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ILC2018 Summary*

International Leucaena Conference 2018: Highlights and priorities

Conferencia Internacional sobre Leucaena 2018: Aspectos destacados y prioridades

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Preamble

A very successful International Leucaena Conference (ILC2018) and field tour, organized by The University of Queensland, was staged from 29 October to 3 November 2018. Approximately 120 conference delegates from 12 countries, comprising researchers, consultants, producers and students, shared their research knowledge and practical experiences regarding leucaena. Many excellent speakers exchanged information, and challenged the ideas and conceptions of those attending regarding how we plant, manage and use leucaena around the world.

Engagement and networking ensured there was enthusiastic and fruitful discussion on future priorities and collaborative opportunities.

General comments about conference from delegates

"Thanks for a very productive and encouraging conference. This was the most networking I have done at any conference in my career" - Travis Idol, University of Hawaii, USA.

"The papers and discussions were of a high standard and the meeting had a great feeling of cooperation and collaboration" - Bev Henry, Agri Escondo Pty Ltd, Australia.

"There was a great amount of information on leucaena experiences from around the world. The Conference was an excellent opportunity to share information with peers and to meet researchers and practitioners from different regions and to hear their perspectives" - Julián Chará, CIPAV, Colombia.

"The pre-conference tour of several leucaena producers with different production systems was enriched by the interactions and thoughtful discussions/comments by participants from many parts of the world, each with his/her own point of view" - Daniel Real, Department of Primary Industries and Regional Development, Western Australia.

"A highlight was the high level of landholder input in a comprehensive program that included presentations and discussion of both benefits and negatives associated with leucaena" - Shane Campbell, University of Queensland, Australia.

"Great to hear about the extensive leucaena R&D occurring across the tropical world, and interestingly, there were similarities in the animal productivity benefits in a range of situations. It was very interesting to hear how cattle in some countries were fed 100% leucaena without toxicity issues and achieved high liveweight gains"- Stuart Buck, Queensland Department of Agriculture and Fisheries, Australia.

Conference delegates. Photo: Mic Halliday.

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*Summary and conclusions of the International Leucaena Conference, 1–3 November 2018, Brisbane, Queensland, Australia.

Conference in session. Photo: Mic Halliday.

Field tour participants. Photo: Nahuel Pachas.

Highlights and priorities

The principal topics and issues discussed during the Conference are now summarized.

Germplasm resources of leucaena

Existing varieties. In his plenary presentation, Dalzell (2019) noted early use of leucaena by humans was based entirely upon the very narrow germplasm of a single genotype of *Leucaena leucocephala* ssp. *leucocephala* ('common' leucaena), that had spread pantropically from its center of origin in Mexico. Genetic improvement began in the 1950s when vigorous 'giant' leucaena genotypes (*L. leucocephala* ssp. *glabrata*) were identified. Cultivars such as Hawaiian Giant K8, Peru and El Salvador were selected and promoted in silvopastoral systems in Australia and in multipurpose agroforestry systems throughout the tropics. Plant breeding for improved forage production resulted in the release of cv. Cunningham in Australia in 1976. These cultivars of 'giant' leucaena displayed broad environmental adaptation, but lacked tolerance of cold temperatures (and frost) and adaptation to acid soils. The spread of the psyllid insect pest (*Heteropsylla cubana*) from the Caribbean in the early 1980s devastated both 'common' and 'giant' leucaena all around the world. However, some giant leucaenas exhibited a degree of tolerance to the psyllid pest and were released in Australia as cultivars Tarramba and Wondergraze and in Hawaii as cv. LxL. Cvv. Wondergraze and Cunningham were the most productive in northern New South Wales (Harris et al. 2019), while cv. Tarramba has been successful in eastern Indonesia (Nulik et al. 2019). Since the 1990s, plant breeding programs to develop cultivars with greater psyllid tolerance, derived from the interspecific hybridization between *L. pallida* and *L. leucocephala* ssp. *glabrata*, resulted in the release of cv. KX2-Hawaii in Hawaii for timber and forage production, and cv. Redlands in Australia as a forage cultivar.

