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*ILC2018 Plenary Paper**

Intensive silvopastoral systems with *Leucaena leucocephala* in Latin America

Sistemas silvopastoriles intensivos con Leucaena leucocephala *en América Latina*

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Abstract

Leucaena leucocephala has played a key role in the development of sustainable cattle ranching in Latin America. This species is the backbone of the so-called Intensive Silvopastoral Systems (ISPS) that combine high-density cultivation of leucaena as fodder shrubs (4,000–40,000 plants/ha) with grasses and trees. The layers of vegetation added by shrubs and trees increase the system's capacity for transforming solar energy into biomass and enhance habitat complexity. Although part of the biomass is transformed into livestock products, a significant amount is deposited as litter on the soil and, along with the nitrogen fixed by leucaena and other trees, has positive effects on soil properties and grass production. The increased complexity of the system has measurable effects on biodiversity. ISPS with leucaena support more species of birds, ants, dung beetles and woody plants than conventional pasture monocultures, contribute to landscape-scale connectivity and provide environmental services. They also enhance animal welfare through reduced heat stress and improved availability and quality of fodder resources. ISPS contribute to climate change mitigation by improving above- and below-ground carbon sequestration and by cutting down greenhouse gas emissions per units of dry matter consumed and cattle product. Although these systems have been successfully implemented in Colombia, Mexico and other countries, their adoption is still limited in relation to the area suitable for their introduction.

Keywords: Biodiversity, carbon capture, environmental services, GHG emissions, soil protection.

Resumen

Leucaena leucocephala ha jugado un papel crucial en el desarrollo de sistemas sostenibles de producción ganadera en América Latina. Esta especie es la columna vertebral de los llamados Sistemas Silvopastoriles Intensivos (SSPi) que combinan el cultivo de leucaena como un arbusto forrajero en alta densidad (4,000 a 40,000 plantas/ha) con pastos y árboles. Los estratos de vegetación adicionados con los arbustos y los árboles incrementan la capacidad del sistema para transformar la energía solar en biomasa y aumentan la complejidad del hábitat. Aunque una parte de la biomasa es transformada en productos animales, una cantidad importante es depositada en el suelo como hojarasca y, junto con el nitrógeno fijado por la leucaena y otros árboles, tiene efectos positivos sobre las propiedades del suelo y la producción del pasto. El incremento de la complejidad del sistema tiene efectos medibles sobre la biodiversidad. Los SSPi con leucaena sirven de hábitat para más especies de aves, hormigas, escarabajos del estiércol y plantas que los sistemas convencionales, contribuyen a la conectividad a escala del paisaje y proveen servicios ambientales. También contribuyen a mejorar el bienestar animal a través de la reducción del estrés calórico y una mayor disponibilidad y calidad de recursos forrajeros. Los SSPi contribuyen a mitigar el cambio climático al mejorar la captura de carbono en la biomasa aérea y en el suelo y al reducir las emisiones de gases de efecto invernadero por unidad de materia seca consumida y por unidad de producto. Aunque han sido implementados con éxito en Colombia, México y otros países, su adopción es aun limitada en la región en relación con el área apta para su introducción.

Palabras clave: Biodiversidad, captura de carbono, emisiones de GEI, protección del suelo, servicios ambientales.

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Introduction

Silvopastoral systems (SPS) are defined by the intentional integration of livestock, trees, shrubs and grasses on the same land unit in order to optimize the beneficial interactions between components (modified from Jose et al. 2019). SPS allow the intensification of cattle production through natural processes and are acknowledged as an integrated approach to sustainable land use (Chará et al. 2019). Globally, the main SPS include live fences, windbreaks, scattered trees in pasturelands, managed plant successions, fodder tree banks (e.g. areas of cultivated protein-rich fodder plants), cut-and-carry systems, tree plantations with livestock grazing, pastures between tree alleys and intensive silvopastoral systems (ISPS) (Murgueitio and Ibrahim 2008; Murgueitio et al. 2011; Calle et al. 2012).

Intensive silvopastoral systems (ISPS) are a type of SPS that combines high-density cultivation of fodder shrubs (4,000–40,000 plants/ha) with improved tropical grasses and tree or palm species at densities of 100–600 trees/ha. These systems are managed under rotational grazing with ad libitum provision of water and mineralized salt in each paddock, and 12–24 hour grazing periods that alternate with 40–50 day resting periods (Calle et al. 2012; Murgueitio et al. 2016).

Such silvopastoral systems with high density of *Leucaena leucocephala* have been promoted in several Latin American countries, mainly Colombia and Mexico, but also in Paraguay and Argentina where they have shown important production and environmental benefits (Chará et al. 2019). However, their adoption is still very limited in relation to the area suitable for their introduction. According to Pachas et al. (2019) the area planted in Latin America ranges between 45,000 and 55,000 ha.

Here we review recent studies carried out in Latin America (with emphasis on Colombia) regarding the environmental benefits of leucaena-based ISPS, including their effects on soil, biodiversity, environmental services and climate change mitigation.

