after themselves' by one of FAO's community forestry programs. During more than 10 years of community forestry, it has been established that many of the most successful projects are those which aim specifically to increase income and employment.

In theory, there are many alternatives like those outlined in Table 2. The goal is to achieve an integrated scheme in which farmers receive profits. However, it should be pointed out that the emergence and adoption of development alternatives is generally slow, so this perspective for leucaena will not be an exception.

The first priority is to identify the economic, social and institutional constraints of the farmers. The next step is to devise practical, working alternatives which can be implemented with government aid by the farmers themselves.

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APPENDIX

Leucaena: a case in Malimatoc village, Mabini, Batangas (Upland/hilly area near the sea)

Raising of cattle is the primary enterprise in this village which depended principally on leucaena as feed before the psyllid infestation in 1985. A survey showed that following the infestation, the number of animals raised by farmers was reduced to 50% and some farmers stopped raising cattle (Moog and Sison 1986). According to the Municipal Agriculture Office of Mabini, 100 ha was planted to leucaena before the infestation. This brought loss of income to farmers and compelled their family members to seek employment abroad. Land ownership in the village range from 0.5–2 ha with most villagers having less than 1 ha.

At present, the farmers are still interested and keen on leucaena. Very few trees have survived the infestation; however some farmers have started replanting. One to 2-year-old leucaena can be seen in the village despite the infestation that is present. Leucaena is intercropped with corn, cassava or vegetables. How do they manage leucaena with the infestation? Farmers have planted napier grass to provide the bulk of the feed particularly in the dry season. Napier was not planted before the infestation. In general, they harvest leucaena only twice a year, in May and August, the start and the peak of the rainy season, respectively. They seldom harvest in the dry season and if they do, they make sure the pest is not present or the plants are bearing pods, otherwise if they cut with psyllids present, the regrowth is immediately attacked and the plants eventually die. In addition, when they harvest infested leucaena, the mature psyllids swarm on their faces which makes harvesting uncomfortable and the sticky shoots are disliked by cattle. When leucaena is not available, the farmers feed their cattle with coconut fronds, banana stems and leaves, and other tree leaves. The other immediate solution is to reduce the number of animals they raise in the dry season. Examples are given below:

Name of farmer	Number of cattle raised	
	Rainy season	Dry season
Nicolas Visco	4	2
Silvino Reyes	3	1
Galicano Bantogon	4	2
Reming Castillo	5	3
Pabling Hulgado	7	6 goats
Mariano Maniebo	4	2
Pedro Adao	7	2

Farmers in the village claim that leucaena is still the best feed for fattening cattle and though they have planted napier, it is only to prevent their animals from getting hungry. Farmers are keen on having a solution to the psyllid problem. The immediate solution thought of by farmers was spraying, which would not help if carried out only locally because the pest can easily transfer from adjacent areas. However, they were told that a new resistant variety or species might soon be available.

These farmers clearly indicated that there was still scope for leucaena. This was, however, not so in other villages where there is no preference for leucaena.

Leucaena in Smallholder Farming Systems in Africa: Challenges for Development

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Abstract

The use of *Leucaena* species in African smallholder farming systems is reviewed. A wide range of *Leucaena leucocephala* cultivars from a wide range of seed sources have been in use, principally for soil fertility amelioration, fuelwood and fodder. With the recent invasion of the leucaena psyllid, lesser-known *Leucaena* species and provenances are currently being evaluated in diverse eco-regions for adaptation and possible integration into African farming systems.

THE USE of tree/shrub species to offset the shortage of quality feeds for ruminants during the dry seasons is widespread in Africa. As the dry season advances, the native-grass pastures succumb to water deficit, leading to low availability and quality of forages. This problem is aggravated in areas prone to periodic droughts.

Leucaena leucocephala (Lam.) de Wit (leucaena) has been used widely not only for fodder but also for provision of fuelwood in areas where deforestation of natural woodlands is severe. *L. leucocephala* has also been used widely in soil amelioration work in humid and sub-humid areas with some success. However, in semi-arid regions, its effect on crop yields has been negatively correlated with the amount of precipitation received.

In Africa, the term agroforestry is often synonymous with *L. leucocephala*-growing, because of its widespread use in alley-cropping and alley-farming in the humid tropics of West Africa (Kang et al. 1981). In agroforestry systems, *L. leucocephala* plantings offer considerable potential where there is pressure to find forms of land use which address production and environmental concerns (Rabbinge et al. 1994). However, because of a heavy reliance on one or two cultivars with a narrow genetic base, the psyllid insect (*Heteropsylla cubana* Crawford) has had a devastating effect on *L. leucocephala* in some areas (Bray and Sands 1987). The rapid spread of the leucaena psyllid in the mid-1980s from tropical America to Asia, Australia and finally to the African continent during the 1992–1994 period has restricted the use of this important and versatile leguminous tree (Geiger et al. 1995).

Prompted by experience with the leucaena psyllid, a number of institutions in Africa have participated in the search for alternative species, both within the *Leucaena* genus and outside it. The primary objective for alternatives has been to assemble a comprehensive collection of *Leucaena* lines, representing available biodiversity in the genus, to assess their adaptation to different African environments.

This paper reviews published information about *Leucaena* in African farming systems, and important technical, social and economic factors that restrict or promote the adoption of *Leucaena*, as well as programs that should be in place to promote its increased use.

The Farming Systems of sub-Saharan Africa

The farming systems found in sub-Saharan Africa are determined by the agro-climatic zonings described by Jahnke (1982) and listed in Table 1.

Humid zone

In the humid zone found along the coast of West and Central Africa and in the central Congo basin, farmers are mostly smallholders because of high land

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Table 1. Agro-climatic classification of sub-Saharan Africa.

Zone	Area ('000' km^2)	Growing period (days)	Rainfall range (mm)
Arid	7673	0–90	<500
Semi-arid	3915	90–180	500–1000
Sub-humid	4834	180–270	1000–1500
Humid	4137	270–365	>1500
Highlands	934	Usually >180	1000–2000

productivity. Large variability exists in the population density, with as few as 10 persons per square kilometre found in the Congo, Gabon and Zaire, whereas the density exceeds 500 persons/km^2 in Eastern Nigeria.

The population density influences the options taken by farmers to maintain soil fertility. Shifting cultivation is practised where population density is low. Where population density is high, non-crop vegetation and crop residues are used as soil mulch. In this zone, livestock production is restricted by the prevalence of diseases, especially *Trypanosomiasis*. However, for the few trypano-tolerant livestock that are there, feed consists of natural vegetation, which tends to be abundant but of poor nutritive quality. It must be appreciated that non-availability of adequate farm power, and inability to use draught power in the humid zone (because of disease risk) are additional factors influencing people to cultivate small areas.

Sub-humid zone

The sub-humid zone extends from the centre of West Africa, through parts of East and Southern Africa. Low rainfall variability makes this zone suitable for production of a number of crops. Maize, sorghum, rice, yams, cassava, fruits, groundnuts and vegetables are examples of crops that can be grown in this zone. Farmers are again mostly smallholders. Although the livestock population is lower in this zone than in the semi-arid zone, the longer, sub-humid rainy season allows for a more sedentary production system, which is mainly agro-pastoral. Crop residues provide supplementation to natural and planted pastures.

Semi-arid zone

Smallholder farmers in semi-arid zones are in an adverse situation due to high crop production risks caused by low and erratic rainfall and the poor soil characteristics of the zone. Although the crop cultivars grown are drought-escaping, crop failure is common due to frequent severe droughts. Thus, farmers tend to spread the risk by diversifying. A mixture of crops is grown in the same plots, and livestock-keeping is widespread, with mixed herds of cattle, goats and sheep being kept. They form the most important cash generator for the smallholders and hedge against crop failure. *Trypanosomiasis* and other parasitic diseases are not as common as in the humid and sub-humid zones. However, low seasonal rainfall and inadequate feed quantity and quality, especially in the dry season, are major constraints to increased livestock productivity.

Highland zone

The highland zone is the most productive due to long growing season, but it is also the most populated. The cool climate causes much reduced evapotranspiration. The soils in the highlands of East Africa include deep vertisols and nitosols that are very productive. Crops grown are wheat, barley, maize, sorghum, beans, potatoes, as well as a number of tree and root crops. Coffee and tea are also grown. Livestock production in this zone is mostly intensive, using perennial pasture and intensively managed forages.

A peri-urban production system is also growing within the region, due to a growing demand for milk, eggs and high-value horticultural products by urban dwellers. The feed resource base for livestock production is very limited in this system and the producers depend on agro-industrial by-products from processing plants in the urban centres.

The versatility of *L. leucocephala* allows it to have a role in any one of these smallholder production systems where rainfall is above 600 mm on free draining soils (Skerman 1977). However, the greatest concern of farmers about *L. leucocephala* is its slow rate of establishment, especially from seed, and this tends to discourage farmers' interest. Further, in free ranging production systems, and especially where land is communally owned, protection of the establishing stands (by fencing) from goats is a prerequisite to successfully growing *L. leucocephala*.

Available *Leucaena* Germplasm

Before the arrival of the leucaena psyllid, accounts of *Leucaena* were mostly of *L. leucocephala,* often referred to as *L. glauca*. This was principally the result of introductions made in the 1960s of the major types, Hawaiian, El Salvador and Peru, to sub-Saharan Africa. There are, however, a range of stands of *Leucaena* types that have been naturalised along the east coast of the African continent. These stands, judging by the tree sizes, for instance, around Fort Jesus in Mombasa, Kenya, Tanga/Bagamoyo and Dar-es-Salaam in Tanzania, could have been the result of much earlier introductions, probably dating to before the turn of the century. Local peoples lopped the trees for fodder for the emerging peri-urban smallholder dairies along the coast of Kenya and Tanzania. These and other *Leucaena* plantings farther inland are the subject of many research efforts for fodder and forestry uses. These probably belong to the shrubby and bushy *L. leucocephala* subsp. *leucocephala* and the arboreal subsp. *glabrata* that have been widely introduced (Shelton and Brewbaker 1994).

More recent introductions, especially through the Oxford Forestry Institute, have covered a wide range of *Leucaena* taxa and provenances, (Karachi and Lefofe 1997; Duguma 1995; Dzowela et al. 1995; Otsyina et al. 1995), (Table 2).

Fuelwood Use

There are few documented accounts of the use of *Leucaena* for fuelwood or energy generation purposes in Africa. It is, however, not uncommon to find it lopped primarily for fodder use or for soil

Table 2. The most recent and most common *Leucaena* introduced in Africa, representative species/subspecies provenances and countries of origin.

Species/subspecies	Oxford ID No.	Provenances	Country
L. esculenta	OFI 47/87	Pachivia Guerrero	Mexico
	OFI 48/87	Tiringucha, Michoacan	Mexico
L. matudae	OFI 49/87	Mexcala, Guerrero	Mexico
L. diversifolia	OFI 45/87	Corral Faso, Veracruz	Mexico
	OFI 46/87	Zalapa, Veracruz	Mexico
	K 156	Veracruz	Mexico
L. trichandra (formerly *L. diversifolia* subspp. *stenocarpa*)	OFI 35/88	Zambrano	Honduras
	OFI 53/88	Los Guates	Guatemala
	OFI 4/91	Erandique	Honduras
L.? hybrid of unknown percentage	OFI 52/87	Chapulco, Puebla	Mexico
L. pallida	OFI 79/87	Tamazalapan, Oaxaca	Mexico
	OFI 137/94	Composite of 16 provenances (CQ 3439)	Australia
	Offspring CPI 85890		Australia
L. collinsii subsp. *collinsii*	OFI 45/85	Chiapas	Mexico
	OFI 51/88	Chacaj	Guatemala
L. collinsii subsp. *zacapana*	OFI 18/84	Puerto de Golpe	Guatemala
	OFI 56/88	Gulan, Zacapa	Guatemala
L. salvadorensis	OFI 7/91	San Juan de Limay	Nicaragua
	OFI 17/86	Lagarita, Choluteca	Honduras
	OFI 34/88	Yusguare, Choluteca	Honduras
L. pulverulenta	OFI 83/87	Atlas, Cumbres	Mexico
	OFI 84/87	South Texas	USA
L. lanceolata var. *lanceolata*	OFI 43/85	San Jon, Oaxaca	Mexico
	OFI 44/85	Escuinapa, Sinaloa	Mexico
L. trichodes	OFI 2/86	Cuicas, Trujillo	Venezuela
	OFI 61/88	Jipijapa, Manabi	Ecuador
L. leucocephala subsp. *glabrata*	OFI 34/92	Coahuila, Saltillo	Mexico
	K 8	Zacatecas, Moyahua	Mexico
	K 636	Coahuila, Saltillo	Mexico
L. leucocephala subsp. *leucocephala*	Various	Various	Various
L. macrophylla subsp. *macrophylla*	OFI 55/88	Bellecitos, Guerrero	Mexico
	OFI 47/85	San Isadro, Llano	Mexico
L. macrophylla subsp. *nelsonii*	OFI 23/86	Sierra La Encantaba	Mexico

organic manuring through the use of foliage and twigs, but with the trunks and branches directed to fuelwood use.

For instance, in Zimbabwe's semi-arid areas where planting of *L. leucocephala* is carried out using an on-farm alley-cropping configuration, farmers are reported to use the foliage and twigs for soil mulching and as a source of nutrients and livestock fodder, and the stems and branches as fuelwood (Judith Nyakabau, pers. comm.).

It is recognised that some of the newer *Leucaena* species introductions in Zimbabwe (e.g., *L. pallida* and *L. trichandra*) could have more fuelwood value than *L. leucocephala* (Pottinger and Hughes 1995). These species produce dense wood of high calorific value. However, there have been no comparative studies of these *Leucaena* species with traditional native or introduced forestry fuelwood species.

Soil Ameliorative Use

L. leucocephala fixes high rates of nitrogen in symbiosis with root nodule bacteria (100–500 kg N/ha/year). Foliage and shoots collected by coppicing can supply some or all of the N and other nutrients required by an intercrop such as maize (Mafongoya and Dzowela 1997). Prunings may be surface applied, as a mulch or incorporated, as a green manure crop. There is evidence of *L. leucocephala* mulch/green manure contributing to soil organic matter. However, the high foliar N-content of *L. leucocephala* (4.3% of leaf DM) contributes to the rapid decomposition of its foliage.

In agroforestry, the growing of trees along with crops and livestock has been established over the decades as enhancing crop yields while producing products such as fuelwood, fodder, fruits and timber (Sanchez 1995). In one agroforestry practice, alley-cropping, as practiced in humid West Africa (Kang et al. 1981), *L. leucocephala* hedges are pruned periodically and the resulting prunings are placed as mulches on the alleys or incorporated into the soil as organic manure to control weeds and to provide nutrients. However, the magnitude of the effect on soil fertility and improvement of crop yields varies drastically with rainfall.

In a semi-arid environment at Machakos, Kenya, a positive soil fertility effect of +11% was observed (ICRAF 1993; Reynolds 1994). In the same environment, alley-cropping of *L. leucocephala* and maize reduced maize grain yield by 10%, basically due to competition for moisture (Wandera 1984). However, in sub-humid environments, negative alley-cropping effects with *L. leucocephala* have been reported (Akyeampong et al. 1995). In the humid tropics, where moisture is not limiting, studies have shown some positive soil fertility effects resulting in maize grain yield responses of +58% (Kang et al. 1981; Sanchez 1995). See Gutteridge (these Proceedings) for a comprehensive review of alley cropping.

Since *L. leucocephala* is primarily valued as fodder, there is a need to assess the trade-off of applying it directly to the soil or feeding it to livestock and applying the manure subsequently. Biomass transfer systems such as alley-cropping for soil amelioration have greatest potential when:

- biomass is of high quality (e.g., *L. leucocephala*) and rapidly releases nutrients;
- the opportunity costs of labour for cutting and transferring biomass to cropping alleys is low (ICRAF 1993);
- the value of the crop is high (e.g., high value vegetable crops);
- the leafy biomass does not have a higher value alternative use than as a source of nutrients (Buresh and Tian 1997).

There is evidence to show that, due to the high quality of *L. leucocephala* leaf, there may be no advantage to crop yields in feeding it and applying manure as a source of N to crops (Mafongoya et al. unpublished data). Mohamed-Saleem (unpublished data) argued that where livestock are well integrated within the farming systems, (for example draught and dairy livestock) it may be much more efficient to feed *L. leucocephala* foliage and fertilise crops with the resultant manure. However, where cropping is the main focus, direct use as organic manure could be justified.

Use in Erosion Control

Planting of *Leucaena* on soil conservation contour bunds has been an effective soil erosion control method in Kenya. *Leucaena* hedges decreased runoff and erosion when coppiced branches were laid horizontally along the contours (Kiepe and Rao 1994).