Leucaena genetic resources. The paper by Abair et al. (2019) provided both new insights into phylogenetic relationships in leucaena, resolving some outstanding uncertainties, and guidance on where future breeding of leucaena for forage might focus. They concluded that the *Leucaena* genus comprises 24 species, belonging to the mimosoid clade of the legume subfamily *Caesalpinioideae*. Of these, they defined 19 self-sterile diploid species in 3 clades, which occupy largely allopatric (separate locational) distributions.

They further confirmed 5 tetraploid species of *Leucaena* of hybrid origin, i.e. allopolyploids, implying sympatry of their diploid parental species, which is rare among wild diploid populations, but consistent with the anthropogenic backyard allopolyploid-formation hypothesis, i.e. parental species were brought together by humans for purposes of cultivation.

Their molecular analysis has led to some important conclusions, namely:

- *L. trichandra* has contributed to the origins of 4 of the 5 tetraploids (*L. confertiflora*, *L. diversifolia*, *L. involucrata* and *L. pallida*), which have low nutritive quality, probably reflecting the poor nutritive value of *L. trichandra*. The fifth tetraploid species, the pantropically naturalized *L. leucocephala*, is derived maternally and paternally from *L. pulverulenta* and *L. cruziana*, respectively.
- There are unlimited genetic markers available for genetic improvement of leucaena and to be exploited in breeding programs designed to identify and breed for sterility, decreased mimosine content and adaptation to salinity, cold, drought, etc.

Priorities for new varieties. In his plenary paper Dalzell (2019) identified 'development of sterile leucaena' as a high priority. It was argued that a sterile leucaena would lead to increased adoption in regions, e.g. Western Australia, where sowing of leucaena is not permitted currently owing to concerns over potential weediness (Revell et al. 2019). Early research to achieve this goal was reported by McMillan et al. (2019) and Real et al. (2019).

Other priorities included:

- Generation of artificial tetraploids from diploid species to increase cross-compatibility, and triploids from the cross of tetraploid *L. leucocephala* with diploid *L. collinsii* ssp. *collinsii*. This latter species has high digestibility and high psyllid resistance (Dalzell et al. 1998; Mullen et al. 1998).
- Development of a cold-tolerant leucaena, which is needed for high-altitude tropical locations, e.g. in Latin America, Hawaii and East Africa. Cold tolerance, which exists within *L. diversifolia*, would also expand adaptation of leucaena to fill winter feed deficits and to sites experiencing light frosts.

Germplasm collections and evaluation. The conference endorsed the need to coordinate international G × E evaluations of existing and new leucaena cultivars and selection of elite germplasm due to limited R&D resources. There are numerous opportunities to share data and effective methodologies for hybridization and vegetative/micro-propagation of elite leucaena germplasm, e.g. sterile hybrids.

It is essential that all R&D personnel involved in leucaena plant evaluation are aware of the origins of the genetic material they are using and the location of international collections of leucaena. The Leucaena Catalogue**,** first published in 1997, provides detailed passport information, including origins, collector, local ID identifiers for cross-referencing with other collections etc. However, this catalogue is dated and needs review and updating to improve formatting of germplasm information to account for new taxonomic classifications and new material in new collections.

Establishment and management of leucaena

Establishment. Buck et al. (2019a) outlined what is widely regarded in central and southern Queensland as best practice to achieve successful establishment of leucaena. In these grazing situations, best outcomes with existing commercial varieties occur on deep, fertile, well-drained neutral-alkaline soils in the 600–800 mm rainfall zone, while psyllid-tolerant cv. Redlands is better adapted in higher rainfall environments. Recommendations are to plant into fully prepared seedbeds with ample stored moisture and corrected for nutrient deficiencies, in twin rows approximately 6 m apart. Seed should be scarified, inoculated with rhizobium and treated for insect control prior to planting with beetle bait applied after planting.