Soil and water conservation of *Leucaena leucocephala* silvopastoral systems

Several studies have shown positive effects of SPS on physical, chemical and microbiological soil properties (Martínez et al. 2014). The layers of woody vegetation added by shrubs and trees accelerate the transformation of solar energy into biomass and the penetration of roots into deep soil layers, from where they extract nutrients and water (Nair 2011; Chará et al. 2015). This structural complexity allows for more abundant and heterogeneous plant residues being deposited on the soil as dry leaves, branches, fruits, resins and exudates with beneficial effects on soil organic matter, nutrients and biota (Vallejo et al. 2012; Martínez et al. 2014). Such benefits are complemented by the effects of nitrogen-fixing trees and shrubs and other associations between trees and microorganisms that increase the availability of vital nutrients for biomass production (Malchair et al. 2010; Rey et al. 2014). Soil microorganisms and fungi, in particular mycorrhizal fungi, enhance the formation and stability of soil aggregates, which further improves aeration and root penetration (Gupta and Germida 1988).

ISPS improve decomposition and mineralization processes carried out by the soil microbiota. Vallejo et al. (2010) found a higher activity of β-glucoxidase, acid phosphatase and alkaline phosphatase in soils under ISPS with leucaena compared with pasture monocultures in the Cauca Valley, Colombia. This not only indicated higher microbial activity in soils with leucaena, but also explained why these systems were able to sustain forage and milk yields even without the application of external fertilizers, since these enzymes play a key role in the recycling and availability of nutrients and energy in the soil (Vallejo et al. 2010; Sierra et al. 2017). These processes were enhanced in ISPS when a third layer of *Prosopis juliflora* trees was added to the leucaena-pasture system, e.g. Vallejo et al. (2012) found significantly higher levels of organic C, total N, nitrates and available P and microbial biomass under the canopy of these trees. As a consequence, soils under leucaena ISPS had a higher organic matter content, lower bulk density and lower penetration resistance than soils under pasture monocultures (Vallejo et al. 2012).

Vallejo et al. (2010) found higher densities of macro- and micro-pores, lower bulk density (<1.4 vs. 1.52 g/cm^3) and lower penetration resistance (<3.3 vs. 3.98 MPa) in soils under leucaena than in soils under pasture monocultures. These traits are associated with improved water retention and reduced runoff. Studies carried out in Costa Rica and Nicaragua showed water runoff equivalent to 28–48% of the precipitation in pastures without trees compared with less than 10% in SPS (Ríos et al. 2007).

Atmospheric nitrogen fixation

During the establishment phase of ISPS *L. leucocephala* seeds are inoculated with specific strains of *Rhizobium* to enhance the fixation of atmospheric nitrogen and avoid the use of synthetic fertilizers. Nitrogen fixed by this mechanism becomes available for the system and contributes to increasing the productivity and nutritional quality of its components. Bueno and Camargo (2015) found an increment from 0.39 to 0.74% in the total soil N content 28 weeks after sowing leucaena, which represents 249 kg/ha of additional nitrogen. This economy in nitrogen fertilizer requirement contributes to meat and milk production, reduces financial costs and cuts down atmospheric N_2O emissions.

Contribution of systems with leucaena to the protection of biodiversity and the provision of environmental services

In general, shrubs and trees in SPS have been shown to enhance biodiversity by creating complex habitats for wild animals and plants (Harvey et al. 2006; Moreno and Pulido 2009), harboring a richer soil biota (Rivera et al. 2013; Montoya-Molina et al. 2016) and increasing connectivity between forest fragments (Rice and Greenberg 2004). In farmed landscapes, SPS provide food and cover for birds, serving as wildlife corridors where unique species assemblages are found (McAdam 2005; Murgueitio et al. 2011; Greenler and Ebersole 2015). In the Quindío region of Colombia, areas with SPS were found to have 3 times as many bird species as treeless pastures (Fajardo et al. 2010) and complemented the conservation value of forest fragments by providing temporary habitat for forest-dependent birds (Tarbox et al. 2018).

This type of effects was also found in ISPS with leucaena. In the Quindío region of Colombia, ant species richness was 62% higher in ISPS with leucaena than in treeless pastures, and the ISPS held 55% of the ant fauna present in adjacent forests (Rivera et al. 2013). This study showed that, although forests play an irreplaceable role in preserving unique species, the introduction of ISPS with shrubs and trees enhances the persistence of biodiversity at a landscape scale by facilitating movement between forest fragments. In the same region of Colombia, dung beetle abundance and diversity were significantly higher in ISPS with high density of leucaena than in control sites with pasture monoculture (Giraldo et al. 2011). A similar trend was found in the Cesar Valley in northern Colombia, where ISPS with leucaena had 18 dung beetle species (50% of which were also found in forest fragments), while the neighboring treeless pastures held only 10 species (Montoya-Molina et al. 2016).

Higher biodiversity in the grazing areas and their surroundings can provide important benefits for the farming system through enhanced pollination, pest control and soil water retention, among other environmental services. In the study by Giraldo et al. (2011), the higher abundance and richness of dung beetles were accompanied by a significant increase in the amounts of excavated soil and buried manure. This study showed an additional benefit of ISPS by reducing the abundance of hematophagous flies that affect cattle.

ISPS with leucaena have a range of positive effects on animal welfare. Nutrient availability and quality are enhanced compared with grass-only systems of the same age (Table 1). Shade reduces heat stress while complex vegetation offers the possibility of concealment for the cattle, reducing fear and anxiety (Broom et al. 2013). As mentioned above, animals also benefit from reduced populations of ectoparasites in ISPS (Giraldo et al. 2011; Bacab et al. 2013).