Closely spaced *L. leucocephala* hedgerows on steeply sloping farms in Ntcheu district, Malawi, have assisted in reducing soil erosion by water through two main processes: first, as a physical barrier of stems, low branches, superficial roots and leaf litter against running surface water (Sanchez 1995); second, as sites where water infiltrates faster because of the generally better soil structure under tree than on adjacent land (Banda et al. 1994).

Fodder Use

Much of the research with *L. leucocephala* has concentrated on its use as fodder. Based on the work of Addy and Thomas (1976), the use of *L. leucocephala* dried leaf meal in smallholder dairy feeding systems has taken root in Malawi's peri-urban centres. Similarly, in Zimbabwe's smallholder dairy production system, the ICRAF Agroforestry project has encouraged the development of fodder banks based on fodder species, *Acacia angustissima, Calliandra calothyrsus, L. trichandra* and *L. pallida*. The objective has been to create on-farm species diversity within the fodder banks. Planted areas range from 0.1 ha to 0.9 ha for farmers who have between 2 to 5 cows (Dzowela and Mafongoya 1997). Farmers are using the fodder bank material as protein supplements in a feeding system based on Napier grass (*Pennisetum purpureum*), various crop residues and conserved hays and silages. Evidence is emerging that where farmers are feeding between 1 to 4.0 kg DM/cow/day as supplement, milk yield responses range from 0.5 to 2 kg/cow/day over and above the control protein supplement of cotton seed cake which is reportedly variable in quality.

In Tanzania too, smallholder dairy farmers in the Shinyanga region have maintained milk yields of 10 kg/cow/day when cotton seed cake was substituted by dried *L. leucocephala* leaf meal fed at the rate of 1.4 to 3.0 kg/cow/day (Musengi, unpublished data).

In other studies, lactating cows were able to maintain their body weight when fed on Napier grass diets supplemented with *L. leucocephala* leaves (Muinga et al. 1995). This agrees with recent results by Dzowela et al. (1997a) in which *L. leucocephala* supplementation of cows on a diet of maize silage and *Cynodon* species hay gained in live weight by 8.1 kg/cow compared to 10.1 kg/cow when they were supplemented with *A. angustissima* during a 3-month dry season experimental period. Milk yields were ranked: conventional dairy meal>*L. leucocephala*>*Acacia*, with yields of 15.6 kg/cow/day, 14.4 kg/cow/day and 11.6 kg/cow/day, respectively. In all this work, the rate of supplementation was 3.5 kg/cow/day on a dry weight basis, cows weighed 458 ± 50.6 kg live weight and had a potential daily dry matter consumption of 13.7 kg/cow/day. Where feeding is targeted to improve manure quality, Cobbina et al. (1989) found that the N-concentration of the litter (wood shavings plus manure) of goats fed on a basal diet of *Panicum maximum* supplemented with leaves of *L. leucocephala* increased with the increase in the percentage of *L. leucocephala* in the diet. Manure in most mixed smallholder farming systems in Africa is an important by-product of the livestock production sub-sector, especially in the Central Highlands of Kenya and in Zimbabwe's communal areas where it is widely used as a cheap alternative to inorganic fertilisers for maintaining soil fertility.

Farm households using dairy concentrate in Kenya substituted 7 kg of fresh *L. leucocephala* leaves for 2 kg dairy meal. Others who supplemented 7 kg fresh *L. leucocephala* leaves to a cow's normal diet of low quality forages indicated that the economic benefits for substituting tree fodders to dairy meal was much higher than directly supplementing fodder trees to a cow's diet (Van den Veen 1994). Also in Eastern Africa, crossbred dairy cows showed a significant ($P<0.05$) increase in milk production to supplementation with *L. leucocephala* during early lactation in the dry season. In mid to late lactation, the response was through increased milk yield and improved body weight changes. This latter effect has a beneficial impact on subsequent reproductive performance. In several studies, the fortification of the basal diet (Napier grass) with dried *L. leucocephala* leaf has had the same effect of improving milk yield as the fortification with conventional dairy meal in Kenya (Nyamai et al. 1995).

In Ethiopia, Kaitho et al. (1996) reported that all *Leucaena* species were ranked among the highly palatable group of species. *Leucaena*-supplemented Horro sheep attained a superior average growth rate compared to others fed herbaceous legume hays, urea and noug cakes, and because of its additional advantages (fuel wood, high dry season leaf retention and higher crude protein (CP), Lemma Gizachew (1993) reasoned that *L. leucocephala* will be preferred by the smallholder farmers in western Ethiopia. Lemma Biru et al. (1989), working with dairy cows during the dry season, could replace up to 47% of the concentrate with *L. leucocephala* supplement without adverse effects from mimosine. When higher amounts of *L. leucocephala* were in the supplemented diet, work oxen in eastern Ethiopia also gained weight without adverse effects from mimosine (Tesfaye Cherinet et al. 1989). It is acknowledged that the toxic effects of mimosine and its breakdown products can be overcome by rumen inoculation with the bacteria *Synergistes jonesii*. However, the bacteria is currently unavailable in Africa due to quarantine restrictions.

In an on-farm, tree fodder banks impact assessment in the Guruve smallholder dairy project, Zimbabwe, the senior author has documented a positive milk increase of 1 to 2 kg/cow/day with *Leucaena* or *Calliandra* fodder supplementation of the basal diet of Bana napier (Figure 1.). This positive milk increase was in relation to the use of the conventional commercial dairy concentrate supplement which is (according to the farmers) highly variable in quality. Regardless of the cow's lactation phase and period of year when the cows were supplemented, the superiority of tree fodders as protein supplements is evident (Figure 1).

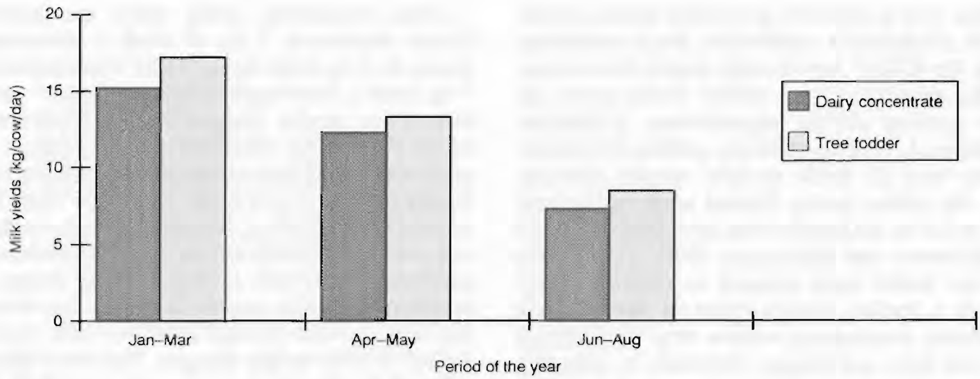

Figure 1. Milk yield responses in an on-farm situation comparing supplementation with tree fodder (*Leucaena* or *Calliandra*) with commercial concentrate supplementation in Guruve Communal Area, smallholder dairy production project, Zimbabwe.

A major proportion of the variable costs in a dairy enterprise (i.e., 70%–80%) is accounted for by cost of concentrates. On-farm experience in Zimbabwe, indicates that tree fodders such as *L. leucocephala* leaf have a high potential for increasing smallholder milk productivity, thus assuring profitability of the enterprise, especially if the tree fodder is grown on-farm.

In Tanzania goats increased their total dry matter feed intake as the *L. leucocephala* supplement level increased, indicating that *L. leucocephala* could replace cotton seed cake as a protein supplement in on-farm feeding systems, (Ndemanisho et al. 1994). The study concluded that the 25%–47% crude protein supplied by cotton seed cake could be substituted by *L. leucocephala* in ration formulations for livestock.

In Mozambique, where goats are commonly tethered during the rainy season, supplementation with *L. leucocephala* leaves most months of the year, and especially during the dry season improved live weight gains. This supplementation also resulted in higher carcass percentage and lower digestive tract percentage during a low rainfall year compared with unsupplemented tethered goats (Muir and Massaete 1996).

In semi-arid areas where use of oxen for cropping activities is widespread, prolonged dry spells expose the draught oxen to periods of a very low plane of nutrition, especially just before ploughing and planting. This makes them unable to perform farm operations satisfactorily. Oxen grazing poor quality natural pasture have maintained weight and provided adequate draught power when supplemented with *L. leucocephala* and urea-treated maize stover (Tessema and Emojong 1984).

Challenges for Development

Leucaena leucocephala has exceptional characteristics as a multipurpose tree legume and it is often recommended in smallholder mixed farming systems in Africa. But the leucaena psyllid challenge has prompted the world to seek alternative species. A wide range of *Leucaena* taxa species and provenances has been acquired and is in various stages of evaluation. From an agronomic evaluation standpoint, a great deal of promise is exhibited by these and other materials. The species *L. pallida, L. trichandra* and hybrid of *L. leucocephala* with either *L. diversifolia* or *L. pallida* continue to show great yield potential for fodder. However, to date no other fodder species have surpassed the versatility and high fodder quality of *L. leucocephala*. Thus, gains made in identifying materials of high agronomic performance in psyllid-prone environments may not result in higher animal performance. This is the biggest challenge to development of soil fertility replenishment and livestock feeding systems based on *Leucaena* species other than *L. leucocephala*.

Farmers, at least in Zimbabwe where *Leucaena* is being promoted in agroforestry plantings of fodder banks, complain of the weed potential resulting from the prolific podding and seed-setting of *L. leucocephala*. When not fully managed in intensive cutting management systems, massive seed production has resulted in a thick mat of what could be considered weed stands. This poses a major environmental challenge in farming systems south of the Sahara where *L. leucocephala* is not directly grazed.

In acid soil and cool sub-tropical or montane environments, the establishment and growth of *L. leucocephala* has been particularly disappointing to smallholder farmers. Farmers have had to wait at least three years before realising substantial harvests of foliage/fodder. Other species, such as *Acacia angustissima* have yielded nearly five times the fodder yields of *L. leucocephala* in those environments (Dzowela and Mafongoya 1997). Other *Leucaena* species, specifically *L. trichandra* and *L. diversifolia*, show considerable potential in highland tropical environments but require on-farm evaluation.

Most of the psyllid-resistant *Leucaena* species (*L. pallida, L. esculenta, L. diversifolia* and *L. trichandra*) do not have the versatility and forage quality characteristics of *L. leucocephala*. Species constrained by high concentrations of condensed tannins, e.g., *L. diversifolia* and *L. pallida*, which have lower in vitro dry matter digestibilities and lower rumen degradabilities compared to *L. leucocephala* (Dzowela et al. 1997b), may be improved by application of tannin neutralising substances such as polyethylene glycol (PEG) or any detoxifying agents, as has happened with the use of cultures of the bacteria (*Synergistes jonesii*) to address the problems of mimosine toxicity. Such attempts could have far-reaching implications for enhancing the utilisation of these alternative *Leucaena* species.

The International Centre for Research in Agroforestry (ICRAF) is collaborating with other international centres such as the Oxford Forestry Institute in the multiplication of *Leucaena* seed. This will be especially relevant for alternative species to the psyllid-prone *L. leucocephala*. These species are currently being evaluated across many ecosystems in Africa. ICRAF has realised that certain species are being screened and evaluated for various uses and there is likely to be a high demand for seed. This has been ICRAF's experience with species like *Calliandra calothyrsus* and *Grevillea robusta* in Kenya. Planning needs to take place beforehand on how to satisfy this expected demand with high quality germplasm. One of the ways ICRAF hopes to do this is by on-farm seed production. Farmers are being encouraged to grow seed which can be sold to ICRAF. This is especially important as, in many African countries, production of germplasm for agroforestry and many other purposes is being carried out increasingly by non-governmental organisations (NGOs) and the informal sector.

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Leucaena in Latin American Farming Systems: Challenges for Development

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Abstract

Several species of *Leucaena* have been used traditionally by indigenous people of Mexico and Central America as part of their subsistence use of plant resources available in the natural environment. However, this does not imply an intensive use of *Leucaena* in their farming systems. *Leucaena leucocephala* is the most widely-used species, but it has limitations such as slow growth during establishment, low drought and cold tolerance, poor growth on acid soils and susceptibility to defoliating psyllid insects. These inherent problems of *L. leucocephala* added to deficient technology transfer programs, poor diffusion of technical information and farmers' tradition, are responsible for its limited adoption in farming systems of the American tropics. With the present technology available for *L. leucocephala*, productivity of large areas of the region can be improved either by incorporating leucaena in grazing systems or into crop lands. However, to realise this potential, technical and technology transfer problems must be solved.

THE genus *Leucaena* is native to the New World and extends from southern United States through middle South America. Presently, there are 22 species identified (Bray et al. 1997); however *L. leucocephala* is the species that has been most investigated and utilised (Casas and Caballero 1996), followed by *L. diversifolia* (Salazar 1986).

For centuries, indigenous people of the American tropics have used *Leucaena* species as a source of edible pods, as forage for domestic animals, as poles for construction, as firewood, and as shade in permanent plantations. But despite the diverse uses of *Leucaena*, and the convincing research results that show significant increases in animal products, improvement of the soil through nitrogen fixation and the possibilities of using this legume in alley cropping systems, there is not intensive use of *Leucaena* in the region.

This review discusses the present status of *Leucaena* in the region and comments on some of the reasons for the poor adoption of the legume on a wide and intensive scale. The production potential of *Leucaena* and recommendations for future development are also presented.

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Traditional Use of *Leucaena*

The presently recognised species of *Leucaena* have a long history of human use by indigenous communities of Mexico and Central America. Usually the *Leucaena* species are protected in traditional agroforestry systems (Hughes 1993). For example five taxa are reported to be utilised by Indian groups of Mexico: *L. lanceolata*, *L. confertiflora* var. *adenotheloidea*, *L. pallida*, *L. esculenta*, *L. leucocephala* subsp. *leucocephala* and *L. leucocephala* subsp. *glabrata* (Casas and Caballero 1996).

The species of *Leucaena* that are most widely cultivated by indigenous people in Mexico are *L. esculenta* and *L. leucocephala* subsp. *glabrata*. The former is called guaje rojo (red guaje) and local people, mainly of the Mixtec group, gather pods, seeds and young leaves for human consumption. The seeds are eaten raw, roasted, cooked in stews or milled and added to traditional chilli sauces (Casas and Caballero 1996). The cultivation of this species is not intensive and edible parts are gathered from individual plants grown in home gardens and from wild populations or from selected individuals spared in croplands.

Leucaena leucocephala is widely distributed in the region and *L. leucocephala* subsp. *glabrata* has become naturalised in Honduras. Other species native to this country *are L. salvadorensis*, *L. diversifolia*, *L. shannonii* and *L. lempirana* (Ponce 1995). Indigenous people of Honduras have also managed the leucaena trees for a long time and use them as a source of edible pods, as forage for pigs, rabbits and cattle, for firewood, for construction, as living fences, as shade and as green manure. Similar use of leucaena is practised by small farmers of Guatemala (Arias 1994), Costa Rica (Camacho 1989) and in other countries of the region.

A more detailed list of uses of *Leucaena* species by local people is presented in Table 1. However, it needs to be clarified that this use of *Leucaena* is part of a diversified practice for family subsistence of indigenous people that take advantages of all available plant resources in the local environment to fill particular needs. It does not mean that there is presently an intensive use of *Leucaena*.

Present Status of *Leucaena* in the Region

Research

Considerable research on *Leucaena* has been carried out in the region, including the humid subtropics, during the past 10 to 15 years, particularly by agronomists whose primary interest has been production of livestock feed (Hughes 1993). In this regard, the contribution of *Leucaena*, mainly *L. leucocephala*, to the improvement of animal production (beef and milk) is well documented (Faría-Mármol 1996; Ruíz et al. 1996; Dávila and Urbano 1996; Suárez et al. 1987; Goldfarb and Casco 1995).

Lascano et al. (1995) reviewed *Leucaena* research results in countries of Central and South America and the Caribbean, and concluded that there is sufficient germplasm and experimental information available in the region for different environments. Based on soil and environmental data (soil pH (H_2O) >5.5, Al saturation >40%, altitude <1500 m.a.s.l. and dry periods of 3 to 6 months) they described macro-regions and agricultural production systems that could benefit from *Leucaena*. Much of the research has been conducted on *L. leucocephala*, particularly the 'K' varieties from Hawaii (Viquez 1995), the cultivars Perú and Cunningham and germplasm supplied by RIEPT (CIAT's supported pasture network).

From 1986 to 1991, the Proyecto Madeleña (CATIE–ROCAP) studied the adaptation and the potential use of *L. leucocephala* and of *L. diversifolia* as firewood, charcoal and forage at several sites in Guatemala, Honduras, El Salvador, Nicaragua, Costa Rica and Panamá (Salazar 1986; Camacho 1989). The sites varied in elevation from 0 to 1200 m.a.s.l., mean temperature from 20 to 30 °C and total rainfall from 1635 to 3433 mm. The soils had a pH > 5.0 and no aluminium toxicity. *L. leucocephala* adapted well to soils which were well drained and with little compaction, and in sites with a well-defined wet season. *L. diversifolia* adapted better to environments over 800 m.a.s.l.