The significance of good early weed control, especially regarding companion grasses, was emphasized (Buck et al. 2019a). An adapted inter-row grass can be introduced when leucaena is >1 m tall, permitting a first light grazing when plants are ~1.5–2 m tall, followed by full grazing when plants are 3–4 m tall.

Differences in the levels of mechanization and the costs of establishment and maintenance between regions were highlighted by Zapata Cadavid et al. (2019).

Planting configuration. Differences in production systems and therefore recommendations on planting configuration were highlighted in presentations from different regions of the world (Pachas et al. 2019).

In Australia and some countries in Latin America (Paraguay and Argentina), leucaena is planted in single or twin hedgerows with inter-row alleys between 6 and 10 m wide (1,000–5,000 trees/ha), the focus being on beef production, with grass a major and sometimes the principal component of the diet (Pachas et al. 2019).

As a contrast, in Colombia, Mexico, Cuba, Venezuela and Northeast Brazil, intensive silvopastoral systems (ISPS) are promoted. Leucaena is planted at high density (>10,000 trees/ha) in combination with improved tropical grass and high-value timber species (200–400 trees/ha) and intensively managed with rotational grazing (Chará et al. 2019; Pachas et al. 2019).

In some Latin American countries (e.g. Cuba; Ruiz et al. 2019) and countries of Southeast Asia (Indonesia and Thailand), leucaena is established as a protein bank using single/multiple rows often for cut-and-carry feeding to beef and dairy cattle, goats and dual-purpose animals. In these systems, leucaena is often the major component of the diet, sometimes constituting 100% of the ration, especially during the dry season (Dahlanuddin et al. 2019). The arboreal variety cv. Tarramba is especially suited to the cut-and-carry systems in Indonesia (Sutaryono et al. 2019).

R&D priorities. Inter-row spacing and grass:legume balance were contentious issues at the conference. Foreign delegates questioned why Australian graziers were extending the width of inter-rows to 10 m, while also insisting that "more leucaena = more beef". New research (Pachas et al. 2017) showed that wide inter-rows (~10 m), exacerbated by grass competition, reduced the production of leucaena in the pasture to <20% of total feed on offer. Thus questions arise concerning width of the inter-rows, namely:

- What is the effect on animal productivity of closer row spacing and a higher % of leucaena in the diet? Does more leucaena mean increased liveweight gain/ha/year?
- What is the role of the grass component?
- Can system productivity be increased by cultivating the inter-row areas with forage oats, forage sorghum or other legumes? What is the feasibility and effect on overall productivity and profitability of inter-row cropping of old sugarcane lands in Hawaii, or intensive leucaena systems in Southeast Asia with corn or horticultural crops, or the incorporation of high-value timber in Latin American systems?
- What is the influence of soils and climate, especially rainfall, on planting configuration?

Conference delegates highlighted the need for flexibility in planting guidelines for different environments within countries. For instance, notwithstanding decades of leucaena establishment experience in central Queensland, Australia, where best results are obtained from full cultivation and preparation of a fine tilth seedbed as used for planting of field crops, there are environments in Western Australia (Revell et al. 2019) and north Queensland with existing tree cover or non-arable landscapes due to rocks, where specialized approaches need to be developed.

While usage of fertilizers with leucaena plantings around the world is minimal, the benefits of fertilizer were highlighted on poorer soils in Thailand (Tudsri et al. 2019) and Australia (Buck et al. 2019a). Radrizzani et al. (2010) demonstrated that maintenance fertilizer application is necessary in older leucaena plantations. While we now have good understanding of critical leaf tissue values for a range of nutrients (Radrizzani et al. 2011), there is limited understanding of the rates, placement and frequency of fertilizer applications to achieve best results (Buck et al. 2019a).