Contribution of leucaena ISPS to ecological restoration

Intensive silvopastoral systems contribute to ecological restoration in cattle ranching landscapes through three complementary mechanisms (Calle et al. 2011; Chará et al. 2015): 1) The farm-scale natural intensification of cattle production on the most suitable land allows the release of fragile or strategic land for the recovery of forests and other ecosystems; 2) ISPS generate environmental services, and their complex vegetation supports part of the local biodiversity; and 3) the high density of shrubs and shade trees in ISPS provides a

Table 1. Average composition of diets for cattle grazing in ISPS with *Leucaena leucocephala* (Ll) and a pasture monoculture in Colombia (forages were sampled at 45 days of regrowth).

Nutrient	Ll + *Cynodon plectostachyus*[1]	Ll + *C. plectostachyus*[2]	Ll + *Megathyrsus maximus*[3]	Ll + *C. plectostachyus* + *M. maximus*[4]	Control *C. plectostachyus* diet[1]
Crude protein (%)	13.9	15.7	14.2	15.5	10.8
NDF (%)	64.9	60.8	60.1	60.7	74.6
ADF (%)	41.9	38.6	41.2	38.4	43.0
Ether extract (%)	1.17	1.58	2.24	1.55	1.16
Gross energy (MJ/kg)	18.3	17.0	17.6	16.9	17.9
Ash (%)	9.6	10.8	12.3	11.9	10.2
Calcium (%)	0.42	0.45	0.61	0.43	0.37
Phosphorus (%)	0.33	0.27	0.27	0.26	0.33

[1]Molina et al. 2016; [2]Rivera et al. 2015; [3]Gaviria et al. 2015; [4]Molina et al. 2015. NDF: Neutral detergent fiber; ADF: Acid detergent fiber.

permeable matrix and facilitates the movement of plants and animals. In turn, this enhances seed dispersal and the spontaneous recovery of forests and ecosystem services at the landscape scale.

Invasive behavior of *L. leucocephala*?

Leucaena leucocephala is native to the Yucatán peninsula in Mexico. Invasive behavior of this species has been observed in the Galapagos Islands, Taiwan, Hawaii and the Ogasawara Islands, where it is considered a weed of riparian and coastal habitats because it forms dense stands and can inhibit the regeneration of native species (Calle et al. 2011; Campbell et al. 2019; Idol 2019). Based mostly on studies done in islands, some environmental agencies have expressed concern about the use of *L. leucocephala* in various types of livestock systems.

In Colombia, *L. leucocephala* grows spontaneously, forming homogeneous stands in disturbed sites, where it accelerates the recovery of degraded land. Native tree species that are unable to regenerate in open areas can become established under leucaena trees. Thus, instead of inhibiting the growth of native species, leucaena facilitates the establishment of shade-tolerant trees and woody plants, as has been shown to occur in the understory of tree plantations in Puerto Rico (Parrotta 1999) and experimental plots in Malaysian slopes (Osman and Barakbah 2011). In addition, nutrient-poor soils affected by severe degradation achieve a rapid physical, chemical and biological recovery under leucaena trees (Parrotta 1999).

Leucaena leucocephala has not invaded mature and well-preserved ecosystems in Colombia. As a typical pioneer tree, it will not spread in habitats with a dense canopy. Seeds require bare soil to germinate and young seedlings cannot tolerate light interception from grasses or weeds. Flooding, high elevation and soil acidity will also prevent its successful establishment. In short, although in other environments *L. leucocephala* could become a weed, in Colombia, far from behaving as an invasive species, it has played a key role in the rehabilitation or ecological restoration of degraded lands (Calle et al. 2011).

Costa and Durigan (2010) surveyed 11 distinct forest patches in Brazil covering 200 ha around a *L. leucocephala* stand established in 1983 without finding a single individual of the species beyond the limits of the planted stand. Even though leucaena regenerated abundantly under the planted trees in Brazil, the relative density of the species in the understory decreased with time and shade-tolerant native species gradually began to dominate. Costa and Durigan (2010) concluded that leucaena behaved as a ruderal species at their Brazilian study site, where it does not invade or threaten natural ecosystems or cause economic damage.

Contribution to climate change mitigation

The contribution of ISPS involving leucaena to climate change mitigation is a result of the improved carbon storage both above- and below-ground and the lower emissions of methane (CH_4) per unit of DM consumed and per unit of livestock product.

Carbon storage

Several studies have shown that incorporating trees in croplands and pastures results in greater net C storage above- and below-ground (Montagnini and Nair 2004; Montagnini et al. 2013). The above-ground carbon storage potential for SPS ranges between 1.5 t/ha/yr (Ibrahim et al. 2010) and 6.55 t/ha/yr (Kumar et al. 1998). In the Patagonia region of Argentina, 148.4 t C/ha were stored in SPS, approximately 85% of which was stored in the soil, 7% in below-ground biomass (understory and tree roots) and 8% in above-ground biomass. Below-ground biomass thus represented an important C storage pool in that ecosystem (Peri et al. 2017). These values are a direct manifestation of the ecological production potential of SPS, depending on factors such as site and soil characteristics, species involved, stand age and management practices (Nair et al. 2010). The amount of soil organic carbon (SOC) can be increased between 20 and 100% when N_2-fixing tree legumes are incorporated, since they enhance plant productivity (Kaye et al. 2000). To take full advantage of the sequestration potential and other benefits of trees, a careful selection of the species is required and both density and design of the arrangement should be managed to avoid competition for light or water.