Based on dry matter (DM) yields under different plant densities of trials conducted in Costa Rica, Salazar et al. (1987) developed preliminary predictive model equations to estimate DM yields of foliage, firewood and total biomass of *L. leucocephala* and *L. diversifolia*. The equations are based on the natural logarithm of the diameter at breast height of the main stem (dbh) and the plant total height. For instance, for *L. diversifolia*, firewood (kg/tree) could be estimated by the equation $\ln Y = -1.7544 + 2.4039 \ln dbh$ (Y= firewood DM).

Table 1. Main use of native *Leucaena* species by indigenous people of Mexico and Central America (Adapted from Hughes 1993)

Species	Main use
L. collinsii subsp. *collinsii* and subsp. *zacapana*	Firewood, fence posts, wood for construction, unripe pods consumed
L. confertiflora	Unripe pods consumed
L. cuspidata	Unripe pods consumed
L. diversifolia	Shade tree, fodder for domestic animals, wood for construction
L. greggii	Firewood, fodder for goats
L. lanceolata	Firewood (prefered over *L. leucocephala*), fodder for pigs
L. leucocephala subsp. *leucocephala* and subsp. *glabrata*	Unripe pods consumed (has occurred for millennia), fodder for livestock, green manure, firewood, wood for construction
L. macrophylla	Unripe pods consumed
L. multicapitula	Wood for construction, firewood
L. pulverulenta	Firewood, wood for construction, shade tree
L. salvadorensis	Firewood, fence posts, living fences
L. shannonii	High value as bee forage, firewood, fence posts
L. trichodes	Firewood, livestock food (mainly for goats); toxic to horses

Leucaena diversifolia is a tree of medium size and regarded as easier to manage as shade for coffee than the traditional species used such as *Inga densiflora* and *Gliricidia sepium*. This species is suitable for the production of posts (the wood is hard and heavy) and has a high calorific value as firewood (approximately 4400 kcal/kg). Table 2 indicates that at one site in Costa Rica (La Garita), it produced in a period of 4.4 years, 45.9 metric tonne/ha of firewood and 89.0 metric tonne/ha of total biomass in three harvests (Salazar et al. 1989). It also has potential as a forage plant since the mimosine content is low (CATIE 1986). However, farmers have preferences for species of *Inga*, *Erythrina* and *G. sepium* as shade trees in coffee plantations of Central America, probably due to ease of propagation, either from seed or cuttings, and faster growth of these compared to *L. diversifolia*.

More recently, lesser known *Leucaena* spp. have been under evaluation and the results show great variation in vigor, forage and wood biomass production, branching habits, drought and psyllid tolerance (CONIF 1986; Viques 1995; Argel and Pérez 1996). Among the more promising species worthy of mention are *L. collinsii*, *L. trichandra*, *L. diversifolia*, *L. pallida*, *L. salvadorensis*, *L. macrophylla* subsp. *istmensis* and *L. esculenta*. However, the new species must find a place in crop production and agroforestry systems to have a chance for wide adoption.

The interspecific crossing between *L. leucocephala* and *L. diversifolia*, with the aim of identifying hybrids tolerant to acid soils, continues in Brazil (Schifino-Wittmann et al. 1995); however, although superior acid-tolerant phenotypes have been selected, no cultivar has been released up to date (Hutton 1995).

Utilisation in production systems

Leucaena, particularly *L. leucocephala*, has the potential to be used in a diversity of production systems in the region, either *Leucaena*-based pastures (Faría-Mármol and Morillo 1997) or in crop production activities such as shade in perennial crops, for erosion control planted as hedges on hillsides, as mulch and green manure, for wood, firewood and fence posts.

However, the reality is that despite positive research findings that show the potential that *Leucaena* has to improve different agropastoral production systems of the region, its use by farmers is limited. In Brazil, Venezuela, Colombia, Mexico and countries of Central America and the Caribbean, *L. leucocephala* is planted on a small scale as a forage plant (protein banks or associated with grasses) mainly as part of research or development projects, and in only a few cases planted at the farmer's own initiative. Figures detailing the total area of *Leucaena* planted are not available.

Leucaena leucocephala planted as strips into existing grasses in Campo Grande (Brazil), has increased beef production threefold (P. Rayman pers. comm.). However no more than 500 ha are presently planted and farmers show little interest in this technology for reasons listed below. In the Cerrados and Northwest of Brazil, *Leucaena* has been promoted for use as a windbreak and protein bank among small farmers, but it is used only on a small scale (M. Soter and C. T. Karia pers. comm.). Similar situations with the use of *L. leucocephala* occur around the Maracaibo Lake in Venezuela (D. Urbano pers. comm.), in the Cauca Valley of Colombia (Shultze-Kraft 1994) and in the State of Chiapas in Mexico (I. Carmona pers. comm.).

Table 2. Growth and regrowth yields of *L. diversifolia* in La Garita de Alajuela, Costa Rica (Adapted from Salazar et al. 1987).

Variables	First harvest* (2.6 years)	Regrowth harvests 1st (0.8 yrs)	Regrowth harvests 2nd (1 yr)**	Total production
Total height (m)	6.0	5.3	5.3	—
dbh (cm) of main stem	4.7	2.9	2.8	—
Foliar DW (tonne/ha)	13.9	10.3	18.9	43.1
Firewood DW (tonne/ha)	23.4	14.9	7.6	45.9
DW standing biomass (tonne/ha)	37.3	25.2	26.5	89.0
Specific gravity (g/cm^3)	0.54	0.54	—	—

* Harvest of the original stand
** Harvest of regrowth at 10 to 12 month intervals

Leucaena diversifolia is used and preferred over other species by local farmers of Guatemala as firewood, because it splits easily, burns slowly and produces little smoke. The hardwood is used to make axe handles and to build attics for drying tobacco. Also, *L. leucocephala* is used on a small scale by farmers of Nicaragua as a windbreak planted together with stands of *Tecoma* and *Eucalyptus camaldulensis*, thus offering a better foliar surface for wind control (CATIE 1986).

Regional projects, such as Madeleña (CATIE–ROCAP) and COHDEFORD in Honduras have encouraged, during the last ten years, the use of *Leucaena* (mainly native lines) in agroforestry systems and as live fences among indigenous people (Ponce 1995). However, statistics on the degree of success are not available. Similarly, CATIE has researched the use of *Leucaena* in alley cropping systems in Nicaragua and Costa Rica (Viques 1995), but the utility and advantages of the system are not known nor it is a popular practice among farmers.

Limitations to Adoption

Technicians have concentrated research and promotion on *L. leucocephala*, which is known for its poor cold tolerance, heavy defoliation during prolonged dry periods, poor growth on acid soils, heavy pod production, low wood durability and susceptibility to a defoliating psyllid (Hughes 1993), although the high forage quality of this species is well recognised. Therefore, there are factors inherent to the species that limit its adoption, but there are additional factors that merit mention:

- There are no well supported technology transfer programs to promote the utilisation of *Leucaena* in the region.
- Farmers do not understand or are not fully aware of the benefits of using *Leucaena* as a fodder plant or in agroforestry systems.
- Traditionally for a cattle farmer, a pasture is formed by pure grass only; farmers have difficulties accepting a pasture formed by trees.
- Technical information on establishment at low cost and management methods to regenerate plantations is scarce.
- *Leucaena*-based pastures need intensive management under rotation, a practice that is not common among cattle farmers of the region.
- Ants and termites are a problem during the establishment phase of *L. leucocephala* in areas such as the Cerrados of Brazil.
- There are no studies that show the economic impact of using *Leucaena* at the farm and community level, and the contribution of the legume to the cycling of nutrients and improvement of the soil.

Potential and Recommendations for Development

With the present technology available, large areas of the Latin American tropics could be planted with *L. leucocephala*, particularly areas of the region with medium to good fertility soils and a well defined dry season. According to Lascano et al. (1995), these areas are present in the southern part of Mexico, in some islands of the Caribbean, along the Pacific coast of Central America, parts of Colombia, Venezuela, Guyana, Ecuador, Bolivia, Paraguay, northern Argentina and east and northeast of Brazil. Generally, these areas already hold a high population of beef and dual-purpose cattle.

To this area, millions of hectares need to be added of very acid oxisol and ultisols with pH < 5 and Al saturation of 47–87% that cover around 55% of South America and 68% of Brazil (Hutton 1995). These areas could be planted with acid-tolerant hybrids of *L. leucocephala* × *L. diversifolia* that are well advanced in Brazil (Schifino-Wittmann et al. 1995), or with newly identified species presently under evaluation (Argel and Pérez 1996).

However, for this potential to be realised a series of problems and limitations need to be overcome with the presently available lines of *Leucaena*, including:

- Improve the growing methods, focusing on establishment and soil nutrient requirements of *L. leucocephala*. Farmers have to wait too long from planting to the first grazing. Appropriate planting techniques are needed, together with the selection of robust genotypes with faster growth.
- Organise and establish technology transfer programs that provide incentive for farmer participation in the planning, growing and management of *Leucaena*. A government incentive may be considered such as one that is presently in place in Mexico, where the state provides to a farmer around 60% of the cost of establishment of a new pasture (usually the seed cost of grass establishment).
- Improve the dissemination of technical information on the potential and limitations of *Leucaena*-based systems to farmers, extension agents and policy makers. This can be assisted by establishing a regional network to share germplasm, experimental results and experiences with farmers. The present chain of experiments already under way in Latin America with new species of *Leucaena* supported by the Oxford Forestry Institute in collaboration with CIAT, may be the base for a future regional network.
- Incentive programs to identify new lines tolerant to high Al saturation and low Ca soil concentration either by breeding or selection from new species of *Leucaena*.

Conclusions

Leucaena species are utilised for different purposes by indigenous people of Latin America as part of a diversified practice that takes into account all plant resources available for subsistence in the local environment.

Leucaena leucocephala is the species that has been most widely distributed and researched; however there is no wide utilisation of this species in the agropastoral system of the region. New species of *Leucaena* are still in an early phase of evaluation.

The potential of *Leucaena* to increase animal production, as well as to contribute to more sustainable crop practices, is enormous, but there are several factors that limit adoption. These factors include lack of effective technology transfer programs, farmers' traditions, slow establishment and poor growth in acid soils. These issues need to be resolved if intensive use in different production systems of this important legume is to be achieved in the near future.

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Leucaena in Large-Scale Grazing Systems: Challenges for Development

P.H. Larsen[1], C.H. Middleton[2], M.J. Bolam[3] and J. Chamberlain[4]

Abstract

In Australia, leucaena is grown in rows with grass in the inter-rows and used almost exclusively in large-scale grazing systems. Currently, about 50 000 ha of leucaena are used for beef production in tropical and sub-tropical Australia. Most of this is raingrown in Queensland on fertile clay-clay loam soils in the 600–800 mm mean annual rainfall zone. A small, but highly productive, irrigated area is grown in the Ord River area of northwest Australia. Leucaena has been grown commercially in Australia for nearly 40 years. Despite its known production potential and large areas of suitable soils, its adoption has been slow.

LEUCAENA (*Leucaena leucocephala*) is a highly nutritious forage used mainly for finishing different classes of beef cattle for slaughter for both domestic and export markets in Southeast Asia, Japan, Korea and USA, with a smaller amount going to EEC countries. In the Ord, it is used principally to finish cattle for the live export trade to Southeast Asia.

The high quality of leucaena makes it ideal for finishing cattle and it is replacing more costly finishing systems like annual forage crops and feedlots. It is the only tropical forage system in Australia capable of finishing beef animals that can meet all export carcase specifications. A recent grazing demonstration (Esdale and Middleton 1997) showed that under favourable seasonal conditions, liveweight gains from raingrown leucaena/grass of 1.25 kg/steer/day were possible. Furthermore, carcase quality was no different from carcases from grass or grain feeding.

Leucaena has advantages over crop finishing in that high quality forage is available continuously. With oats, the cattle tend to get 'fatter' the longer they are on the oats. On leucaena, the cattle continue to go through growing and fattening phases. Cattle can be turned off anytime during the year to meet market demands and better prices.

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Future development in Australia
In spite of its known production potential and large areas of suitable soils, leucaena adoption has been slow. Some thoughts and observations on limitations and future development opportunities are given independently by an experienced grower and practising scientists and extension specialists.

1. A Grazier's View (P.H. Larsen)

What limits adoption?
The restrictions to the adoption of leucaena in Australia can be categorised in three ways: technical restrictions, social restrictions and economic restrictions.

1. Technical restrictions
The greatest restriction in this area is the lack of government registration of chemicals to control insects and especially weeds. While much work has been done by DPI and CSIRO in the pest control area, there is a reluctance by chemical companies to spend time and money on registration of chemicals for use on crop and pasture species which seem insignificant to them.

The greatest cause of failure in establishing leucaena is poor weed control. While many modern day farmers are geared to chemical weed control, this author prefers the low cost, hard work mechanical control methods and where necessary, even hand hoeing. While many producers often prefer other establishment and weed control methods, they frequently do not have the ability or inclination to do the job effectively. They invariably fail and do not have the will to try again. A 90% success rate in establishment across the industry will only be achieved when easy, highly effective methods are perfected, such as selective chemical weed control.

What technical answers are still needed?

- Trials need to be conducted on breeding cows to confirm Dr Raymond Jones' claim that leucaena will have no adverse effect provided the cows have the rumen bug (*Synergistes jonesii*). Most DPI staffs are not prepared to make the claim that leucaena feeding to breeders does not affect calving or calves at birth.
- Growers need technical information on why steers tend not to over-fatten on leucaena. Is this to do with the feed or the young age of the beast?
- Growth rates after seedling emergence need to be monitored to see if there are differences between seed scarified by boiling water and mechanical means. Time to emergence and subsequent growth both need to be measured.
- Nitrogen fixing trials need to be conducted in order to establish if leucaena in the field is fixing expected amounts of nitrogen, especially in the normally high-nitrogen, brigalow clay soils of central Queensland where there is little visible evidence of nodulation.
- More taste testing trials on beef from leucaena-fed animals will demonstrate the high quality of this product.
- Trials need to be conducted on machine scarified seed to determine the effect of atmospheric conditions on seed quality and germination over time.
- Trials need to be conducted on individual cultivars to determine the response to coppicing at various heights, in comparison to a standard height of about 2 m that animals graze to in the field. Does the coppicing height have any effect on psyllid populations?
- The registration of weed and insect control chemicals for use in leucaena needs fast tracking.
- Research is needed to establish which chemicals can be applied to inoculated seed to control insects that attack emerging seedlings underground. However, leucaena with no live inoculant is better than live inoculant but no leucaena.
- How much existing grass can be retained during establishment without affecting leucaena establishment?
- What is the effect of grass competition on the long term yield and quality of leucaena relative to a pure stand, particularly in relation to soil moisture availability?

2. Social restrictions

There are probably as many social restrictions to leucaena use as there are people who have seen and been impressed by it but failed to attempt to use it. This property hosts about 100 people each year and all are impressed with the leucaena and the cattle grazing it. However, not many of these people are planting it, although successful growers are quite passionate about what they are doing.

Misinformation or misinterpreted information is often used as an excuse not to attempt to grow leucaena. The 'dieback condition' recorded at Blackwater is an example. It appeared in the recent drought and resulted in some plant deaths on severely drought-stressed plants. However, this property lost more native trees in the drought than leucaena. It is of interest that the Blackwater grower (Scott McGhie) who had the longest drought and lost the most plants is continuing with his leucaena planting program and is enthusiastic about it. As a matter of interest, this property has had its greatest establishment success in the driest years, due to lack of weed competition.

Social promotional needs

- **Technical manual**. A new, high quality updated technical manual on glossy paper with colour photos needs to be written, with technical information interspersed with real life testimonials from successful growers. When farmers read a technical manual, they need to become excited to the extent that they have to restrain themselves until they finish the last pages before going off to check the farm for where it is going to happen. No publication is worth the paper it is written on unless it starts people doing something. User testimony is essential.

  Myth eradication is the first target when writing a new publication. The second is to emphasise that: NITROGEN is PROTEIN is BEEF.

  Most graziers have not made this connection.
- **Establishment costs**. This should only be spoken of where a direct comparison is given to the cost of establishing a grain or forage crop over a 10-year period. People need to recognise that the half-life of leucaena is 50 years (Jones and Harrison 1980) and consider the costs and returns on this time scale.

- **Risk reduction.** All risks should be taken out of the establishment phase so that a benchmark of full production in 6 months can be reached. If necessary, graziers should employ experienced farmers to establish the leucaena for them.
- Graziers need to be reminded that animals can be finished to most specifications at any time on leucaena, including during a drought.
- Good leucaena stands need to be established on research stations for trial and demonstration purposes.
- **Grower promotion.** Promotion by experienced, practical growers should take place.
- **Plant breeders rights** need to be in the hands of the right people to ensure benefits to all.