Vegetative propagation. There are many reasons to develop efficient cost-effective micro- and macro-vegetative propagation methods for leucaena. Delegates reported that vegetative propagation would be advantageous for: expediting breeding programs; distribution of sterile materials; planting in non-arable locations; small-scale hand-plantings in Asia; and even for planting on smaller holdings in coastal Queensland, where commercial seedling planters might be effective. Provided soil moisture is adequate, advantages are quicker establishment plus better resistance to challenge from weeds, domestic animals and wildlife.

Idol et al. (2019) compared methods for vegetative propagation of several sterile hybrids of leucaena with propagation via seeds. Rooted cuttings proved the best option for operational-scale propagation, but a misting system or carefully controlled non-misting environment is required for their production.

The JK Paper Ltd company in Gujarat, India, in their program to produce higher-yielding clones for paper pulp, uses misting chambers to produce rooted cuttings of their best clonal selections of *L. leucocephala* and of a triploid hybrid of *L. leucocephala* × *L. collinsii* (Khanna et al. 2019). Nulik and Kana Hau (2019) reported success with bare-stem seedlings generated in purpose-sown high-density nurseries or by retrieval of volunteer seedlings under established tree rows.

Feeding and management for animal production

Animal productivity. Conference delegates confirmed that leucaena is a highly palatable, productive and profitable forage option used by beef producers in northern Australia (Buck et al 2019a; 2019b) and by beef, dairy and goat producers in Colombia (Pachas et al. 2019; Rivera et al. 2019; Zapata Cadavid et al. 2019;), Mexico (Ramírez-Avilés et al. 2019), Paraguay (Glatzle et al. 2019), Argentina (Radrizzani et al. 2019a; 2019b), Indonesia (Dahlanuddin et al. 2019; Waldron et al. 2019), Myanmar (Aung 2019), India (Nimbkar 2019), Thailand (Nakamanee et al. 2019a; 2019b), Venezuela (Escalante 2019) and Cuba (Ruiz et al. 2019).

All of the above results were with *L. leucocephala* so the positive economic response to incorporation of *L. diversifolia* in a Colombian cattle system experiment was especially interesting (Enciso et al. 2019).

In Australia, when sown with either native or exotic companion grasses, leucaena provides significant productivity, economic (Bowen et al. 2016), environmental and social benefits (Buck et al. 2019b). Cattle on leucaena-grass pastures will gain 250–300 kg/year, and at a higher stocking rate than on straight grass pastures, while production per hectare can be 2–4 times that from run-down buffel grass pasture. Leucaena-fed steers can reach 600 kg live weight at 24–30 months of age, 6–12 months earlier than those on grass-only pasture.

A significant benefit of the rapid liveweight gains of cattle is increased flexibility in targeting domestic and export markets to achieve the best prices. If the area of leucaena is limited, it is often reserved for the most valuable stock, to fill autumn-winter protein gaps and to produce animals to target specific premium markets. Leucaena-grass pasture makes it possible to reach high meat quality standards, such as Meat Standards Australia (MSA) and Pasture-fed Cattle Assurance System (PCAS), without grain feeding.

In Indonesia, Dahlanuddin et al. (2019) reported that farmers with an average of 2.8 ha of land and 0.8 ha of planted leucaena fattened Bali bulls in a cut-and-carry system which Waldron et al. (2019) reported to be highly profitable. Mean liveweight gains ranged from 0.4 to 0.6 kg/d and were at least double those achieved in the traditional rearing system. Average daily gains peaked (0.56–0.61 kg/d) in the months of May, June and January, when feed supply and percentage leucaena in diets were highest (close to 100%). The most efficient individual farmers achieved monthly maximum weight gains ≥0.8 kg/d, close to the genetic potential of Bali bulls.