Regarding SPS with high-density leucaena (10,000 plants/ha), Arias et al. (2015) found a mean carbon content in the biomass of 33.14 t CO_2-eq/ha, compared with 10.7 t CO_2-eq/ha in a conventional pasture monoculture in Colombia. Similarly, in Mexico López-Santiago et al. (2019) found that an ISPS with 36,000 leucaena plants/ha had 106.5 t CO_2-eq/ha in the biomass (above- and below-ground) compared with only 17.2 t CO_2-eq/ha in an adjacent grass monoculture. Soil organic carbon showed a similar pattern with 335.3 and 268.6 t CO_2-eq/ha in the ISPS and the pasture monoculture, respectively (López-Santiago et al. 2019). In ISPS, although part of the above-ground biomass is periodically consumed by cattle, the trees remain in the system and the average amount of biomass is higher than that of a pasture monoculture.

Reduction of GHG emissions

GHG emissions in cattle systems are explained largely by the formation of enteric CH_4, made worse by low digestibility of feed and low productive parameters. Slow growth and high age at slaughter contribute to a longer life and to higher emissions per kg of meat produced (Gerber et al. 2013).

In ISPS with leucaena, animals can consume between 24 and 27% of fresh biomass of this species (Molina et al. 2015, 2016; Gaviria et al. 2015), so the diet contains higher protein and lower neutral detergent fiber (NDF) concentrations than when animals are restricted to the resources available in pasture monocultures (Table 1).

An improved diet with a lower NDF concentration reduces CH_4 formation in the rumen. Additionally, production becomes more efficient in terms of lower age at first calving, shorter calving intervals, higher weight gains and increased milk yields, as a result of the higher DM consumption and improved energy, protein and calcium concentrations in diets in SPS with leucaena (Chará et al. 2019).

With regard to enteric emissions, a trial in Colombia, where diets of 25% *L. leucocephala*, 75% *Cynodon plectostachyus* and 100% *C. plectostachyus* were fed to heifers, CH_4 emissions fell from 30.8 to 26.6 g CH_4/kg DM consumed on the diet containing leucaena, with an ensuing reduction in energy loss (Molina et al. 2016). Similar results were found by Molina et al. (2015) when they included 24% *L. leucocephala* foliage in a diet based on *C. plectostachyus* and *Megathyrsus maximus*. In both cases, animals fed diets containing *L. leucocephala* had 15–20% higher DM intakes and daily weight gains than those with the grass-only diet, but CH_4 emissions did not increase to the same extent (149.4 vs. 144.9 g/animal/day for the ISPS and control system, respectively, according to Molina et al. 2016). Thus, heifers in ISPS emitted at least 33% less CH_4 per kg of weight gain than those in grass-only pastures. A possible explanation for these results is that *L. leucocephala* contains less NDF/unit of DM consumed (Table 1), which lowers CH_4 emissions (Archimède et al. 2011). The reduction could also be caused by the condensed tannin content of *L. leucocephala* (Barahona et al. 2003; Naranjo 2014), since tannins inhibit the growth of some ruminal microorganisms that produce CH_4 (Archimède et al. 2011; Huang et al. 2011). Condensed tannins present in *L. leucocephala* have lower molecular weight than those of other legumes, and have no noticeable effects on DM and fiber digestibility (Barahona 1999; Barahona et al. 2003). In an in vitro experiment, Rivera et al. (2015) reported a reduction of 13% in the production of CH_4 per kg degraded DM (P = 0.0016) when 25% of leucaena was included in a *C. plectostachyus* diet.

Regarding GHG emissions from the soil and pastures, ISPS with leucaena 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 input (Rivera et al. 2019). As a result of this and of the lower enteric CH_4 production, the emissions of CO_2-eq per kg of fat and protein corrected milk (FPCM) and per kg of energy corrected milk (ECM) were 13.4 and 12.5% lower, respectively, than in a conventional high-input system similar to the farm's baseline condition (Rivera et al. 2016). Since no chemical fertilizers are applied usually and concentrate feed requirements are greatly reduced, ISPS can use 55–62% less non-renewable energy than a conventional system to produce a kg of ECM and FPCM.

Conclusions

Intensive silvopastoral systems with leucaena respond to the urgent need of providing beef and dairy products while delivering environmental services. They restore soils, sequester carbon and reduce the negative impacts of cattle on natural resources and climate. In Latin America, ISPS can also play a crucial role in improving the efficiency, resilience and profitability of cattle production, while enhancing product quality and animal welfare. *Leucaena leucocephala* has been essential in the development of ISPS due to its rapid growth and biomass production, high nutrient quality and tolerance to cattle browsing, among other characteristics.

However, technical, cultural and financial barriers have limited the adoption of ISPS and only a small proportion of the suitable land in Latin America is currently under these systems despite all proven and potential benefits. National policies should support ISPS adoption by providing specialized credit lines and technical support and facilitating the access to technical assistance, supplies and markets.

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(Note of the editors: All hyperlinks were verified 8 August 2019.)

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*ILC2018 Keynote Paper**

Greenhouse gas implications of leucaena-based pastures. Can we develop an emissions reduction methodology for the beef industry?

¿Podemos desarrollar una metodología para la reducción de las emisiones de gases de efecto invernadero para pasturas con leucaena?