3. Economic restrictions

The main economic restriction has been the high cost of establishment ***failure***, due to poor seed emergence, weeds and the destruction of seedlings by insects. Most of these problems now have answers and can be overcome.

Currently, the most severe restriction is the low world beef prices compared to reasonable grain prices.

Economic promotional needs

- The most effective economic factor supporting the use of leucaena is that beef can always be marketed at the high end of the price range at the time, with little need for the producer to have to negotiate higher prices. This property has been offered 'top dollar' for leucaena cattle for eight years now. When seasonal conditions dictate, the influx of cattle onto the market drives the price down. Eventually, there is a shortage of prime cattle and prices increase. This is the time when meatworks seek leucaena-fed cattle as they know quality can be produced at any time. The only negotiations required with the meatworks is the exact time they need the cattle and advice as to when prices are likely to fall.
- Leucaena should be promoted economically on the basis of comparison with alternative forage crop feeding systems.

2. Pasture Agronomists' View (C.H. Middleton and J. Chamberlain)

Current use in Australia

Middleton et al. (1995) reviewed the status of leucaena use in Australia. They concluded that there were about 50 000 ha in use almost exclusively in large-scale grazing systems where the leucaena is grown in rows 6–12 m apart with sown grass between the rows. Except for the Ord River area which is irrigated (see next section), it is raingrown on fertile clay soils in areas with 600–800 mm annual rainfall. It is used principally for growing beef animals but all classes of cattle can be used provided they have been treated with the rumen bacterium.

The large-scale grazing systems used in Australia (large arable land area, non-acid soil, small population and large farms) are not widespread throughout the world. However, there are similar systems, but on a smaller scale, in southern USA and Central and South America and Pacific Islands. The potential for larger areas of large-scale open grazing is substantial both in Australia (Middleton et al. 1995) and elsewhere (Lascano et al. 1995).

Once established, leucaena is tolerant of grazing and flexible in its management. Grazing systems range from rotational grazing to continuous grazing.

It is well recognised that leucaena in association with sown grass is the highest quality forage system available to graziers with suitable soils in the subtropics and tropics of Australia. It is also known that high animal production levels (>1 kg liveweight gain/animal/day) are achievable. All this is possible where most Australian leucaena in grown, i.e., at the lower end of its rainfall adaptation limit.

Given the high performance of leucaena, the large successful plantations already in use and the large area of soil to which it is highly adapted, the perennial question is 'Why is there not more?' After all, a less productive shrubby legume (*Stylosanthes scabra*) released for use 20 years later than leucaena, already covers close to 1 million hectares in northern Australia (Partridge et al. 1996).

With existing leucaena cultivars, 50–100 times the current sown area is suitable (on the basis of soils and rainfall) for leucaena growing in Queensland. The potential area would be even greater with better psyllid, frost and drought tolerance.

Restrictions to adoption

There have been many reasons for the slow adoption of leucaena over the decades, ranging from unfamiliarity of using and managing 'trees' as grazed forage plants, mimosine effects on ruminants, poor establishment, psyllid damage, lack of frost tolerance, high cost of establishment and competition from other land use options.

However, current technology exists to the extent that the area of economically and environmentally viable leucaena could be expanded enormously with existing cultivars and with only minor problems with psyllids and frost. A few comments are offered on factors believed still to have a bearing on adoption. In the authors' opinion, some of these problems are often more perceived in the mind of the grazier than appear in reality.

a) Establishment problems

Establishment difficulty still rates highly as a major limitation to use (Shelton 1994; Middleton et al. 1995 and Lascano et al. 1995). Most raingrown leucaena in Queensland is grown close to its rainfall adaptation limit because this is where the best soils (neutral to alkaline, relatively fertile, deep, well-drained clay/clay loam soils) occur. Light to moderate winter frosts occur. The bonus is that in this environment psyllids are generally not nearly the problem they are in the higher rainfall coastal areas or indeed in other countries.

Because of slow establishment of leucaena and the devastation that weed competition can cause, the practices to ensure success must be rigidly adhered to. The technology to do this is available but often not carried out. In many cases, the necessary high level of farming skills and machinery to establish leucaena are lacking, despite all the good intentions. Unfortunately, as in any profession, the skills and abilities of graziers follow the normal distribution curve. A few are capable of achieving a high success rate in establishing leucaena, but many are not.

It probably costs 50%–100% more to establish leucaena compared to the conventional buffel grass (*Cenchrus ciliaris*) pasture. In effect, two pastures have to be planted, leucaena and subsequently buffel grass. Most of the additional cost is due to leucaena seed treatment, insect and weed control chemicals and their application, additional inter-row weed control and the time the 'two' pastures are not available for grazing. Costs can be reduced where leucaena is sown into existing grass pasture or where grass is sown at the same time (provided 2.0 m each side of leucaena row is kept weed and grass free). Lascano et al. (1995) suggest intercropping may help pay for establishment. This has been tried in Queensland but generally the low rainfall of the area and competition from established leucaena has adversely affected the performance of both leucaena and crop.

The comparison in the adoption rates in Australia of two adapted pasture forage legumes (leucaena and stylo) is interesting. Introduction of stylo (*S. scabra*) into the native pasture communities of northern Australia is characterised by a set of circumstances that are quite different from those where leucaena is grown. Stylo establishment is characterised by:

- low cost, low risk and ease of establishment (minimal seedbed, aerial planting, small investment in machinery, highly competitive with grasses);
- grazing can continue during the establishment phase therefore not loosing land productivity;
- stylo is widely adapted to soils and tolerates low fertility;
- the inclusion of stylo has not changed the pasture management methods of graziers. They still have a suite of plants, grasses and shrubby plants, with which they are familiar;
- the inclusion of stylo is replacing a low production system (native pasture) so that big benefits are guaranteed with little effort. Leucaena planting is replacing an already reasonably high production system (buffel grass pasture, crops).

It is necessary to convince graziers that the benefits of leucaena, even where it replaces an existing high production grass pasture, is unequalled by any other improved pasture system.

b) Competition from other land use

The soils on which leucaena is grown in Australia are generally also highly suited to both summer and winter crops. Leucaena must compete against these. Also, it is harder to incorporate leucaena in diversified and/or rotational management systems involving some cropping than with less permanent pasture systems. The degree of competition from cropping varies according to the comparative net returns operating at the time.

c) Research and development funding

Funding for agricultural research, development and extension in Australia has declined substantially in recent years. This means not only less money but also less staff. All research and development conducted by agencies is prioritised and leucaena is not high on the list. It is not widely recognised that R&D priorities today are largely set by industry bodies, not by scientists or extension people.

d) Extension material and methods

In Australia, leucaena has been subjected to more than its fair share of publicity by all the conventional methods utilising personal contact, written, radio and TV/video media, field meetings etc. It is believed that most graziers are aware of the technology and its value and that factors other than lack of awareness are responsible for inadequate adoption.

More recent extension strategies are discussed under the adoption strategies section below.

Adoption strategies

a) Getting the message across

How far can anyone go in 'encouraging' people to adopt a technology that they can benefit from financially? The moral obligation of scientists and extension specialists is to make sure the grazier has all the necessary information (both positive and negative) to make decisions as to whether leucaena is appropriate. To be adopted by graziers, any new technology must suit their lifestyle, their 'pocket' and their production system; they will take it on in their own time.

Participatory research (Lascano et al. 1995) and extension is a tool which the authors have been involved with in Queensland since 1986 through the Producer Demonstration Site (PDS) project. Groups of graziers conduct on-farm demonstrations of new technologies, partly funded by industry (Meat Research Corporation—MRC). The group activities are usually facilitated by technical 'experts' in that particular technology. The aim is to improve grazier skills, give them 'ownership' of the project and ultimately achieve technology adoption. In the past five years, several leucaena demonstrations have been carried out successfully.

A similar approach, part-funded by industry (MRC), is the PIRD project (Producer Initiated Research and Development). Groups of producers initiate and conduct their own projects with or without input from technical people. Its aims are somewhat similar to the PDS. The two projects will be amalgamated in 1998 into a common PIRD approach.

There is no doubt that successful 'on farm' demonstrations are a highly useful method of getting the message across. A large production demonstration carried out in association with the 1997 Queensland Beef Expo (Beef '97) allowed graziers to compare the production and carcase traits of their animals against others under different feeding systems (Esdale and Middleton 1997). During a 150-day period, the average daily liveweight gain of 150 steers grazing leucaena/grass was 1.26 kg/steer/day compared to 0.82 kg/day from buffel grass alone. The implications of this performance in terms of age of turnoff and marketing flexibility are obvious.

Chamberlain (these Proceedings) has taken another approach to getting the leucaena establishment message across to leucaena growers and to train them in establishment technology. As an alternative to on farm demonstrations, he took a bus load of graziers interested in leucaena on field visits to existing leucaena growers. The visits were designed to see both successful and unsuccessful establishments and get grazier interaction on the processes. Several group members planted leucaena as a result of the exercise.

The authors believe the best way to achieve greater adoption of leucaena or any other technology is to increase the skills level of the users and to involve them in the process of testing or demonstrating the technology to ensure ownership.

b) Increased funding

If industry considers that leucaena research, development and extension deserves higher priority than it currently receives, then it must be proactive in canvassing its representatives in industry associations, the Regional Beef Research Committees, Queensland Beef Industry Institute, R&D funders (Meat Research Corporation), and the agribusiness companies that produce chemicals for insect and weed control.

c) Leucaena establishment cost

While the cost of leucaena establishment is high relative to establishment of grass pasture, the additional benefits far outweigh this. Graziers already have a high producing buffel grass pasture (160–180 kg liveweight gain/animal/ha). The need is to convince them of the additional financial benefits and market flexibility that a pasture capable of producing 300 kg/animal/year of liveweight can bring.

d) Queensland Leucaena Growers Association

This association does not exist, but perhaps it should! Broadacre leucaena growing for beef production is a specialised farming system that can produce a high quality product. A specialist group might have three principal aims:

- training and skills development of existing and potential growers through interchange of ideas, training workshops, etc.;
- a common interest group to promote the system and to canvass for and seek funding for research, development, extension and training;
- develop and promote a **Quality Assured** product that leucaena/grass pasture can produce.

3. Intensive Irrigated Production Systems (M.J. Bolam)

The current system

Leucaena has been grown in the Ord River Irrigation Area (ORIA) of north-western Australia since plantings by CSIRO in the early 1970s. It was not until the discovery of the DHP destroying bacterium, *Synergistes jonesii,* that leucaena began to establish itself as a profitable option for farmers in the ORIA. No further reports of toxicity have been recorded since shortly after introduction of these bacteria. Subsequently, the Department of Agriculture (now Agriculture WA) focused on developing a management system to intensively graze flood-irrigated leucaena in the Ord valley. The industry began to develop in 1985 and today approximately 1400 ha of leucaena are under grazing in the area.

The stocking rates on well managed leucaena in the ORIA average six head/ha and growth rates of

200–250 kg/head/year are regularly achieved. This equates to 1200–1500 kg/ha/year of liveweight gain. These are some of the best levels of animal production recorded from leucaena, or any other tropical pasture, in the world. The value of the industry in 1996/97 is estimated at $2 million.

Leucaena is grazed in a rotational management system, with an optimal rotation length of six weeks (one week grazing/five weeks rest). The leucaena is planted on beds with an optimum row spacing of 1.8 m. The inter-row is planted with grasses such as Pangola (*Digitaria eriantha*) or Tully (*Brachiaria humidicola*). An ideal configuration developed by Agriculture WA and growers is to plant two rows then miss one. This provides ease of access to machinery and a good stand of grass which has been shown to be an important component of the grazing animals' ration.

The crop is flood-irrigated, on average fortnightly, during the dry season with approximately 1 megalitre of water, equating to an annual water use of around 29 megalitres per hectare. Leucaena/grass pastures are cut to maintain the stand at a height of 1.0–2.0 m every year or two (preferably cut with a circular saw, not a slasher) and fertilised to maintain soil phosphorus levels at approximately 20 parts per million.

Leucaena's susceptibility to waterlogging requires that good water management be applied including laser-levelling before planting. Seeding rates of 10–13 kg/ha are used in the valley. Full stocking rates are not achieved until 18–24 months after planting. It is important not to overstock the crop for a further 12 months to ensure lifetime productivity. Yields of dry matter range from 12–48 tonnes/ha/year. For a more detailed description of the production system, see Petty et al. 1994.

Almost all the cattle grazing on leucaena in the ORIA are destined for live export. The good growth rates, high stocking rates and all-year-round access provide a market advantage for leucaena growers. The leucaena growing areas are an important part of the vertical integration of extensive grazing enterprises. There is also the potential to produce cattle for slaughter for the domestic trade of equivalent quality to those finished in southern areas. Leucaena is also used by the local dairy to carry dry cattle and steers.

Limitations

The poor availability of slaughter facilities is at present limiting this marketing option for growers.

Two periods of reduced liveweight gains are evident in the year-round grazing system. The first is during the middle of the northern cool/dry season (May, June, July) and the second is during the mid-to-late wet season (January, February). Recent work by the Department of Agriculture has focused on improving the productivity of the leucaena/pangola system even further.

Reduced yield of herbage mass on offer has been identified as the key reason for the dry season reduction in liveweight gain. This has been addressed in two ways: firstly, to provide energy supplementation during this period using maize or molasses; and secondly, by using a grazing system that increases herbage allowance, known as the 'leader-follower' system. The use of maize in the dry season has the potential to increase annual animal liveweight gain to more than 300 kg/head. Increasing the herbage allowance to 10 kg dry matter/100 kg liveweight of cattle/day resulted in improved liveweight gain but above this, no further improvement was recorded.

The most likely reasons for the reduced liveweight gain are the wetter months during a combination of high temperature and humidity limiting the animals' ability to dissipate heat, overcast weather conditions limiting growth of both leucaena and pangola, and muddy conditions making cattle reluctant to graze.

Challenges for development

- **Economics of energy supplementation**. The improvement in liveweight gain demonstrated from maize supplementation in the dry season has also been demonstrated with molasses as the energy source. Molasses is now available in the ORIA from the recently constructed sugar mill. The technology to feed and handle molasses is well developed in the eastern states of Australia and could be readily applied in the ORIA.
- **Increased density of leucaena** (more forage in each bite). The low bulk density of leucaena leaf as compared to the pangola grass in the rotational grazing system of the ORIA results in decreased herbage intake per bite for the grazing animal. The low bulk density of leucaena would be the most likely factor limiting the intake of leucaena and is a key factor in the nutritional limitations to liveweight gain in this system (Petty et al. 1997).
- **Continued effort in promoting the quality of leucaena finished beef**. There is significant bias exhibited by buyers of cattle for slaughter against Brahman and Brahman cross animals. The tropical environment of the ORIA region requires a high content of *Bos indicus*. There needs to be continued promotion of the high quality of finished beef from *Bos indicus* based animals.
- **Pirex control and management**. The root-rot fungus, *Pirex subvinosus*, is the main recognised disease of leucaena in the ORIA. The ecology of this fungus, its mode of action and methods for control and management are not well known. This

is an important area for research in the ORIA, as is the establishment of the real, long-term impact of its presence.

- **Evaluation of new cultivars under grazing**. The assessment of new cultivars of leucaena for their agronomic limitations, animal production potential and disease resistance is essential to provide options for inevitable problems growers will face in the future.
- **Faster and more efficient establishment of leucaena**. The use of post emergent weed control could reduce the period of establishment of leucaena from 18 to 6 months. Reassessment of the benefits and costs is necessary (Pratchett and Triglone 1990).
- **Water use efficiency**. A key area of challenge for all irrigated crops including leucaena is improved use of the valuable water resource.
- **Leucaena as a weed**. Leucaena has the potential to be a weed in ungrazed areas. Selection of low seeding cultivars or sterile F1 hybrids should be given priority. The control of undesirable regeneration (by seed) of leucaena on farms should be promoted. The seed-destroying bruchid beetle that recently arrived in Queensland may help in the control of leucaena on undesirable sites.
- **Difficulties in trading cattle.** The lack of management flexibility in long-term crops such as leucaena and the problems in buying stores and selling finished cattle pose significant problems. While the focus is in the areas of expertise such as the agronomy of leucaena and animal production, it is essential to keep abreast of the realities of market issues, level of risk for producers, and the need for flexibility and coping with change.
- **Production losses due to thrip insects**. The damage to leucaena during recovery from grazing or cutting from thrip insects is recognised but poorly defined in terms of forage production and economic loss.
- **Dryland leucaena.** The potential for leucaena in the Kimberley area under dryland conditions needs to be properly evaluated.