In Colombia, Zapata Cadavid et al. (2019) reported the work of the CIPAV Foundation (Centro para la Investigación en Sistemas Sostenibles de Producción Agropecuaria) on the establishment, management and promotion of intensive silvopastoral systems (ISPS). Leucaena is planted at high densities (>10,000 plants per ha) in rows 1–1.5 m apart, with 0.3–0.6 m between leucaena trees within rows, and inter-planted with a range of tropical grasses. ISPS are grazed rotationally by beef and dual-purpose dairy cattle. At stocking rates of 2.5–4.5 head/ha, beef cattle gained 0.65–0.8 kg/hd/d, while dairy cows yielded 5–14 kg milk/cow/d, depending on animal genetics, season and supplementation, with up to 17,000 kg milk/ha/year.

Goat production systems in the tropics and subtropics were reviewed by Cowley and Roschinsky (2019) and described in case studies from Thailand (Harrison et al. 2019; Nakamanee et al. 2019a, 2019b). They concluded that goats are well adapted to leucaena, and are productive in terms of liveweight gains, milk production and reproduction on diets containing up to 100% leucaena. Successful feeding systems included both grazed and cut-and-carry intensive strategies.

Energy supplementation of leucaena-fed animals was reviewed by Harper et al. (2019). They reported that production (liveweight gain or milk production) from leucaena was increased by the addition of supplements containing fermentable metabolizable energy, such as cereal grains, cassava, molasses, rice bran and crop residues. While substitution of the basal leucaena in the diet by the energy sources might occur, this allowed more animals to be supported, especially if there was limited leucaena available. Some Australian graziers supplement their cattle on high leucaena diets with low quality roughage and molasses (Heatley 2019).

Grazing management. Appropriate grazing management is necessary to maximize production from leucaena-grass pastures; however, many graziers do not manage this aspect well and it can be costly to correct. In Colombia, Zapata Cadavid et al. (2019) reported that overgrazing leading to reduced productivity was common. In Australia, the reverse often occurs with undergrazing of leucaena paddocks, especially on large areas, leading to excessive growth of the trees, requiring expensive machine cutting (Harris and Harris 2019). These authors stated: "When cattle eat the leucaena we make money, but when we have to mulch it, it costs us money". A range of commercial and home-made slashing devices are used to mechanically cut tall leucaena to bring it into the reach of grazing animals (Harris and Harris 2019; Heatley 2019).

While delegates noted the need for more bushy varieties to reduce excessive height of leucaena, improved animal management using high-density short-duration rotational grazing was recommended to control excessive height. Zapata Cadavid et al. (2019) recommended a rotational grazing system of 1–5 days grazing followed by 45–50 days for recovery. Australian graziers reported using rotational grazing systems, moving cattle every 14 days (Heatley 2019) and using high stocking rates of at least 5–10 head/ha (Craig Antonio pers. comm.). Large cattle, especially lactating cows, achieved best height control (Peter Larsen pers. comm.). Rotational grazing also achieves rapid nutrient cycling and permits rationing of leucaena, although it is costlier to set up and manage.

R&D priorities. Delegates identified that information is needed on the best dietary combination of leucaena and grass, or leucaena and crop residues to maximize productivity. Dietary intake information of this nature would allow optimum planting strategies, including row spacing, configuration and alignment, companion grass species selection and fertilizer needs, as well as optimum stocking rates and spelling periods, to be determined. Hopkins et al. (2019) found that measurement of leucaena content of the diet of cattle grazing leucaena-grass pastures, using current broad calibration NIRS equations, was associated with substantial errors and needs further refinement.

Southeast Asian delegates expressed interest in conservation technologies (hay and silage) as a management strategy for smallholders employing cut-and-carry systems to provide a store of fodder for dry season feeding. The strategic use of conserved leucaena or as a forage bank to supplement dairy cattle and breeding cows to increase pre-weaning calf growth was a priority (Dahlanuddin et al. 2019).