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Abstract

The perennial legume leucaena (*Leucaena leucocephala*) is grown across the subtropics for a variety of purposes including livestock fodder. Livestock in Australia emit a significant proportion of the methane produced by the agriculture sector and there is increasing pressure to decrease emissions from beef cattle production systems. In addition to direct productivity gains for livestock, leucaena has been shown to lower enteric methane production, suggesting an opportunity for emissions mitigation and Commonwealth Emissions Reduction Fund (ERF) methodology development, where leucaena browse is adopted for high value beef production. Determining the proportion of leucaena in the diet may be one of the more challenging aspects in attributing mitigation. Current enteric emission relationships for cattle consuming mixed grass-leucaena diets are based on intensive respiration chamber work. Herd-scale methane flux has also been determined using open path laser methodologies and may be used to validate an on-farm herd-scale methodology for leucaena feeding systems. The methodology should also address increased potential for soil organic carbon storage by leucaena grazing systems, and changes in nitrous oxide production. This paper outlines the background, justification, eligibility requirements and potential gaps in research for an emissions quantification protocol that will lead to the adoption of a leucaena methodology by the Australian beef industry. Development of a methodology would be supported by research conducted in Australia.

Keywords: CO_2 mitigation, cattle, grazing, methane, modelling, nitrous oxide, ruminants.

Resumen

La leguminosa perenne leucaena (*Leucaena leucocephala*) se cultiva a lo largo del subtrópico para una variedad de propósitos, incluido el forraje para el ganado. El ganado en Australia genera una proporción significativa del metano producido por el sector agrícola y existe una presión creciente para reducir las emisiones procedentes de los sistemas de producción de ganado de carne. Además de las ganancias directas en la productividad ganadera, se ha demostrado que leucaena reduce la producción de metano entérico. Esto sugiere una oportunidad para la mitigación de emisiones y el desarrollo de metodologías en el marco del Commonwealth Emissions Reduction Fund (ERF), adoptando tecnologías de leucaena para la producción de carne de res de alto valor. Determinar su proporción en la dieta animal es posiblemente uno de los desafíos más importantes para cuantificar la contribución de la leucaena a la mitigación de las emisiones. Los conocimientos actuales relacionados con las emisiones de metano por el ganado que consume dietas mixtas de gramíneas con leucaena, se basan en trabajos intensivos en cámaras respiratorias. Para medir el flujo de metano a escala de rebaño

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existen metodologías láser (OP-FTIR laser) con las que se pueden validar metodologías a nivel de sistemas de producción que incluyen leucaena como alimento. La metodología también debería considerar el potencial de sistemas de pastoreo con leucaena tanto para la acumulación de carbono orgánico en el suelo como para cambios en la producción de óxido nitroso. Este documento resume los antecedentes, la justificación, los requisitos para la elegibilidad y las necesidades de investigación para un protocolo de cuantificación de emisiones que llevará a la adopción de una metodología de leucaena por parte de la industria australiana de carne bovina. El desarrollo de esta metodología se apoyaría principalmente en investigaciones realizadas en el pasado en Australia.

Palabras clave: Ganado, metano, mitigación de CO_2, modelación, óxido nitroso, pastoreo, rumiantes.

Introduction

The perennial leguminous shrub leucaena (*Leucaena leucocephala*) is grown across the tropical and subtropical regions of South/Southeast Asia and northern Australia for livestock fodder, nitrogen fixation, firewood and paper pulp (Shelton and Brewbaker 1994). In Australia, the shrub can be incorporated in grass pastures for beef cattle, providing liveweight gains superior to those from most other legume-grass pastures and comparable with feedlot finishing. Across Queensland, approximately 125,000 ha has been identified by satellite imagery as dedicated to leucaena pastures (Beutel et al. 2018). Recent research has demonstrated additional benefits in the form of potential reduction of enteric methane production and increased soil carbon (C) storage, implying that the shrub may also reduce greenhouse gas (GHG) emissions at the farm level (McSweeney and Tomkins 2015; Harrison et al. 2015; Vercoe 2015; Conrad et al. 2017). This presents an emissions-mitigation opportunity that would apply across the industry where leucaena is managed. To reduce the carbon footprint of the Australian beef industry, particularly for northern bioregions where emissions per livestock unit are typically higher than for southern cattle (Charmley et al. 2008), there is justification for developing an 'emissions-reduction methodology' based on leucaena. A proposed methodology is supported by research conducted under the National Livestock Methane Program (MLA 2015a), modelling work undertaken under the Whole Farm Systems Abatement Modelling program (WFM 2017) and a series of independent studies.

This paper outlines the background, justification, eligibility requirements and potential gaps in research for an emissions-quantification protocol that will lead to the adoption of a methodology. A methodology would recognize reduced methane emissions by animals grazing leucaena.

Emissions-reduction potential and attribution

Approximately 16% of Australia's greenhouse gas (CO_2-eq) emissions come from agriculture, with 65% of this emitted by ruminants as methane. Cattle are responsible for about 70% of the enteric methane produced (Commonwealth of Australia 2014) and there are increasing efforts to decrease intensity of emissions from the livestock sector (MLA 2015b). A number of plants, plant products and plant secondary compound fractions have been demonstrated to have potential to reduce enteric methanogenesis (Vercoe 2015) when consumed by ruminants. The main compounds in leucaena that confer antimethanogenic effects in vitro and in vivo include phenolic compounds such as condensed tannins and flavanol glycosides (Kennedy and Charmley 2012; Vercoe 2015; McSweeney and Tomkins 2015).