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Adaptability Trials with *Leucaena* in Vietnam and its Potential Use in the Uplands: a Case Study

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Abstract

Leucaena leucocephala subsp. *glabrata* was tested in various forest sites in Vietnam ranging from latitude 10°41′N to 21°40′N at elevations of 10–800 m above sea level (ASL). The results showed that *L. leucocephala* is widely-adapted to different climatic conditions in Vietnam, but the key factor that limits growth rate of this tree species is soil acidity. In suitable soils with pH(KCl) >4.8–5.0 and good management after 4 years, *L. leucocephala* had reached a mean height of 8.7–10.4 m and produced an average dry biomass of 53.6–60.8 t/dw/ha. At all trial plots, *L. leucocephala* produced good quantities of seed with germination potential from 80% to 85%. Because of simple planting methods, vigorous coppicing and high potential for soil improvement, this species has been accepted enthusiastically by upland farmers. *L. leucocephala* is one the most suitable NFT species for intensification of fallow management in Northwest Vietnam and other similar areas.

SHRUBBY *Leucaena leucocephala* has been planted for garden fencing in the alluvial soils of lowland central and northern Vietnam for a long time. It was classified previously as *L. glauca* (now considered as a synonym of *L. leucocephala*). Because of its small size and low adaptability to degraded soils in the uplands, the distribution was limited.

In order to find new, fast-growing trees suitable to the wastelands of Vietnam, the Forest Science Institute of Vietnam (FSIV) has introduced 14 new exotic nitrogen-fixing tree species since 1992 for trials within the framework of a research project.

L. leucocephala subsp. *glabrata* (Ipil-Ipil) and *Calliandra calothyrsus* look very promising because of their adaptability to a wide range of climatic conditions, their quick growth and high coppicing potential. They thus have the potential ability to provide quick income to poor farmers in the uplands. This has created a demand for these species, and they are constantly requested by many people in projects dealing with upland development and aiming at the establishment of SALT models. The goal of the trial reported here was to assess the adaptability of a new arborescent leucaena in different ecological zones, and its potential use for firewood, fodder and soil improvement in fallow periods.

Material and Methods

Seed origin

Seeds of *L. leucocephala* subsp. *glabrata* (OFI 44/88) were obtained from Java, Indonesia, through the Firewood Project funded by Food and Agriculture Organisation (FAO) of the United Nations. The original seed collection by Oxford Forestry Institute was made at Gualan, Zacapa, in Guatemala.

Forest sites of trial plots

Ten forest sites were selected for trials in various bio-climatic zones between latitudes 10°41′N and 21°48′N. The sites were at elevations of 10–80 m ASL with 1320–2270 mm annual rainfall. Mean annual temperature ranged from 20 to 26.5 °C with minimum temperature of about 16 °C in the south and –1 °C in the north (Table 1, Figure 1).

The soil types were classified as red and brownish feralites developed from limestone or reddish yellow feralites from gneiss, sandstone, or basaltic soils of volcanic origin. Most of the sites can be described as hillsides degraded due to mismanagement and severe erosion with pH(KCl) of 3.6–5.1 and very low

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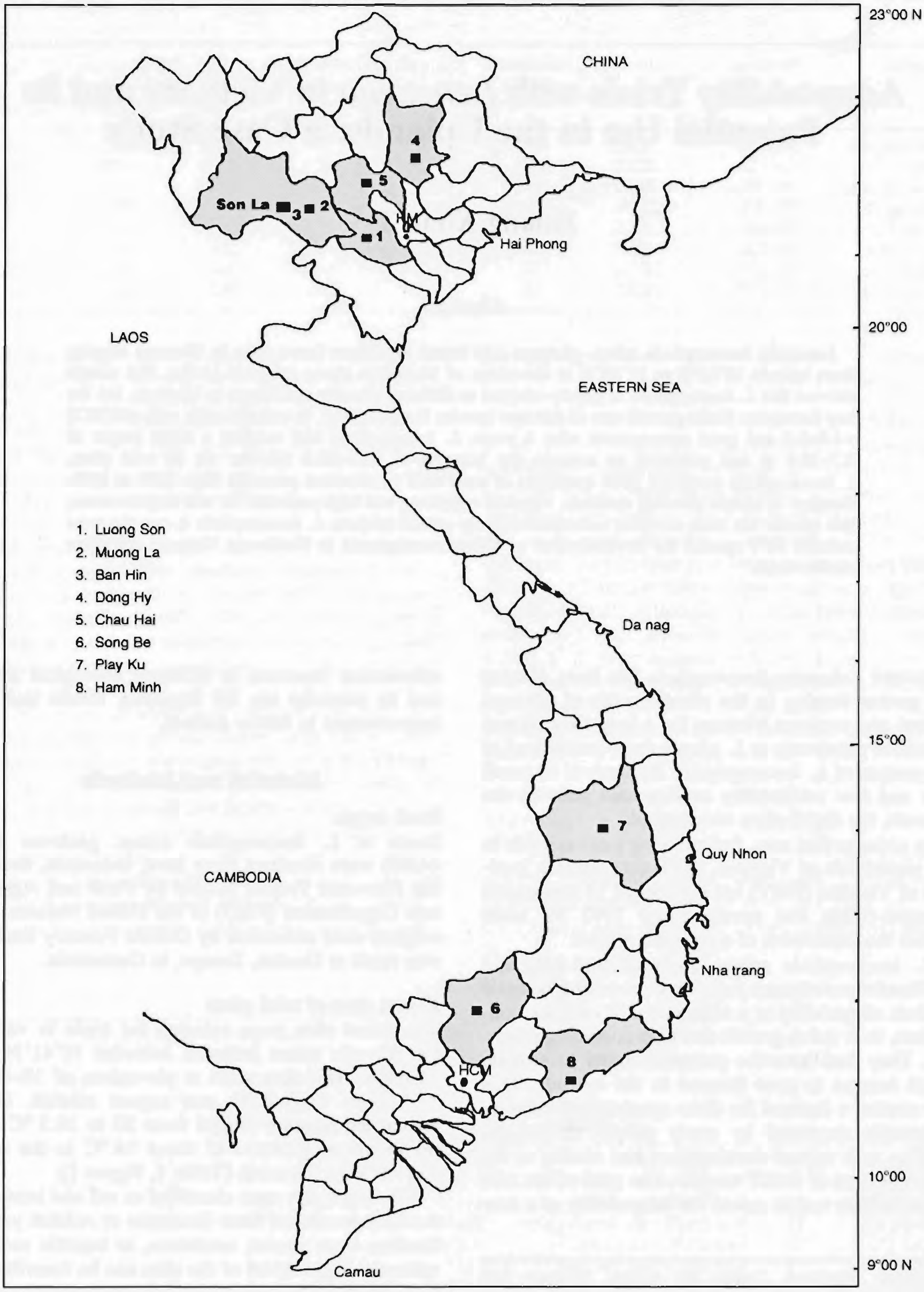

Figure 1. Distribution of 8 trial *L. Leucocephala* sites in Vietnam (1992–1995).

Table 1. Climatic conditions of the *L. leucocephala* trial sites in Vietnam (Source: Meteor-hydrology Institute of Vietnam, 1996).

Location	Province	Latitude	Elevation m ASL	Rainfall mm	Number dry months	Temperature °C		
						Mean	Maximum	Minimum
1. Muong La	Son La	21.22	400	1460	5	21.0	38.0	− 0.8
2. Ban Hin	Son La	21.22	800	1450	5	21.0	38.0	− 0.8
3. Luong Son	Hoa Binh	20.52	100	1800	4	23.2	41.2	1.9
4. Dong Hy	Bac Thai	21.36	50	2025	4	23.0	39.5	3.0
5. Cau Hai	Vinh Phu	21.32	60	1850	3	23.0	40.7	3.2
6. Play Ku	Gia Lai	13.59	800	2272	4–5	21.8	36.0	5.7
7. Song Be	Song Be	11.32	30	1800	5–6	26.2	38.6	11.9
8. Ham Minh	Binh Thuan	10.41	10	1420	5–6	26.5	35.3	16.6

amounts of available organic matter, phosphorus, potassium and nitrogen (Table 2).

Establishment of trial plots and data recording

Seeds were scarified by dipping into hot water at 80 °C for 15 minutes but were not inoculated with *Rhizobium*. Seedlings were raised in plastic tubes 6 × 12 × 30 cm in size. The plots were prepared by ploughing and were 30 × 30 m with sub-plots 30 × 10 m. The initial plant spacing was 2 × 1 m (5000 seedlings/ha).

Regular weeding was carried out and tree measurements were taken periodically. Plant measurements included basal diameter (10 cm above ground), height and dry biomass at 1, 2, 3, and 4 years after transplanting. Data were analysed with GENSTAT. Chemical analysis of soil and plant components included nitrogen (Kjeldahl method), humus (Tiurin method), pH(KCl) by pH meter, potassium (flame photometer).

Results and Discussion

Growth rate

Survival of *L. leucocephala* was good (85%–90%) in the first year, but there were significant differences in the growth and health of trees in each site.

After the first and second years, the growth differences at the various sites became apparent through the measurement of both diameter and height. At the end of the second year, average heights in the most suitable sites (Luong Son and Muong La) ranged from 6.6 m to 7.1 m, but those in the unsuitable locations (Cau Hai, Play Ku) were only 2.4–2.5 m (Table 3).

After 3 and 4 years, there were obvious differences in growth (diameter and height) of stands among sites. The three best sites were Luong Son, Muong La and Ban Hin. The Ham Minh and Bac Thai sites were considered as moderate while Play Ku, Song Be, and Cau Hai sites were not suitable for *L. leucocephala*. At Play Ku, the health of *L. leucocephala* was very poor and 60%–70% of plants were dead by the third year. Among the reasons for this could be that the dry season was too long (6 months in 1994), the ground water level was too deep (25–30 m from surface) and the wind velocity at this site (800 m ASL) was too high.

What are the key factors relating to growth rate of the tree species in the different sites? When bioclimatic conditions and soil properties of the trial sites are compared with the growth rate of leucaena,

Table 2. Characteristics of *L. leucocephala* trial sites in Vietnam.

Sites	Slope (Degrees)	Soil type and parent material	Soil depth (cm)	Soil analysis (0–10 cm layer)				
				Available P_2O_5 mg/100g	Available K_2O mg/100g	pH (KCl)	OM (%)	Total N (%)
1. Muong La	12	Feralite on schist	>100	0.4	8.1	4.9	3.6	0.18
2. Ban Hin	17	Red feralite on limestone	>120	0.3	6.3	5.0	3.0	0.15
3. Luong Son	20	Red feralite on schist	40–50	0.6	4.1	4.8	2.5	0.14
4. Dong Hy	12	Red feralite on metamorphic	30–50	1.0	5.3	4.2	1.6	0.12
5. Cau Hai	18	Red feralite on gneiss	>150	1.1	8.1	3.9	3.8	0.15
6. Play Ku	7	Red feralite on volcanic	150	0.8	6.9	3.7	3.5	0.14
7. Song Be	5	Red feralite on schist	60	1.2	7.3	4.2	2.4	0.15
8. Ham Minh	2	Sand	150	1.0	4.8	3.6	1.5	0.09

Table 3. Growth rate in diameter (cm) and height (m) of *L. leucocephala* at different forest sites.

Location (site)	1 year		2 years		3 years		4 years	
	Diameter	Height	Diameter	Height	Diameter	Height	Diameter	Height
1. Muong La, Son La	2.3	2.6	6.1	6.6	7.6	8.1	8.4	8.7
2. Ban Hin, Son La	1.8	2.1	4.3	5.1	5.3	6.2	6.4	7.5
3. Luong Son, Hoa Binh	3.1	3.8	6.2	7.1	8.6	9.2	9.8	10.4
4. Dong Hy, Bac Thai	1.5	1.8	3.2	4.5	4.1	5.3	no	data
5. Cau Hai, Phu Tho	0.6	1.4	1.3	2.4	2.7	3.9	3.6	3.7
6. Play Ku, Gia Lai	0.6	1.4	1.2	2.5	Dead	Dead	Dead	Dead
7. Song Be	0.8	1.5	1.4	2.8	3.7	4.1	4.9	5.5
8. Ham Minh, Binh Thuan	1.4	1.8	3.6	3.7	4.8	6.1	no	data

it is evident that soil pH is the most important factor directly affecting nutrient uptake and symbiosis with *Rhizobium*.

At sites where leucaena grew well, soil pH(KCl) ranged from 4.6 to 5.0. The most suitable sites were those in Luong Son, Muong La, and Ban Hin, where the soils are formed on limestone areas or on rock schist mixed with limestone at elevation 100–800 m ASL. There were no close relationships between leucaena growth rate and other soil properties relating to soil depth, nutrients or with the latitude or other climatic conditions.

From the growth rate at the trial sites, it was concluded that *L. leucocephala* could grow well only on the sites with low acidity, that is, with pH(KCl) greater than 4.8. The northwest of Vietnam has a high potential for planting this tree species because most of the soils in this area were formed from limestone and schist and have low acidity.

Biomass production

Biomass data were recorded by weighing the aboveground components (stem, leaf, branch) of 4 trees with average height and stem diameter.

Three sites with the best growth of leucaena were selected, and the biomass results are given in Table 4.

The total biomass yield of *L. leucocephala* in the suitable sites ranged form 13.4 to 16.1 t/ha/yr, of which stem and branch comprised 86% and leaf 14%. At the same forest sites, *C. calothyrsus* had a total biomass yield 10% smaller than that of *Leucaena*.

Nodulation

Almost all seedlings planted in nylon pots produced nodules in the nursery after 4 weeks without inoculation with *Rhizobium*. The number of nodules on the root systems depended on the pH and soil texture in the nursery stage (Table 5). When inoculated with

Table 4. Dry biomass (t/ha) of *L. leucocephala* at favourable sites (stands of 4 years growth).

Site	Plant density (plants/ha)	Dry biomass (t/ha)				Mean annual DM increment t/ha/yr
		Stem	Branch	Leaf	Total	
1. Muong La	4500	43.2	9.4	8.2	60.8	15.2
2. Ban Hin	4000	37.5	8.6	7.5	53.6	13.4
3. Luong Son	3800	46.5	9.0	8.9	64.4	16.1
Average	3776	42.4	9.0	8.2	59.6	14.9

Table 5. Nodulation of *L. leucocephala* seedlings in nursery (3 months old) in 1992.

Site	Soil pH (KCl) (in nylon pot)	Height (cm)	Number of nodules per seedling (>1 mm)
Luong Son	5.2	35	40
Muong La	5.1	37	36
Cau Hai	4.1	34	8
Song Be	4.5	30	12
Ha Noi	5.8	45	50

effective *Rhizobium* the dry biomass of leucaena seedlings increased 3–4 times when compared to sterile pot conditions. This situation was the same with calliandra.

Soil improvement and weed control

Topsoil samples (0–10 cm) collected just before planting and 3 years after planting at two forest sites were analysed. Some important soil properties are shown in Table 6.

The data showed that humus, N and KCl content had increased, especially humus after 3 years.

The light intensity under the canopy of the *L. leucocephala* stand decreased quickly from the second and third years. At the Muong La and Ban Hin sites, the leucaena had been planted on the fallow lands of slash-and-burn agriculture systems. There was no *Imperata* regrowth but other grasses re-grew well under a closed canopy of leucaena with a density of at least 4500–5000 stems/ha from the third year after planting.

Because of this, the highlanders in this area preferred leucaena and calliandra to other small legumes (such as *Tephrosia candida*) well known in the country.

Seed production

At all the trial sites, leucaena flowered from the second year and produced good seed even at the unsuitable locations. At the good sites, each tree in the stand at 3–4 years old could provide 1–2 kg of seed. Some single trees 4–5 years old produced 4–5 kg of good seed. The best time for seed collection in Vietnam is from October to December.

Pests and diseases

No disease was recorded at any of the trial sites, but the leucaena psyllid insect appeared in North Vietnam from November to January. Damage so far has not been severe, because the area of leucaena is very limited. Selecting psyllid-resistant leucaena for the future should be one of the priorities for research in Vietnam.

Conclusions

- *L. leucocephala* has a wide adaptability to different bioclimatic conditions from the north to the south of Vietnam at elevations from 10–800 m ASL.
- The key factor that limited leucaena growth was soil acidity. Leucaena grew well only on the soil with pH(KCl) above 4.8. In these conditions, leucaena can grow well even in degraded soil if it is managed properly in the early stages.
- The northwest part of Vietnam is considered as a high potential area for planting this species for fodder, firewood and especially for fallow management of shifting cultivation systems.
- On suitable sites in Northwest Vietnam, leucaena can reach a total biomass ranging from 13.4 to 16.1 t/ha/yr.

Leucaena has a high potential to reduce the fallow period because of its soil improving and weed control abilities.

Psyllid resistance and acid soil tolerance of leucaena should be the most important issues for future study.

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Table 6. Changes in top soil properties 3 years after planting *L. leucocephala* at two sites (layer of 0–10 cm).