Leucaena toxicity. It is well known that leucaena contains the non-protein amino acid mimosine (Honda and Borthakur 2019), and that cattle, naïve to leucaena, can be affected initially by mimosine toxicity, showing symptoms of hair loss, salivation and loss of appetite. It is also known that mimosine is rapidly converted to DHP, which is reported to be chronically toxic (Shelton et al. 2019). However, most livestock raisers in Australia and internationally observe that symptoms are short-lived, with animals quickly recovering to show excellent production (Shelton et al. 2019). The current understanding in Australia is that graziers with cattle on leucaena are wise to inoculate cattle with *Synergistes jonesii* as protection against toxicity. However, new evidence from Bali cattle being fed diets up to 100% leucaena in Indonesia showed that conjugation of DHP by the liver, and not *S. jonesii*, though ubiquitously present at low populations (McSweeney et al. 2019), was the major detoxification pathway, and inoculation was not necessary (Shelton et al. 2019). Since no other country has access to the laboratory-fermented source of *S. jonesii*, this finding, if widely applicable, has the potential to remove a major world-wide barrier to adoption of leucaena for feeding ruminants.

R&D priorities for preventing leucaena toxicity. The following issues are deserving of priority:

- While there is evidence of similar hepatic conjugation of DHP in ruminants consuming leucaena in Australia and other countries where leucaena is being fed, this new hypothesis needs to be confirmed by additional studies in those countries.
- Further study is also needed to clarify the effects of feeding high leucaena diets on the reproductive performance of ruminants as there are published (Holmes 1980; Holmes et al. 1981) and anecdotal reports (O'Neill and O'Neill 2019) that pregnant females, naïve to leucaena, can suffer reduced calving percentages if grazing leucaena prior to and during joining. It may be possible to avoid negative effects on herd reproduction by appropriate herd management (Shelton et al. 2019).
- A number of other specific issues regarding leucaena toxicity need further clarification, namely:
  a. Understanding the relative significance of metal ion chelation versus negative effects on thyroid hormones as the principal mode of toxicity of DHP (Shelton et al. 2019); and
  b. Additional investigation of alternative rumen organisms for degradation of DHP other than *S. jonesii* as reported by Aung (2019). An audit of total mimosine ingested versus total DHP voided in urine and faeces might indicate the contribution of other micro-organisms in the detoxification of DHP.

Alternative uses of leucaena

There is increasing interest in leucaena as a dual-purpose plant suitable for producing both biofuel and feed for livestock. Tudsri et al. (2019) reported that the chemical composition of leucaena was excellent for heat generation on combustion. They reported that the arboreal character and wood yield of cv. Tarramba, as well as many hybrid lines, showed excellent potential as biofuel and recommended planting configurations that provided triple bottom-line benefits.

Khanna et al. (2019) reported that India was a major producer and consumer of paper and pulp products and has developed leucaena plantations to provide raw materials for industry. One of the largest Indian paper companies (JK Paper Ltd) has promoted establishment of leucaena plantations in Gujarat, Maharashtra and Madhya Pradesh States with >7,800 farmers planting areas totalling >18,400 ha for producing paper pulp. The company's R&D network, using genetic improvement through mutation techniques and hybridization programs for wood quality improvement, has developed high production clones, and established clonal seed orchards.

Leucaena and the environment

There are multiple environmental benefits from planting and managing leucaena for livestock production based on its system sustainability that provides triple bottom-line benefits (environmental, social, economic) including carbon storage, animal welfare and reduced enteric methane emissions.

In addition to the animal welfare benefits from more high-quality feed during the dry season and during droughts, livestock raisers interviewed in Thailand, Vietnam, the Philippines and Indonesia claim that consuming leucaena delivers control of many internal parasites. Organic beef production in Australia is possible from leucaena pastures on fertile soils.