Kennedy and Charmley (2012) demonstrated that the level of readily fermentable crude protein (RFCP) in legumes can be negatively correlated with methane production. Whether this indicates the operation of hydrogen (H) sinks associated with the RFCP fraction is uncertain, but it does indicate a need to incorporate a factor such as legume content of the diet in predictive equations for methane production, especially where plants such as leucaena are a significant proportion of the diet. Determining the proportion of leucaena in the diet would be one of the more challenging aspects in attributing methane mitigation. Current options to estimate grass:legume proportion in the diet include the use of faecal NIRS methodologies and $\delta^{13}C$ ratios (Coates and Dixon 2007).

If the legume content of the diet of the northern beef herd could be accounted for, then estimates of aggregate herd emissions may be reduced by around 30% (Kennedy and Charmley 2012). In addition, growth rates of cattle grazing leucaena-Rhodes grass (*Chloris gayana*) pastures are substantially higher and methane production commensurately lower than those of cattle grazing a Rhodes grass-dominated pasture (Harrison et al. 2015), particularly when leucaena is irrigated (Taylor et al. 2016).

A proposed methodology may be specific to a production system as defined by herd composition (class, age, live weight), where leucaena is used to finish steers to a target live weight or support breeding animals during periods of low pasture availability. The duration of leucaena feeding and intake or proportion of the diet will also be critical in revising the Herd Management Calculator (http://bit.ly/2SZf2qI).

Increased soil carbon storage opportunities

Incorporating leucaena into a grass grazing system increases biomass production (Radrizzani et al. 2016) and C inputs to soil, which leads to increasing organic C storage, especially in N-depleted soils. Conrad et al. (2017) estimated that a leucaena-buffel grass grazing system had an increase in soil C storage of 280 kg C/ha/yr in the top 30 cm of a Vertisol soil over a 40-year period. This equates to 1.03 t CO_2-eq/ha/yr with 50% of this C incorporated in the top 15 cm horizon (Radrizzani et al. 2011). This increase in C storage occurs primarily from the increased C inputs from biomass increase due to symbiotic N_2 fixation, which can account for up to 36 kg N/ha/yr in the soil (Resh et al. 2002; Conrad et al. 2018). Increased grass yield, C inputs, humus formation, slowing C decomposition and providing for increase in C storage become co-benefits for leucaena-based pastures (Kopittke et al. 2018). However, the increase in soil C storage in leucaena-grass grazing systems may be limited due to nutrient deficiencies of P and S, which occur frequently in Australia (Radrizzani et al. 2016), indicating that periodic application of nutrients other than N may be beneficial to increased soil C storage.

Mineralization of leucaena-N_2 fixed organic N produces nitrate-N and NO_3^- and results in nitrous oxide (N_2O) and di-nitrogen (N_2) production. Nitrous oxide is a potent GHG, with a global warming potential of 296 CO_2-eq on a 100-year time horizon (Dalal et al. 2003; EPA 2018). It is possible that N_2O emissions from soil supporting a leucaena-grass pasture may partially negate the positive impact of increase in soil C storage on GHG mitigation. Quantitative estimates of N_2O emissions from a leucaena-grass pasture system are scarce. It is likely that the nitrate-N level in soil remains relatively low due to the uptake by grasses, thereby minimizing N_2O production (Conrad et al. 2017).

Rumen microbial structure and function of leucaena-fed cattle

Understanding effects of leucaena on rumen microbial populations is an important factor in developing an emissions methodology. Analyses of rumen metabolism have indicated that leucaena-fed steers had an increased supply of amino acids and soluble carbohydrates, resulting in an apparent increase in microbial protein synthesis and a sink for metabolic H (McSweeney and Tomkins 2015). In addition, a shift in fermentation from acetate to longer chain fatty acids has been reported and can be expected to result in greater energy capture for the animal.

DNA sequencing of the rumen microbiota has demonstrated a consistent difference in the diversity of methanogens in cattle foraging leucaena-grass systems compared with grass pastures for both irrigated and dryland systems (McSweeney and Tomkins 2015). The relative abundance of *Methanosphaera* spp. alone as a proportion of the total methanogen population was higher in leucaena-fed animals and may be responsible for differences in methane emissions. *Methanosphaera* spp. have been previously reported to be enriched in 'low methane' emitting ruminants (Shi et al. 2014). Analyses at the bacterial family level have shown that some species belonging to Lachnospiraceae, Prevotellaceae, Spirochaetaceae, Desulfovibrionaceae, Ruminococcaceae, Bacteroidaceae and Veillonellaceae increased significantly in cattle grazing leucaena, while other species belonging to Erysipelotrichaceae and also Prevotellaceae and Bacteroidaceae decreased significantly relative to pasture-fed cattle (McSweeney and Tomkins 2015). This indicates a specific response to leucaena in the diet. It is likely that the shift in bacterial populations and metabolism associated with the presence of leucaena results in less metabolic H being produced for hydrogenotrophic methanogens because microbial protein and longer chain fatty acids become sinks for H. These shifts in the bacterial and methanogen populations are the likely basis for alterations in methanogenesis in leucaena-fed cattle.