Soil properties	Muong La		Ban Hin	
	Before planting	After 3 years	Before planting	After 3 years
Humus %	3.2	3.6	2.9	3.4
N (total) %	0.14	0.19	0.13	0.16
pH (KCl)	4.8	4.7	4.9	5.3
P_2O_5 Available mg/100 g	2.12	3.12	4.03	4.00
K_2O Available mg/100 g	8.71	9.87	10.7	12.9

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Leucaena in Alley Cropping Systems: Challenges for Development

R.C. Gutteridge[1]

Abstract

Alley cropping has been promoted as a sustainable agroforestry practice for upland tropical agriculture since the late 1970s. Early trials and demonstrations in humid locations on more fertile soils have indicated a number of positive benefits on crop performance. However, when the technology was used in less favourable sites, negative impacts, particularly due to competition between hedgerow and crop, became apparent. The root distribution of hedgerow species is one of the main factors influencing competition but research on this topic to date has been minimal. *Leucaena leucocephala* has been the most widely used hedgerow species in alley cropping but its competitiveness makes it less suitable in harsher environments. A number of species from other genera as well as lines from within *Leucaena* such as the new KX2 hybrid may be suitable alternatives for these sites. Adoption of the alley cropping technology by the farming community has been less than satisfactory in most areas. Some of the reasons for the poor adoption and how this may be improved are discussed.

ALLEY CROPPING, or hedgerow intercropping, as it is also known, is a sustainable agroforestry practice in which perennial, preferably leguminous trees or shrubs are grown simultaneously with a crop. The trees are grown in wide-spaced rows with the crop in the interspace or alley between the trees. Just prior to and during the cropping season, the trees are pruned and the prunings used as mulch on the crop to improve the organic matter status of the soil and provide nutrients, particularly nitrogen, to the crop.

Alley cropping was first developed in humid tropical regions as a replacement for the traditional bush fallow slash and burn system of agriculture (Kang et al. 1981).

The bush fallow system utilised the restorative power of deep-rooted trees to recycle plant nutrients, build up soil organic matter, reduce erosion and suppress weeds. Alley cropping attempts to combine the restorative attributes of the bush fallow with arable cropping so that instead of separating the two cycles, as happens in shifting cultivation, the two processes can occur simultaneously, thus allowing the farmer to crop the land for an extended period.

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The beneficial effects of alley cropping including improved crop performance, reduction in the use of chemical fertilisers and reduced soil erosion on sloping land (Kang and Gutteridge 1994) were widely promoted in the early 1980s. This resulted in the initiation of a substantial number of research and demonstration programs largely in more humid locations on reasonably fertile soils.

As the technology spread to less favourable climatic and edaphic locations, the negative impacts of alley cropping, most notably competition between tree and crop, often began to outweigh the benefits.

A number of general reviews of alley cropping (Kang 1993; Reynolds 1994; Sanchez 1995) have described the technology and outlined its impact over the past 10–15 years. This paper addresses both the positive and negative factors that influence the outcome of alley cropping, together with the role that *Leucaena* has played as a hedgerow in the system.

Choice of Hedgerow Species

The choice of hedgerow species for alley cropping is extremely important and can often determine the success or failure of the system. Rachie (1983) suggested that the ideal hedgerow species should have the following attributes:

- rapid establishment and growth rate;
- ability to regrow after frequent cutting;
- nitrogen fixing capacity;
- low tannin content in leaf;
- deep rooted with a different root distribution to the crop;
- ability to withstand environmental stresses.

Leucaena leucocephala has been the most widely used hedgerow species in research and demonstration activities on alley cropping, because it combines many of the attributes mentioned above (Kang and Gutteridge 1994). Also, in a number of comparative studies, it was shown to be superior to other species (Kang and Reynolds 1986). However, most of the work on alley cropping in the early 1980s was undertaken in favourable humid environments on reasonably fertile, high base-status soils where *L. leucocephala*, prior to the arrival of the psyllid, excelled. When alley cropping was tried in less favourable environments, such as low fertility, acidic, low base-status soils and semi-arid climates, the beneficial effects of the system were often nullified. This was largely due to the strong competitive effect of the tree on the crop for the limited resources particularly moisture.

This, together with the impact of the psyllid (*Heteropsylla cubana*), prompted a major effort to seek alternative hedgerow species. Ethno-botanical surveys were undertaken in regions dominated by low activity, acid infertile soils to try to identify appropriate species. *Flemingia macrophylla* (Kang et al. 1991), *Erythrina poeppigiana* (Kass et al. 1992), *Alchornea cordifolia*, *Dactyladenia barterii* (Lawson and Kang 1990) and *Peltophorum dasyrachis* (Van Noordwijk et al. 1995) have all proved to be of some value for alley cropping in more difficult sites. However, none have really reached the potential of *L. leucocephala* in the more favourable environments before the arrival of the psyllid.

Crop Performance

An effective, objective means of evaluating crop performance in alley cropping systems is essential, as this is the factor of most interest to the farmer.

Sanchez (1995) utilised a modified tree-crop interaction equation to quantify the crop and tree components in alley cropping as follows:

$$I = F - C$$

where I = overall interaction as a percentage of sole crop yields free from interference with trees.

F = the fertility effect, the percentage of crop yield increase caused by soil fertility improvements from added tree mulch.

C = the competition effect, the crop yield decrease caused by competition with trees for light, water and nutrients.

A summary of some long-term alley cropping experiments conducted over a range of environments and soil types is presented in Table 1. In general,

Table 1. Alley cropping results from a range of environments. Values for I, F, C expressed as a percentage of sole crop yields. (After Sanchez 1995)

Location	Climate	Soil	Tree	Crop	I	F	C	Reference
Hyderabad, India	Semiarid 550 mm	Alfisol pH 6.0	*L. leucocephala*	Millet, Peanut	−58	+19	−77	Rao et al. (1991)
Machakos, Kenya	Semiarid 230 mm	Alfisol pH 5.6	*Senna siamea*	Maize	−31	+ 3	−34	ICRAF (1993)
Chipata, Zambia	Subhumid 760 mm	Alfisol pH 4.6	*L. leucocephala*	Maize	−20	+36	−56	Akyeampong et al. (1995)
Ibadan, Nigeria	Subhumid 1400 mm	Sandy Entisol pH 6.2	*L. leucocephala*	Maize	+ 4	+58	−54	Kang et al. (1981)
SE Qld, Australia	Subhumid 1400 mm	Ultisol pH 5.2	*L. leucocephala*	Kenaf	+27	+33	−6	Gutteridge (1988)
Yurimaguas, Peru	Humid 2200 mm	Ultisol pH 4.2	*Inga edulis*	Rice	−30	+28	−58	Szott et al.(1991)
North Lampung, Indonesia	Humid 2700 mm	Ultisol pH 4.7	*Peltophorum dasyrachis*	Maize	+32	+58	−26	Van Noordwijk et al. (1995)

these indicate that in semi-arid locations on acid soils there is a large negative impact of alley cropping. In more humid areas, alley cropping generally has a positive effect but where soils are highly acidic, a negative result can also occur, for example in Peru (Szott et al. 1991).

These results highlight some of the problems associated with alley cropping primarily due to competition between the tree and the crop.

In more favourable humid locations, competition for light is usually the most important factor limiting yield depending on the vigour of the tree. In studies where the tree was allowed to grow during the cropping season, serious competitive impacts (C = –54%) occurred (Kang et al. 1981). Conversely, in southeast Queensland where *L. leucocephala* was cut 2 or 4 times to 25 or 50 cm during the cropping season, competition for light was much reduced to a C value of –6% (Gutteridge 1988). Thus, the simple solution to competition for light in more humid environments is to prune the tree frequently at a low cutting height during the cropping season.

Competition for moisture in semi-arid areas is a much more serious problem with yield reductions of between 30 and 75% occurring in the alley treatments in some experiments (Singh et al. 1989; Rao et al. 1991; ICRAF 1993). The solution to overcoming the problem of competition for moisture is not an easy one. Techniques such as the insertion of root barriers or trenching beside the tree rows have been proposed (Verinunbe and Okali 1985) but are generally far too costly and often not very effective. Deep ripping along the tree row at the start of the cropping season is a feasible option as this severs lateral roots that have grown into the alley area during the off-season. Severe pruning at the time of crop planting can also reduce root density and this, in combination with deep ripping, may reduce competition particularly if the pruning is continued during the crop growth cycle. Another alternative is to alter the arrangement of the tree and crop by increasing the distance between tree rows and allowing a space of up to 2 m between the tree and the first crop row. The use of a more productive tree such as the KX2 hybrid (*L. leucocephala* × *L. pallida*) (Mullen et al. these Proceedings) may be useful in this situation to help compensate for the increase in area that requires mulching with increased tree row spacing. However, its greater vigour is likely to be accompanied by greater competition for available resources.

Competition between tree and crop for below ground resources depends to a large extent on the root architecture of the tree. Trees that rely mainly on superficial root systems are probably highly competitive with shallow rooted crops. One of the objectives of alley cropping is to utilise trees that have a complementary root architecture to the crop and thus minimise below ground competition.

Quantifying tree root architecture and thus its likely competitive nature is a very difficult and laborious process and often cannot be related to farmers' criteria for assessing the performance of trees. Van Noordwijk and Purnomosidhi (1995) proposed an 'index of root shallowness' as an indicator of competitiveness for the tree. Indices of 2.13, 0.97 and 0.39 were calculated for *L. leucocephala, Paraserianthes falcataria* and *Calliandra calothrysus* (calliandra) respectively, indicating decreasing competitiveness.

However, other studies indicated that *L. leucocephala* may be less surface rooted and therefore less competitive than calliandra. For example, Swasdiphanich (1993) found that root length density in the top 50 cm of soil within 50 cm of a *L. leucocephala* hedgerow was 0.5 cm/cm^3 while that for a calliandra hedgerow of the same age was 2.0 cm/cm^3. Mugwe et al. (these Proceedings) found that maize sown in association with calliandra was lower yielding than when grown with *L. leucocephala* indicating the greater competitiveness of calliandra. Evidence from Mt Cotton in southeast Queensland (Gutteridge unpublished data) where grass growing in association with calliandra was observed wilting before that growing with *L. leucocephala* in dry periods also points to calliandra being more competitive.

As suggested by Van Noordwijk and Purnomosidhi (1995), much more work is required in this area before a reliable, effective indicator of tree competitiveness can be developed.

Level of Nutrient Addition from Hedgerows

The level of nutrients applied to a crop from the hedgerow will vary with climate, soil type, species of tree and its management. In many situations, the gross amount of nutrients applied in the mulch from tree legumes over the cropping season will be in excess of the requirements of the crop (Table 2). Conversely, the nutrients (particularly N, P, K) supplied from non-legume trees are generally not sufficient for a crop, indicating the benefit of using tree legumes (Table 2). However, even though the gross amount of nutrients from tree legumes is sufficient, a problem arises due to slow rate of release and availability of the nutrients out of synchrony with crop requirements. Factors such as C:N ratio, lignin and polyphenol contents of the mulch influence decomposition rate, the subsequent release of nutrients and their uptake by the crop (Kang and Gutteridge 1994). Differences between tree species can also be important. Gutteridge (1990) showed that mulch from *Sesbania sesban* was superior to *L. leucocephala* and gliricidia (*Gliricidia sepium*) in supplying N to

Table 2. Nutrients supplied (kg/ha) by 4t leaf mulch from tree legumes and non-legumes in comparison to the nutrient requirements for an average corn crop (from Juo and Kang 1989 and Palm 1995)

	N	P	K	Ca	Mg
Average of 5 tree legumes[1]	140	10	80	50	10
Average of 2 non-legumes[2]	56	3	28	50	8
Corn requirements	80	18	66	15	10

[1] *Erythrina poeppigina, Inga edulis, Leucaena leucocephala, Gliricidia sepium, Senna siamea.*
[2] *Dactyladenia barteri, Grevillea robusta.*

maize but mulches from calliandra, *Acacia cunninghamii* and *A. fimbriata* were ineffective sources of N over a 56-day period. This may have been due to the high polyphenol and/or lignin content of the latter species. *L. collinsii* may have potential as a hedgerow species because of its relatively high yields and very low tannin contents (Dalzel et al., these Proceedings). While some of the other *Leucaena* species such as *L. pallida* and *L. trichandra* are high yielding, they have high tannin concentrations and low in vitro dry matter digestibilities. This makes them less useful in alley cropping because of the slower breakdown rate of their leaf.

However, rapid decomposition and release of nutrients may not always be an advantage in alley cropping as many farmers prefer mulch to be long lasting to help control weeds and provide a better soil environment (Palmer 1996). This problem has been addressed to some extent in the Philippines by utilising double hedgerows of *Desmodim rensonii* and *Flemingia macrophylla*. The leaf of *D. rensonii* breaks down quickly and releases nutrients while the larger more fibrous leaf of *Flemingia* lasts longer giving good cover and protection to the soil.

Socio-economic Factors Influencing Alley Cropping

In the early 1980s, a large number of research trials and demonstrations on alley cropping were established by local, national and international agencies but subsequent uptake of the technology by the farming community was low.

A number of reasons have been put forward as to why this was the case. One of the primary reasons for rejection of the technology by smallholder farmers was that it was too labour intensive and that labour for pruning hedgerows was required at the time of peak labour demand for other activities such as land preparation and crop planting. Other reasons for poor adoption include:

- alley cropping was found to be not suited to many environments;
- results from 'on station' research were not repeatable 'on farm';
- often the technology did not address the farmers real problems;
- there was a long lead time for benefits to take effect.

On the last point, Rusastra et al. (1997) compared open field farming with hedgerow intercropping in *Imperata* dominated areas of Lanpung, Indonesia, and found that the hedgerow system provided higher yields after 5 years and higher economic returns after 10. These lead times are far too long for most smallholder farmers who are primarily interested in the yield from the next crop.

However, in some areas, notably Southern Mindanao and Cebu in the Philippines and the islands of Timor and Flores in Indonesia, alley cropping or its modifications have been well adopted by the local farmers. Surveys undertaken in these areas have pointed to a number of common factors that give a good indication of whether the technology is going to be successful. These include:

- the existence of a stable land tenure;
- good community interaction;
- accessibility to markets;
- appropriate extension systems with farmer to farmer contact;
- sloping land with an erosion hazard;
- flexible technology which can be modified to meet farmers' needs.

In the Philippines, the original Sloping Agricultural Land Technology (SALT), a system of alley cropping developed by the Mindanao Baptist Rural Life Centre, has now been extended to four modified versions based on livestock production, timber trees and perennial fruit trees. There is also substantial flexibility within each SALT version making them very attractive to local farmers (Palmer 1996). This flexibility may have been one of the reasons for relatively high adoption rate in this region.

In parts of Africa, there has been greater interest shown by farmers in a modified alley cropping version known as 'alley farming' (Reynolds 1994) in which livestock play an important role in the system. Farmers who own livestock are more inclined to feed the foliage produced from the hedgerows directly to their animals particularly if the hedgerow species is of high forage quality such as *L. leucocephala*. Manure from the animals is then spread over the interrow areas giving similar benefits to the conventional alley cropping system.

Conclusions

Leucaena leucocephala has been the most widely used woody species in alley cropping largely because it has many attributes that make it suited to the system. However, its competitiveness makes it less suitable in harsher environments. The new *Leucocephala* hybrid (KX2) as well as other hybrids may be suitable alternatives to *L. leucocephala* in psyllid-prone environments and less favourable sites, but their competitiveness with crops needs to be examined. Combinations of species will also add to flexibility and biodiversity. More research should be directed to describing the root distribution of hedgerow species and quantifying its effect on competition with crop species.

In general, alley cropping is an appropriate agroforestry technology given the right biophysical and socio-economic circumstances, but it should not be regarded as a panacea for all the problems of upland agriculture, as it perhaps once was. Flexibility is the key with a system designed to meet the needs of the smallholder farmer.

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Poster Papers

Leucaena leucocephala in Papua New Guinea Smallholder Farms

M.E. Moat[1], K.K. Galgal[2], M.K. Komolong[3] and J. Tarabu[4]

Abstract

The use of *Leucaena leucocephala* in a range of smallholder cropping systems, as livestock feed, for shade, and other multipurpose uses are discussed. Improvements in these systems will be based on new high-yielding pest- and disease-tolerant species, together with a well-coordinated and funded extension program. The importance of focusing on a specific industry is emphasised.

MORE than 80% of Papua New Guinea's 4.0 million people live in rural areas and depend on semi-subsistence agriculture. The development of sustainable smallholder farming systems is therefore essential for the socio-economic stability of rural PNG.

The use of multi-purpose leguminous tree species for improving smallholder agriculture has been recognised. *Leucaena leucocephala* (leucaena), introduced more than 100 years ago and extensively naturalised in PNG, has been accepted into the rural farming communities. Its importance and its uses are highlighted in this presentation.

Leucaena in Food Cropping Systems

The naturalised leucaena has found its way into various smallholder food cropping systems as a short-term fallow, and for alley cropping and land stability on sloping lands.