Leucaena and greenhouse gas implications. A subject area which provoked extensive discussion was the positive impact of leucaena plantings on reducing GHG emissions with papers by Tomkins et al. (2019) from Australia, Chará et al. (2019) from Colombia, Banegas et al. (2019) from Argentina and Ramírez-Avilés et al. (2019) from Mexico. Tomkins et al. (2019) reported data that showed soil C in rangelands after 40 years was 17–30% higher under leucaena-grass pastures than under grass-only pastures. Other Australian work showed that enteric methane emissions were reduced (~20%) in cattle grazing leucaena-grass pastures compared with cattle grazing grass only. Chará et al. (2019) reported results on GHG emissions from soil and pastures in an intensive silvopastoral system (ISPS) with leucaena in Colombia that generated 30% less CO_2, 98% less CH_4 and 89% less N_2O soil emissions per ha per month, when compared with an adjacent conventional farm with irrigation and high fertilizer inputs. Ramírez-Avilés et al. (2019) reported experiments in which methane emissions were reduced by >50% as leucaena in diet was increased from 0 to 80%, and carbon storage was increased by 38% in leucaena-grass systems compared with pure grass pasture.

King and Burgess (2019) reported that Emissions Reduction Fund (ERF) payments might be possible in Australia based on reduced CH_4 and N_2O emissions (N_2 fixation, dung and urine) and soil C storage. However, since the current price of carbon or an Australian Carbon Credit Unit (ACCU) is $13.52/t, Tomkins et al. (2019) observed that animal production benefits from leucaena plantings on-farm would outweigh income potential generated from carbon credits.

Weediness. Despite the many positive attributes, environmental concerns about the weed potential of leucaena remain a major issue in Australia and worldwide (Campbell et al. 2019; Idol 2019).

It is generally accepted that leucaena does not invade undisturbed ecosystems (Idol 2019; Zapata Cadavid et al. 2019). Nevertheless, if not properly managed, current commercial varieties of leucaena produce long-lived seed that can spread initially between rows and eventually outside of planted paddocks onto roadsides and along riparian zones. Several control options are available, namely: development of a sterile variety of leucaena (McMillan et al. 2019); promotion of The Leucaena Network's Code of Practice that provides guidelines to reduce and control unwanted plants (Christensen 2019); and collaboration with government and chemical companies to formally register a broader range of herbicides for control of leucaena (Campbell et al. 2019).

It was concluded that the benefits of leucaena need to be promoted as they will become increasingly important with time due to global and community pressures for attention to GHG reduction strategies, animal welfare, product quality, soil improvement and production system sustainability.

Nevertheless, it was recommended by Campbell et al. (2019) that leucaena growers should:

- Acknowledge the potential detrimental environmental issues, while highlighting the positive environmental benefits;
- Work collaboratively with weed scientists and attend weed control conferences convened by Local Government and environment groups; and
- Consider developing a self-auditing process for leucaena growers to demonstrate that they are being proactive in preventing leucaena from escaping their properties.

Biodiversity. Dr Julián Chará, while in Australia, commented on the low diversity of the Australian leucaena-cattle systems and specifically the low density of trees. He said that Colombian experience indicated the importance of planting other multipurpose trees to provide additional sources of income (diversification) and to obtain the advantages of trees, e.g. reduction in the impact of frost events, improvement in biodiversity, enhancement of nutrient cycling and promotion of carbon storage.

Delegates from CIPAV proposed intensive silvopastoral systems (ISPS) with an upper tree layer to provide environmental services and economic returns (wood). Chará et al. (2019) reported that ISPS "increased complexity of the production system with measurable positive effects on biodiversity supporting more species of birds, ants, dung beetles and woody plants than conventional pasture monoculture. ISPS contributed to landscape-scale connectivity and environmental services".

Conference delegates agreed that the potential of leucaena internationally should not be limited to livestock production. Livestock raisers would have a stronger argument against the negative environmental views held by some sectors of society regarding farmers and graziers, if leucaena was integrated into diverse agricultural landscapes and delivered a variety of environmental services.