Modelling whole-farm impacts on production, profitability and net emissions

Modelling of leucaena-based production systems can provide estimates of impacts on farm profitability of changes in liveweight gain (LWG), increase in soil C storage, methane emissions and urinary nitrogen concentration. To compute GHG emissions on a whole-farm basis, herd numbers and age/class structures can be used in static GHG emissions calculators, such as the Beef-Greenhouse Accounting Framework (B-GAF) (Doran-Browne and Eckard 2018). The diversified emissions profiles encompassed by B-GAF are essential for estimating whole-farm emissions from leucaena systems. Alternatives to static tools for estimating steady-state herd structures and GHG emissions include APSIM (Keating et al. 2003). APSIM can simulate temporal changes, which static models do not. Inclusion of a leucaena module in a dynamic farming system model such as APSIM would allow further investigation of how leucaena growth and defoliation through grazing influence LWG and profitability.

Measurements of the nutritional value of leucaena and potential to increase soil C storage at depth are required for model parameterization. The nutritive value of leucaena (Bassala et al. 1991; Agbede and Aletor 2004) and effects on LWG (Shelton and Brewbaker 1994; Harrison et al. 2016) have been well described. Few experiments simultaneously measure leucaena nutritive value, LWG, increase in soil organic C storage and GHG emissions, although these data are critical for parameterizing and developing model formulae for leucaena grazing systems.

Since leucaena generally provides more available forage than comparable pasture grasses, higher stocking rates are sustainable, but this results in greater total emissions per unit area (Harrison et al. 2016). Model-specific metrics are required to standardize comparisons. Harrison et al. (2015) described the comparison between 3 leucaena grazing scenarios and a baseline scenario in terms of: 1) average annual stocking rates; 2) total LW production; and 3) net farm emissions. To maintain the same average annual stocking rate or LW production, Scenarios 1 and 2 carried 5 or 12% fewer cattle than the baseline because animals on leucaena grew faster and had greater mean LW. In contrast, the number of animals carried and LW production in Scenario 3 increased by 15 and 31% relative to the baseline, respectively, due to enteric methane abatement and greater LWG of animals grazing leucaena. In all scenarios, emissions intensity (net farm emissions per unit LW sold) was reduced by more than 23% relative to baseline emissions. Other modelling studies incorporating leucaena have demonstrated that: reducing the ratio of breeding cows relative to steers and unmated heifers; higher female fecundity; and earlier joining of maiden heifers, were conducive to increased profitability (Harrison et al. 2016), but only higher fecundity and/or early joining of maiden heifers resulted in lower emissions per unit of live weight, especially when combined with existing interventions.

Although calibration data are required for reliable parameterization, models can contrast various scenarios with baseline systems, or simulate long-term implications of climate change on whole-farm emissions intensities. Future modelling aspects for leucaena could develop more dynamic biophysical models that incorporate livestock rotations between paddocks and seasonal climatic effects on leucaena growth and emissions from the grazing system.

Methodology development, validation and limitations

Any methodology has to be cost-effective to implement and readily verifiable. A leucaena methodology will need to account for methane and nitrous oxide emissions and soil C components. These components of a methodology will need to be measured or estimated from models. A methodology for measuring reductions in GHG emissions by grazing cattle on leucaena-based pastures has potential to complement the existing Beef Cattle Herd Management methodology (Commonwealth of Australia 2015), which captures reductions in emissions through increasing LWG and earlier turnoff achieved by cattle provided with supplementary feed (including improved pastures). While the current Beef Cattle Herd Management method quantifies the reduction in lifetime emissions through earlier turnoff, a method proposed specifically for leucaena would target: direct reduction in enteric methane emissions caused by leucaena in the diet of grazing cattle; increase in soil C storage; and losses from N_2O.

The current emissions relationship is based on respiration chamber work (Kennedy and Charmley 2012) and is the basis for estimating emissions from cattle consuming grass-leucaena diets. Herd-scale methodologies are available for validation on-farm based on methane flux determination using open path, OP-FTIR laser technologies (Jones et al. 2011; Tomkins and Charmley 2015; Phillips et al. 2016) or eddy covariance methods. The use of the SF6 tracer technique or Greenfeed system (C-Lock Inc., Rapid City, SD, USA) could also be applied in the field and offer an alternative approach to quantify individual methane production data (Arbre et al. 2015). These techniques provide a measure of emissions relativity and are currently the only on-farm non-invasive methods available to corroborate the effects of leucaena inclusion in pasture on enteric methane emissions for grazing cattle.

Conclusions

Research and modelling, that have been reported under the National Livestock Methane Program, the Whole Farm Systems Abatement Modelling program and previous and ongoing independent studies, provide justification to expand methodology opportunities. This is particularly relevant for those parts of Australia's beef industry, where leucaena feeding systems are adopted. In addition to the benefits associated with livestock production gains and efficiencies, the co-benefits in increasing soil C storage, humus formation and pasture improvement are well documented. Advances in methodologies to measure methane flux on-farm at a herd scale and analyses of rumen metabolism at the individual animal scale are sufficiently advanced to validate a methodology based on leucaena feeding. Future modelling must develop more dynamic biophysical models for leucaena systems, incorporating livestock rotations between paddocks and seasonal climatic effects on pasture growth and farm-scale emissions, which will further validate the development, adoption and practical application of a leucaena methodology for the Australian beef industry.