The best example of leucaena use for a smallholder food cropping system is the leucaena fallow for yam cultivation along the coral uplifts of the Huon Peninsula in the Morobe Province. This system has been accepted and used over the last 40–60 years by the local population of more than 30 000 people. The naturalised leucaena thickets cover an area of approximately 50 square kilometres along a narrow (1 km) coastal strip.

The naturalised leucaena thickets are cleared after every 3–4 year fallow for a single yam crop. The local people prefer the leucaena fallow to a grass fallow having recognised the benefits of soil fertility maintenance, especially under increasing land pressure in recent years, and the abundance of the leucaena stakes for yam vine cultivation.

Leucaena as Livestock Feed

Leucaena forage from naturalised stands is readily fed in small quantities to village pigs and poultry. The high protein fodder is also utilised for the newly introduced village livestock, viz. sheep, goats and rabbits. However, the biggest use of leucaena for livestock is by smallholder cattle farmers. There is currently about 200 ha of naturalised leucaena in use for smallholder cattle in Morobe Province.

There are additional areas of naturalised leucaena which not only offer the potential but are being actively promoted and utilised for further expansion of smallholder beef cattle projects. This improvement program for smallholder cattle is well supported by government extension and rural credit schemes.

Other Common Uses of Leucaena

Leucaena's initial role in PNG agriculture as a common shade tree for cocoa and coffee, in both smallholder blocks and large plantations, is still as important to this day. Besides providing shade,

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leucaena is also used as live stakes for crops such as vanilla, pepper and native mustard.

Other important uses of leucaena, viz., fuelwood, fence posts, building posts and poles, are increasingly appreciated in rural communities faced with encroaching grasslands and retreating forests under increasing population pressure.

Leucaena: Challenge for Development

Smallholder farmers in PNG have readily adopted the naturalised shrubby leucaena into their contemporary subsistence and cash-cropping systems. Improvements in these existing farming systems will be based primarily on introduction of new high yielding, pest and disease tolerant leucaenas. Another challenge is a well coordinated and funded extension program on leucaena-based farming systems.

However, the real challenge is to have a focus on a specific industry or primary produce to ensure the initial success of the new and improved leucaenas.

The current pilot extension program for improvement of smallholder beef cattle production depends very much on leucaena for improved nutrition. The success of the smallholder beef farmers is therefore in the interest of efforts for the greater utility of leucaena.

Leucaena and other Shrubby Green Manure Cover Crops in Contour Hedgerow Farming Systems on Sloping Lands in Vietnam

Thai Phien[1]

Abstract

Intensive cultivation of sloping land has led to extensive soil erosion and degradation. This paper summarises the results of experiments at 11 sites in Vietnam, involving eight hedgerow species, two cereal crops and some grain legumes. Hedgerow prunings (and in some cases crop plant material) were returned to the soil. Using the hedgerow system, soil loss was reduced by 50%–60% and the yields of alley crops generally increased, although the extent varied among sites and crop species. It is concluded that the contour-hedgerow and alley-cropping technologies are applicable in a wide range of environments and will produce increasing benefits over time.

THE use of sloping land is vitally important for the development of agriculture in Vietnam because of population pressure. The food deficiency in the 1980s led to massive deforestation and inappropriate landuse causing soil erosion. Consequently, large areas of soil were degraded. Attempts to control erosion on upland sloping lands have largely not been successful.

In 1990, the National Institute for Soils and Fertilisers (NISF) in collaboration with international agencies (IBSRAM, AIC, ACIAR, NGOs) and in-country institutions set up long-term experiments together with on-farm research sites in 1990 to test the improved technology on sloping lands of Vietnam. This research uses a participatory approach, and closely collaborates with farmers to apply hedgerow farming systems as biological measures for erosion control. Shrubby leguminous green manure cover crops are one of the components of these hedgerow farming systems (alley cropping). Farmers are trying to minimise soil erosion and to amend soil fertility for long-term sustainable land use.

This paper gives a synthesis of the observations on contour-farming systems on sloping lands in Vietnam. It gives an evaluation of the system as a soil conservation measure and a crop production enhancement strategy on sloping uplands. Information on the performance of the hedgerow species used, and on the effects of the hedgerow farming systems on soil conservation and crop yields have also been included. Finally, it provides general recommendations to hasten the technical applicability of the technology in a wide range of environments.

Research Program

Sites

The main interest is in the use of hedgrow plants in improving soil fertility and reducing soil erosion, and many experiments have focused on these aspects. The ASIALAND sloping lands network is composed of cooperators from seven countries in Southeast Asia including Vietnam with the NISF as the focal point. In their validation experiments, all the countries have included contour-hedgerow farming or alley cropping as a system of soil conservation and food production. Table 1 shows some of the long-term experiments together with farmers participatory research sites in the ASIALAND network in Vietnam. Many other National and International program/projects especially agroforestry projects are applying contour farming systems as the main measure for soil conservation and erosion control.

Hedgerow species and crops

Species suitable for hedgerows can have many uses. Some of these include:

Garden fencing: *Leucaena leucocephala*, *Cajanus cajan*, *Crotalaria juncea*, *Crotalaria anagyroides*,

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Table 1. Conservation farming technologies evaluated by NISF on sloping lands in Vietnam.

Research site	Slope of site (%)	Year initiated	Conservation farming technology
1. Bavi (Ha Tay)	10–12	1990	Alley cropping Agroforestry Hillside ditch
2. Luong Son (Hoa Binh)			
Hoa Son village	39–42	1992	Alley cropping Agroforestry Hillside ditch Grass strips
Dong Rang village	15–20	1992	Alley cropping Hillside ditch Crop residue incorporation Intercropping Stone contour band
Lam Son village	42–45	1995	Alley cropping Agroforestry Improved fallow Natural fallow
Rut village	16–25	1995	Alley cropping Agroforestry Intercropping with fruit trees
3. Thanh Ba (Vinh Phu)			
Thai Ninh village	18–30	1995	Alley cropping Agroforestry Hillside ditch
Phuong Linh village	20–25	1994	Alley cropping Hillside ditch
4. Dong Dang (Lang song)	25–35	1997	Alley cropping Agroforestry Intercropping with fruit trees
5. Phu Quy (Nghe An)	18–30	1994	Alley cropping Agroforestry Intercropping with coffee
6. Buon Ma Thuot (Dac Lac)			
Eakmat	10–12	1990	Alley cropping Hillside ditch Bunding Intercropping with coffee
Eakchucap	28–30	1995	Alley cropping Hillside ditch Intercropping with coffee

Crotalaria striata, *Crotalaria urasamoensis*, *Tephrosia candida*, *Tithonia diversifolia*.

Wind breaks: *L. leucocephala*, *Acacia confusa*, *A. mangium*, *Casuarina equisetifolia*.

Permanent shading: *Cassia occidentalis*, *Cassia siamea*, *Crotalaria anagyroides*.

Temporary shading: *Cassia tora*, *Crotalaria urasamoensis*, *Sesbania cannabina*, *T. candida*.

For green manure: most of the above species.

For erosion control: all of the above species.

This paper considers only the latter two uses.

Table 2 shows the hedgerow species and the crops used in research and extension on sloping lands in Vietnam. At least eight hedgerow species, two cereal crops, and some grain legumes were used. *Tephrosia candida* was the most widely planted species because of its tolerance to low soil fertility, drought, and pests.

Experimental management of the alley crops and hedgerows

Cereal crops (upland rice and maize) were alternated with leguminous crops in most research and extension sites. The legumes used were peanut, mungbean, black bean, and soybean, based on the predominant crops grown in the area. The alley crops were either unfertilised or had different levels of inorganic fertiliser applied (Table 3).

Table 2. Major contour-hedgerow farming systems on sloping lands in Vietnam.

Alley crops	Hedgerow species
Upland rice	*Tephrosia candida*
Cassava	*Tephrosia candida* + *Crotolaria*
Maize-bean/peanut	*Tephrosia candida* + Tea
Maize-Peanut/bean	Tea
Maize-peanut	*Leucaena leucocephala*
Coffee/tea/fruit trees	*Leucaena leucocephala* + *Tephrosia candida*
Coffee	*Leucaena leucocephala* + *Crotolaria striata*
Maize-bean(peanut)/cassava	*Leucaena leucocephala* + *Cajanus cajan*
Annual crops	*Cajanus cajan*, *Flemingia congesta*, *Tithonia diversifolia*, Lemon grass
Annual crops/fruit trees	Natural grasses, Vetiver grass, Pineapple

Table 3. Application of inorganic fertilisers to the alley crops.

Research sites	Alley crops		Input levels
All sites with annual crops	Upland rice peanut/bean-maize cassava	No input	No fertiliser applied, herbage returned to soil (Farmers' practice)
		Low input	Half basal application of N, P_2O_5, K_2O and CaO (15–45–30–500 kg/ha) with peanut/soybean herbage returned to soil
		High input	Full basal application of N, P_2O_5, K_2O and CaO (30–90–60–1000kg/ha) with peanut/soybean herbage returned to soil
All sites with perennial crops	Coffee, fruit trees	No input	No fertiliser applied, no intercropping (Farmers' practice)
		Low input 1	No fertiliser. Leguminous crops as intercropping, herbage returned to soil
		Low input 2	Half basal rate of fertilisers used for annual crops and intercrops
		High input	Full basal rate of fertilisers used for annual crops and intercrops

The hedgerows were planted at the start of the experiments/on-farm research. They were spaced at 6–8 m intervals; the double hedgerows were about 1 m wide, and the single hedgerows 0.5 m. The hedgerows were trimmed regularly every 60 days after the first cutting in the rainy season, and the prunings returned to the soil as mulch.

Performance of the hedgerow species

The mean herbage yields of the hedgerow species are presented in Table 4.

Nutrient return

One of the factors that influences crop yields and the sustainability of agricultural systems is soil fertility. Since most of the plant nutrients are contained in the upper 15 cm soil layer, the loss of this soil by erosion is detrimental to crop production. By the same argument, minimising soil loss and returning organic residues to the soil may improve its productivity.

Table 4. Average herbage yield (t/ha/yr) of hedgerows in some tested sites on sloping lands.

Hedgerow	No input	Low input	High input
Tephrosia	4.5	5.8	6.5
Tephrosia	—	6.5	—
Flemingia	4.2	5.5	6.8
Flemingia	—	6.6	—
Leucaena	3.5	4.7	6.6
Leucaena	—	5.1	—
Leucaena	—	4.5	—
Cajanus	—	6.5	—
Tephrosia + *Cajanus*	3.8	5.3	5.8
Tephrosia + *Leucaena*	3.5	4.7	5.0
Tephrosia + *Crotolaria*	4.0	5.7	6.8

The hedgerow pruning returned to the soil between 3.5 and 6.8 t/ha for mulching, erosion control and improvement of soil fertility. Based on the nutrient content of hedgerow species (Table 5), and assuming one-tenth of the area is occupied by hedgerows, the amount of nutrient returned from hedgerow species should be of the order of 30 kg N, 3 kg P, and 25 kg K/ha/year.

Table 5. Average nutrient content (% of dry matter) of some hedgerow species.

Species	Nutrient		
	N	P	K
Tephrosia candida	2.30	0.40	2.77
Leucaena leucocephala	2.52	0.37	2.00
Cajanus cajan	1.62	0.37	1.40
Flemingia congesta	2.41	0.25	2.30
Crotolaria anagyroides	3.36	0.23	2.10

Soil erosion

Alley cropping reduced soil erosion at all experiment sites (Table 6) with soil losses all being 50%–60% less than the control.

Formation of terraces

Terrace formation was observed at the study sites between 1990 and 1992. The terraces resulted from filtration and accumulation by the hedgerow plants of runoff sediments. This was enhanced by the cultivation in the alleys. In the experiment site at Hoa Son, the slopes developed a distinctive profile after three years. An abrupt drop of about 10–20 cm was observed a few centimetres downslope from each hedgerow. Below this point, the slope was uniform until 50–70 cm above the next hedgerow, where the upslope limit of an accumulation wedge of soil was seen. The accumulation wedge showed evidence of layering, with each layer presumably representing the accumulated soil drop by the runoff of an individual storm as it was slowed down by the hedgerow.

Similar results were observed from experiment sites in IBSRAM ASIALAND-Sloping Lands Network in Thailand, Philippines, China, and Indonesia.

Changes in soil properties

As much as 60–80 kg/ha/year of N, 25–35 kg P_2O_5, and 20–30 kg K_2O can be lost under the farmers' practice of no hedgerow cultivation. This is more than two or three times the amount of nutrient applied to the crops in the same period. This can drastically reduce the fertility of the topsoil and its capacity to produce crops economically. With alley cropping, the amount of nutrients lost is reduced by the prunings returned to the soil. If the crop residues are also returned, soil fertility will be improved even further.

Observations at the research sites showed that soil moisture contents in the plots with hedgerows were consistently higher than in the plots without hedgerows and bare plots.

With these results, however, there is still a need for further evaluation as there were also observations suggesting possible competition between the hedgerows and the alley crops for nutrients, sunlight, and water. Plants nearer the hedgerows were relatively less vigorous than those at the middle of the alleys.

Yield of the alley crops

The effects of alley cropping on crop yields, when compared to those of the farmers' practice, are presented in Table 7. In general, alley cropping gave equal or even higher yields of crops than those from the farmers' practice despite the reduction in the effective cropping area of 10%–15%, although the response varied across sites and among species. Maize and cassava had the greatest absolute increases in yield.

The positive effect of alley cropping on the yield of crops increased with time. In some experimental sites, an increasing yield difference between the alley

Table 6. Comparison of soil loss between the farmers' practices (control) and alley cropping.

Site	Slope (%)	Mean soil loss (t/ha/yr)		Soil loss reduction (%)
		Control	Alley cropping	
Ba Vi	10–12	2.3	1.1	52
Hoa Son	39–42	20.0	8.0	60
Dong Rang	15–20	30.4	12.3	60
Thai Ninh	18–30	43.1	15.9	63
Phuong Linh	20–25	44.2	17.4	61
Phu Quy	18–30	38.4	14.3	63
Eakmat	10–12	8.2	4.1	50
Eakchucap	28–30	85.2	38.6	55

Table 7. Mean yield of alley crops in farmers' practice (control) and alley cropping.

Site	Crop	Average yield (kg/ha)		
		Control	Alley cropping	Effect (%)
Hoa Son	Black bean	445	556	+25
	Peanut	463	656	+42
	Vigna sinensis	364	436	+20
	Maize	1181	1916	+63
	Cassava	11130	12150	+9
	Cassava	11940	14500	+21
Dong Rang	Peanut	660	850	+29
	Peanut	780	790	+1
	Cassava	18700	19000	+2
	Cassava	12850	11930	–7
Phuong Linh	Peanut	1171	1200	+2
	Peanut	1012	916	–9
	Cassava	16900	17000	+1
	Cassava	14600	15100	+3
Phu Quy	Peanut	986	1126	+14
	Maize	1450	1568	+8
Eakmat	Coffee (fresh)	12100	16100	+33
	Mungbean	1200	1090	–9
	Peanut	1520	1530	+1
	Maize	4500	4500	0

cropping and the farmers' practice treatments was observed over the three-year period of the research. This was observed even if the alley cropping area was only four-fifths of the farmers' practice treatment. Although there was no consistent trend in yield (partly complicated by seasonal change in climate), it was obvious that the alley cropping technique could yield sustainable agriculture on sloping lands. The beneficial effects will be more obvious in later years when most of the surface soil from the farmers' practice (no soil conservation measure) is eroded and its fertility is depleted.

The observations from the field validation experiments on the sloping lands showed the technical adaptability of the contour-hedgerow and alley-cropping technologies in a wide range of environments. The results have shown the beneficial effects of alley cropping in soil and water conservation and in maintaining and increasing crop production. They corroborate the results of earlier studies indicating the positive effects of alley cropping. In relation to these observations, some general recommendations may be considered to improve further the effectiveness of the contour-hedgerow farming system.

The effectiveness of the alley cropping technology should not be evaluated only for its beneficial effects on soil conservation. Of equal importance are the benefits to farmers from the increased yield of the crops. Although alley cropping is unlikely to produce crop yields comparable to yields that can be obtained using optimum inorganic applications with conventional cultivation, the benefits could be enhanced by the application of inorganic fertilisers. These would benefit not only the alley crops but also the hedgerow crops, as shown in the results from the experiments.

Conclusions

L. leucocephala together with other shrubby leguminous cover crops can be used in hedgerow farming systems on sloping lands. These species can contribute to soil erosion control, improvement of soil fertility, and increase crop yields in the alleys.

Management of hedgerow crops and alley crops is vitally important for the benefit of the cultivated systems. Under a systems approach, the compatibility of the hedgerow species with the alley crops planted should also be subject to tests and verification. Aspects of shading, provision of organic matter, and crop yields for sustaining the agricultural systems on sloping lands, need to be investigated.