Adoption of leucaena technology

There was general agreement at the conference that, despite overwhelming evidence for the high productivity, profitability and sustainability of leucaena feeding to ruminants around the world, adoption of the innovation was universally well below expectations. Presentations from Australia (Buck et al. 2019b; Kenny and Drysdale 2019), Colombia (Zapata Cadavid et al. 2019), Argentina (Radrizzani et al. 2019a; 2019b), Mexico (Ramírez-Avilés et al. 2019), Indonesia (Dahlanuddin et al. 2019), Thailand (Nakamanee et al. 2019a), Myanmar (Aung 2019) and India (Nimbkar 2019) all reported that more needs to be done to increase adoption of this highly successful innovation.

Mr Bruce Mayne, a grazier delegate from central Queensland, said that, given the many 'good news' stories on leucaena feeding from around the world, "it was puzzling therefore to see that the uptake of leucaena into pastures across the world has been moderate at best. What is the stumbling block? Is it difficulty in establishment, high cost of establishment, lack of variety suitability or other limitations that constrain it from the expansion worthy of the gains that farmers are able to achieve"?

This problem of low adoption is not unique to leucaena. Shelton et al. (2005) acknowledged the low levels of adoption of tropical pasture legume technology around the world despite decades of R&D. They advanced an analysis of the reasons for successes and failures of efforts to achieve adoption.

Strategies to increase adoption levels were reported from Indonesia (Dahlanuddin et al. 2019) for leucaena feeding in cut-and-carry feeding systems. Kenny and Drysdale (2019) suggested that the adoption analysis tool (ADOPT) would be useful in assisting with design of new communication and extension messages. The program highlights some of the issues that could limit adoption.

Establishment of on-farm demonstration areas that can be used as authentic examples of how leucaena can be used to increase ruminant production, and subsequently promoted in field days and farmer visits, has been used successfully in Australia (Rolfe et al. 2019a; 2019b) and in Indonesia (Dahlanuddin et al. 2019).

Nevertheless, there are many successful examples of adoption of leucaena for ruminant feeding around the world. Australian and international producers presented their experiences at the conference (Antonio 2019; Heatley 2019; Kana Hau and Nulik 2019; Ogg and Ogg 2019; O'Neill and O'Neill 2019; Rea et al. 2019). One of the starkest contrasts in terms of scale was between cattle fattening enterprises of successful Australian graziers (often with >500 ha leucaena) (Harris and Harris 2019) and smallholder cattle fatteners from eastern Indonesia (with 1–2 ha leucaena per farmer) (Kana Hau and Nulik 2019).

R&D priorities. In Australia, only a small percentage of potential land area has been planted to leucaena. Delegates suggested that adoption could be increased if greater effort was made to engage with environmentalists, catchment management groups, green-leaning city folk and all sectors of government – federal, state, local etc. It was argued that a public relations exercise was needed to tell the great story of profit and sustainability in an environmentally friendly way emphasizing the many environmental benefits and the strategies employed to minimize undesirable spread, especially the program to breed a sterile leucaena variety.

Concluding reflections

There is huge potential to expand the area of leucaena pastures in northern Australia and around the world. Much is now known about its establishment and plant and animal management requirements. Delegates were unanimous in agreeing that the momentum for collaboration and information exchange established during the conference should be continued. It was suggested that a research agenda, encompassing the priorities identified, should be created and studies mounted at several locations internationally.

The Indonesian team suggested planning for the next leucaena conference and offered to host a conference in Indonesia. Latin American delegates proposed visits to Colombia and Mexico to better appreciate the ISPS used in these countries. The participation of researchers and farmers in the next International Silvopastoral Congress to be held in Paraguay in September 2019 was encouraged.

The Leucaena Network representative highlighted the value of peer networking, information sharing and mentoring to facilitate greater connectivity internationally to capitalize on the different experiences in different locations.

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