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An Overview of *Leucaena* Usage in the Southern Philippines: The Mindanao Baptist Rural Life Center (MBRLC) Experience

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Abstract

Leucaena leucocephala has been known in the Philippines since the sixteenth century. Extensive research during the 1970s was slowed by the advent of the psyllid. The Mindanao Baptist Rural Life Center (MBRLC) has demonstrated the usefulness of *L. leucocephala* in corn production and as a feed source for dairy goats. MBRLC has also developed sloping agricultural land technologies for corn production using hedgerows of nitrogen-fixing trees and shrubs for soil erosion control and soil amelioration. Whereas *L. leucocephala* was used exclusively for these hedgerows, its popularity has declined due to the psyllid, and it is now being replaced by *L. diversifolia*, *Desmodium rensonii* and *Flemingia macrophylla*.

THE MINDANAO Baptist Rural Life Center (MBRLC) is a rural development ministry of the Philippine Baptist Mission, International Board, USA. The centre is located on a 19 ha demonstration farm at Davao del Sur on the island of Mindanao, Philippines, and is dedicated to the betterment of upland farmers in the Philippines as well as the rest of Asia.

A high emphasis has been given to trees such as *Leucaena* spp. and their role in sustainable farming systems for small landholders. Several internationally known technologies and demonstrations using *Leucaena* and other nitrogen fixing trees/shrubs (NFT/S) have been developed by the MBRLC and extended to the numerous upland farming communities throughout the southern Philippines and the rest of Asia. These are primarily the sloping agricultural land technologies, known generally as SALT.

SALT is a soil conservation-oriented farming system, basically attuned to the corn production of small sloping-land farmers. It makes use of nitrogen fixing trees/shrubs planted thickly as a double hedgerow on contour lines and spaced about 3 to 5 metres apart for soil erosion control and soil amelioration. Every third alley is planted to a locally used permanent crop while the other two alleys are used for food/cash crops.

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This paper looks at the development and use of *Leucaena* in the southern Philippines. It traces the progress of *L. leucocephala* from its promotion as a 'miracle tree' to the post-psyllid era and its resurgence as an integral use in farming systems at the MBRLC and surrounding areas of southern Mindanao.

Leucaena use in Philippines

The original introduction of *L. leucocephala* into the Philippines is thought to have been by the Spanish in the sixteenth century, probably as a forage for their animals. By 1973, largely because of interest aroused by the 'Hawaiian Giant' *L. leucocephala* (K lines from Hawaii), a nation-wide comprehensive research program was in place devoted to exploiting the multiple uses of *L. leucocephala*, the 'miracle tree'. Giant ipil-ipil was widely promoted and tested throughout the Philippines until the mid-1980s when the psyllid (*Heteropsylla cubana*) attacked. *L. leucocephala*, once touted as the miracle tree, was defoliated by the psyllid and research interests as well as local users turned to other species.

MBRLC use of *Leucaena*

Prior to 1985, *L. leucocephala* was the primary focus of MBRLC's NFT/S-based farming systems. It was used as an erosion control and for soil amelioration, as fodder for goats, reforestation and fuelwood production, and fresh composting for production of garden vegetables and fruits.

Initially, the MBRLC SALT models were exclusively built upon *L. leucocephala* as the foundation of the double contour hedgerow system. The original Demonstration SALT, first planted in 1978 on a 40% slope (and still productive today), was solely a *L. leucocephala*-based system. However, due to the psyllid, hedgerow species utilised in the SALT farming systems have been diversified to include *Desmodium rensonii, Flemingia macrophylla, Gliricidia sepium, Leucaena diversifolia, Indigofera tyesmani* and *Calliandra calothyrsus* along with some of the original *L. leucocephala*. Most of the earlier *L. leucocephala* species used for SALT and distributed to local farmers were the 'Hawaiian giants' such as K6, K8, and K28. However, continued testing of *L. leucocephala* and monitoring of its slow but sure recovery have been watched closely by MBRLC.

A complete list of *Leucaena* species tested and used by MBRLC as well as abbreviated results of testing is given in Table 1.

SALT corn production using *L. leucocephala*

The potential of *L. leucocephala* was evaluated as a sole-source of fertility input for corn production in a SALT system. The plot was located on a 30% slope but within the double contour hedges of SALT. Continuous corn was planted on the plots and 23 harvests were recorded in the 11-year period of the test giving, an average of two croppings per year.

The results showed that if *L. leucocephala* hedges can be maintained as productive sources of nitrogen-rich biomass, significantly higher yields of corn can be obtained than those using natural fertility only. Even though sole plots fertilised with *L. leucocephala* do not yield as much as the ones with commercial fertiliser, there is no cost of application outside of the farmer's labor to apply the freshly trimmed leaves.

Dairy goat production using *Leucaena*

L. leucocephala was evaluated as a sole source of fodder for dairy goat production versus two other popular fodder species: rensonii (*Desmodium*

Table 1. List of *Leucaena* species tested and utilised by MBRLC. Biomass production is categorised into high when more than 20 tons/ha/year based on SALT 5-metre double hedges, and low when less than 20 tons/ha/year.

Species	Origin	Date	Characteristics	Biomass yield	Psyllid tolerance
L. diversifolia	Manila seed bank	1985	Fast growing	High	High
L. leucocephala	NFTA	1986	Fast growing	High	Medium
L. leucocephala K614	NFTA	1986	Fast growing	High	Medium
L. leucocephala K636	NFTA	1986	Fast growing	High	Medium
L. leucocephala K584	NFTA	1986	Fast growing	High	Medium
L. glauca	Vietnam	1986	Slow growing	Low	Low
L. diversifolia	CSIRO	1987	Slow growing	High	High
Leucaena hybrid KX2	Hawaii	1989	Fast growing	High	Medium
Leucaena hybrid KX3	Hawaii	1989	Coppice well	High	High
Leucaena hybrid KX3a	Hawaii	1989	Good in coppicing	High	High
L. leucocephala K584 composite	Hawaii	1989	Slow growing	Low	Low
Leucaena hybrid KX1 composite	Hawaii	1989	Slow growing	Low	Low
Leucaena hybrid	Hawaii	1989	Slow growing	Low	Medium
L. diversifolia K156	Hawaii	1989	Fast growing, good in coppicing	High	High
L. lanceolata K393	Hawaii	1989	Fast growing, good in coppicing	High	High
Hybrid KX1 × *L. leucocephala F2*	Hawaii	1989	Fast growing	High	High
L. pallida K376	Hawaii	1989	Fast growing	High	High
L. leucocephala K636	Hawaii	1989	Fast growing	High	Medium
L. leucocephala	Hawaii	1990	Fast growing	High	High
L. pallida K817	Hawaii	1990	Fast growing	High	High
L. diversifolia	Hawaii	1990	Fast growing	High	High
L. retusa	Australia	1990	Slow growing	Low	Medium
L. macrophylla	Australia	1991	For reforestation	Low	Medium
L. shannonii	Australia	1991	Slow growing	Low	Medium
L. pulverulenta	Australia	1991	Slow growing	Low	Medium
L. pallida K376	Australia	1992	Fast growing	High	Medium
L. lanceolata	Hawaii	1992	Fast growing	High	Medium
Three-way hybrid	MBRLC	1994	Slow growing	Low	Medium

rensonii) and flemingia (*Flemingia macrophylla*). The test was run over a five-month period (one lactation). Milk production was higher from *L. leucocephala* (2.25 kg/day) than from either of the other two legumes. If *L. leucocephala* can be produced in large quantities without psyllid interference, the potential is still great to exploit this species as a primary source of animal feeds for both fresh fodder and leaf meal inputs.

MBRLC psyllid predators

In the late 1980s and early 1990s, it appeared that *L. leucocephala* was recovering from the psyllid plague. This observation seemed to be truer in the drier zones of Mindanao around Sarangani Province and the Alip mountain range which receives much less total rainfall as well as fewer wet months per year than other areas of Mindanao. Observations of psyllid activity in the Arakan valley in central Mindanao which also has lower rainfall due to a rain shadow effect of the surrounding mountains seemed to indicate a lower incidence of the pest.

About mid-1995, MBRLC staff began observing certain predator activity against the psyllid with corresponding *L. leucephala* growth. Thus a simple test was set up to monitor and identify the observed activity of psyllid predators on site at the MBRLC. Two beetles were found, one of which was identified as *Curinus coeruleus*, previously introduced specifically into the Philippines to combat the psyllid. The other has not been identified but is suspected to be closely related. Two unidentified spiders have also been observed to be very aggressive in their psyllid consumption. None of these predators by themselves or even in combination with the others are sufficient to wipe out the psyllid or prevent damage to the *L. leucocephala* when an outbreak occurs.

Current Uses of *Leucaena* by Farmers in the Magsaysay Impact Area — A Short Case Study of *Leucaena*

Brief history of Magsaysay IMPACT area and usage

The village development work of the MBRLC is based on the 'Impact' philosophy of working in a small area (usually defined by a geographical community with 15 to 50 families) for approximately 3 years (one year introduction, one year implementation and one year phase down). One such MBRLC Impact area is Purok 1, Bacungan, Magsaysay, Davao del Sur. This village has a history of work with leucaena through contact with MBRLC and serves as a good example of the spread of *L. leucocephala* usage as well as adaptation.

The Bacungan area is very steep, rolling mountains with little or no forest cover. The average slopes are 60% with slope lengths up to 300 feet. The forest slopes of these mountains were logged out in the late 1950s and early 1960s and were thereafter predominantly covered with cogon grass (*Imperata cylindrica*).

In mid-1984, the implementation of 100 hectares of *Leucaena*-based SALT began as a pilot project with a goal of 1000 total hectares expected from a 'radiating' effect. Farmers were provided with enough *L. leucocephala* seed to plant a one-hectare SALT project each. They were given a week of training at the MBRLC as well as a per metre cash incentive to plant contour hedgerows.

In all, a total of 100 hectares of SALT contour hedgerows were established on an average 5-metre spacing which equalled 2000 linear metres of double *L. leucocephala* hedges per hectare for a project total of 200 000 linear metres of contour hedgerows established. This was accomplished over a three year period with approximately one ton of *L. leucocephala* seed being distributed and planted. The leucaena used was primarily a mixture of the 'Hawaiian giants' K6, K8 and K28.

In retrospect, many of these original SALT projects were planted by farmers in order to obtain the cash incentives provided by the program. Thus, after a few years, a majority of the projects were 'abandoned' and left to grow into small reforested areas on the slopes of the Alip mountains.

Upon re-entering the area in 1993, MBRLC noted the local peoples' high priority placed on the old *L leucocephala* growths as well as their integration into the local farming systems. Even though the MBRLC SALT programs had by this time diversified to utilising alternative NFT/S besides *L. leucocephala*, an effort was made to build upon the local farmers' experience and knowledge of *L. leucocephala* and its uses.

After almost 10 years of planting the first original *L. leucocephala*-based SALT farms, the local farmers' usage of leucaena revolved around three areas:

Forage

Local people have long valued the 'native' ipil-ipil as a source of animal feed. The introduction of the giant varieties only made the tree more valuable as a fodder. MBRLC in its Impact work in Bacungan has promoted raising goats for milk, meat and income primarily utilising old *L. leucocephala* stands as the main fodder. To date, over 80 small goat projects (usually consisting of four to five head) have been established in the Magsaysay area. Most of these animals are being raised solely on freshly cut *L. leucocephala* with little or no concentrate given.

Fuelwood

One of the highlights of *L. leucocephala* usage in the Bacungan area is its utilisation for fuelwood and the development of a local market for the firewood. The sale of the fuelwood has been extremely beneficial to the residents of Bacungan during the prolonged dry seasons.

Erosion control/soil amelioration

Some of the farmers who adopted SALT as their primary farming system still farm with *L. leucocephala* based hedgerows today even though many of the old hedges are giving way to *Desmodium rensonii* and *Flemingia macrophylla* hedges. A modification of the original SALT has been implemented by the local farmers. Generally they utilise a long-rotation cycle of where the one hectare *Leucaena*-based SALT would be allowed to grow up for fuelwood harvest. After harvesting for fuelwood, the farmers then plant maize in the alleyways for two to three croppings utilising the natural fertility generated by the *L. leucocephala* hedges and then allow the hedges to re-grow into a small forest to be harvested once again for fuelwood. This creates a continuous cycle of fuelwood harvesting followed by corn cropping. Thus, what had appeared to be abandonment of SALT projects was later verified to be a form of fallowing and long rotations which fit into traditional farming systems.

The Bacungan area, even though situated only a few kilometers from the MBRLC base, has been extremely lightly hit by the psyllid in contrast with the immediate areas surrounding the MBRLC. One explanation is that the area is considerably drier with a longer pronounced dry season (typically January to June).

MBRLC'S Future Plans for Use of *Leucaena*

Leucaena spp. is still a staple NFT/S of the MBRLC but instead of being the main species used as in the pre-psyllid days, it is only one of many possible choices. The days of viewing it as the 'miracle tree' are over but it will continue to play an important role in the southern Philippines as a source of high quality animal feed, soil enricher and sustainable fuelwood production species.

MBRLC and local farmers are still heavily utilising *L. leucocephala* as a multi-purpose species. As an animal feed, it is fed fresh as a fodder and in the form of leaf meal. Currently, about 30 tons of *L. leucocephala* leaf meal per year are utilised through the MBRLC Feed Room as a protein amendment.

Leucaena leucocephala continues to be a popular tree for reforestation primarily targeting light building materials as well as a renewable source of fuelwood. Even though *L. leucocephala* is continuing to be plagued by the psyllid in southern Mindanao (especially the young growth), it is relatively unaffected if left to grow into a large tree.

MBRLC promotion of *L. leucocephala* for use as a contour hedgerow species has ceased. The only exceptions to this are the small leafed *Leucaena* species which are proven to be psyllid tolerant such as *L. diversifolia*. Even though remnants of the original *L. leucocephala* lines exist in the MBRLC hedgerows and surrounding farms, no new promotion is happening for this particular use. The main reason is that the constant coppicing of the hedges encourages growth of young tender shoots which in turn attracts the psyllid attack.

Over 500 kg of *Leucaena* seeds have been produced and distributed to local farmers through the MBRLC Seed Department since 1994. Half of those seeds are *L. diversifolia* with the other half being the older strains of *L. leucocephala*. Moreover, MBRLC will continue a testing and screening program of new species and their various cultivars, especially those which show tolerance to psyllid attack.

Promoting the Adoption of *Leucaena* in Central Queensland

J. Chamberlain[1]

Abstract

Leucaena is well adapted to the Central Queensland environment, and successful establishment techniques exist. Good establishment practices, particularly weed control, were promoted to provide incentive for adoption. A group of 20 prospective *Leucaena* growers was put in contact with successful *Leucaena* growers and on-farm demonstrations identified appropriate strategies, machinery and techniques. Five group members planted *Leucaena* in 1995, three successfully. Eight planted *Leucaena* in 1996 with reasonable establishment.

LEUCAENA (*Leucaena leucocephala*) is a highly productive rain-grown tropical pasture plant capable of producing more than 800 g live weight gain (LWG)/animal/day once established. It is well adapted to clay soils (brigalow, softwood scrub and open downs), and the potential for *Leucaena* on these soils in Central Queensland is considerable.

In the Nogoa/Belyando catchment alone, approximately 600 000 hectares are potentially suitable for *Leucaena* production. Currently, this country runs about 160 000 head of cattle on approximately 150 properties.

The adoption of *Leucaena* in inland areas where there is no serious psyllid problem has been restricted by a succession of low rainfall summers and inadequate attention given to cultural practices prior to, during and after planting. Either singly or in combination, these have led to most establishment failures. It is a priority task that every incentive is provided for *Leucaena* adoption by addressing the establishment issue.

The Meat Research Corporation partially funds Producer Demonstration Site (PDS) groups to increase the rate of adoption of beef industry technology by beef producers and to promote producer involvement in the conduct of 'on-farm' demonstrations. This has been achieved by demonstrating that *Leucaena* is adapted to Central Queensland (600–650 mm monthly average rainfall), demonstrating that successful *Leucaena* establishment techniques exist and promoting the importance of good establishment practices, particularly weed control.

A PDS group was formed from 20 graziers in the Clermont, Kilcummin and Capella grazing/farming districts of Central Queensland. These were all keen to incorporate *Leucaena* in their beef production system.

Through consultation with successful *Leucaena* growers in the Central Highlands (Banana, Blackwater, Rolleston, Clermont) and on-farm visits, the following issues were addressed:

- seedbed preparation;
- planting moisture;
- seeding rate;
- planting depth and seed coverage;
- seed/soil contact and presswheel type;
- post plant weed control (herbicide and cultivation);
- soil insect control.

The enthusiasm generated among the PDS was such that positive feedback is still forthcoming. Five group members planted *Leucaena* late summer (February–March) 1995, with three successfully establishing 500 ha. Summer 1996 provided a further opportunity for planting.

Establishment was generally good but seedlings were ravaged by spur throated locusts and badly affected by lack of rain for 3 months.

The enthusiasm generated in 1994 is still present despite the setbacks although the cattle market slump will delay proposed activity.

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