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ILC2018 Keynote Paper*

Linking leucaena to carbon abatement opportunities in Australia
Leucaena: Una oportunidad para la reducción de carbono en Australia

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Abstract

The Australian Government has committed to reducing its greenhouse gas (GHG) emissions by 26–28% below 2005 levels by 2030. The Emissions Reduction Fund (ERF), a center-piece of Australia's climate change policies, provides incentives to reduce GHG emissions through economy-wide eligible activities, such as energy efficiency, waste management, revegetation, livestock management and savanna fire management. Emissions Reduction Fund methods define eligible activities, how to quantify abatement resulting from the activity and the required compliance measures.

The requirements for developing ERF methods that quantify GHG abatement estimates resulting from eligible activities are described. Leucaena planting is used as an example. For an ERF method to be made and maintained, the activity must meet all the legislative requirements. This includes meeting the offsets integrity standards and having regard to any adverse environmental, economic and social impacts.

Keywords: Climate change, emissions, Emissions Reduction Fund, greenhouse gas, national inventory, offsets integrity standards.

Resumen

El gobierno australiano se ha comprometido a reducir, para el año 2030, las emisiones de gases de efecto invernadero (GEI) de Australia en un 26–28% por debajo de los niveles de 2005. El Emissions Reduction Fund (ERF), una pieza central de las políticas de cambio climático de Australia, proporciona incentivos para reducir las emisiones de GEI, a través de actividades elegibles relacionadas a la eficiencia energética, el manejo de residuos, la revegetación, el manejo de ganado y el manejo de incendios de sabana. Los métodos ERF definen las actividades elegibles, cómo cuantificar la reducción resultante de la actividad, y las medidas de cumplimiento requeridas.

Los requisitos para desarrollar los métodos ERF que cuantifiquen las estimaciones de reducción de GEI resultantes de las actividades elegibles se describen en este trabajo. El cultivo de la leucaena para forraje se utilizó como ejemplo. Para que se pueda realizar y mantener un método ERF, la actividad debe cumplir con todos los requisitos legislativos. Esto incluye cumplir con las normas de integridad (*offsets integrity standards*) y tener en cuenta cualquier impacto ambiental, económico y social adverso.

Palabras clave: Cambio climático, emisiones, Fondo de Reducción de Carbono, gases de efecto invernadero, inventario nacional.

Introduction

In line with international frameworks, the Australian Government has committed to reducing its greenhouse gas (GHG) emissions by 26–28% below 2005 levels by 2030 (Department of Environment and Energy 2015). In 2016, agricultural emissions contributed 12.6% of Australia's total emissions. For the 2030 targets to be

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reached, agricultural industries must make a contribution and opportunities for the agricultural sector to reduce emissions must be identified.

One possibility in northern Australia is the planting of leucaena, which could both increase livestock productivity and reduce enteric methane emissions. The combination of reductions in enteric emissions and possible increases in soil carbon would contribute to reducing Australia's GHG emissions.

For an Emissions Reduction Fund (ERF) method to be designed that provides incentives for using leucaena as a livestock feed, the activity must meet all legislative requirements. Importantly, methods must meet the offsets integrity standards as stated in Section 133 of the *Carbon Credits* (*Carbon Farming Initiative*) *Act 2011* (Australian Government 2017) to maintain scheme integrity and deliver credible abatement. The offsets integrity standards require that endorsed methods must credit only abatement that: (a) is additional to that which would occur normally; (b) is measurable and verifiable; (c) contributes to reducing Australia's GHG emissions; (d) is supported by clear and convincing evidence; (e) accounts for project emissions; and (f) results in a conservative estimate of net abatement. In addition, before establishing a method the Minister for the Environment must consider whether activities under endorsed methods are likely to result in adverse economic, environmental or social outcomes [Subsection 106(4) *CFI Act*] (Australian Government 2017). All ERF methods are regularly reviewed to ensure they continue to meet the offsets integrity standards and other legislative requirements, and reflect new scientific knowledge.

Domestic climate change policy in an international setting

Australia's National Greenhouse Gas Inventory (NGGI) (Department of the Environment and Energy 2018a) is compiled using methodologies consistent with the international guidelines and reporting rules prepared by the Intergovernmental Panel on Climate Change (IPCC) and adopted by the United Nations Framework Convention on Climate Change (UNFCCC).

Australia's National Inventory Report (NIR) is submitted to the UNFCCC as part of Australia's reporting obligations under the UNFCCC and the Kyoto Protocol. The NIR contains both national GHG emission estimates and estimation methods from 1990 onwards. The annual NIR (Department of the Environment and Energy 2018a) and the annual GHG projections (Department of the Environment and Energy 2017) enable the Government to track progress against Australia's emissions reduction commitments.

Under international reporting obligations, sources of agricultural emissions are: enteric fermentation; agricultural soils; manure management; liming and urea application; rice cultivation; and field burning of agricultural residues. In 2016, emissions from Australia's agricultural industries contributed an estimated 69.1 Mt CO_2-eq, which represents 12.6% of Australia's total emissions (Figure 1) (Department of the Environment and Energy 2018b). Enteric fermentation was the main source of agricultural emissions and was estimated to be 49.7 Mt CO_2-eq or 71.9% of all emissions from agriculture. The next largest source was agricultural soils (18.5%), followed by manure management (5.2%).

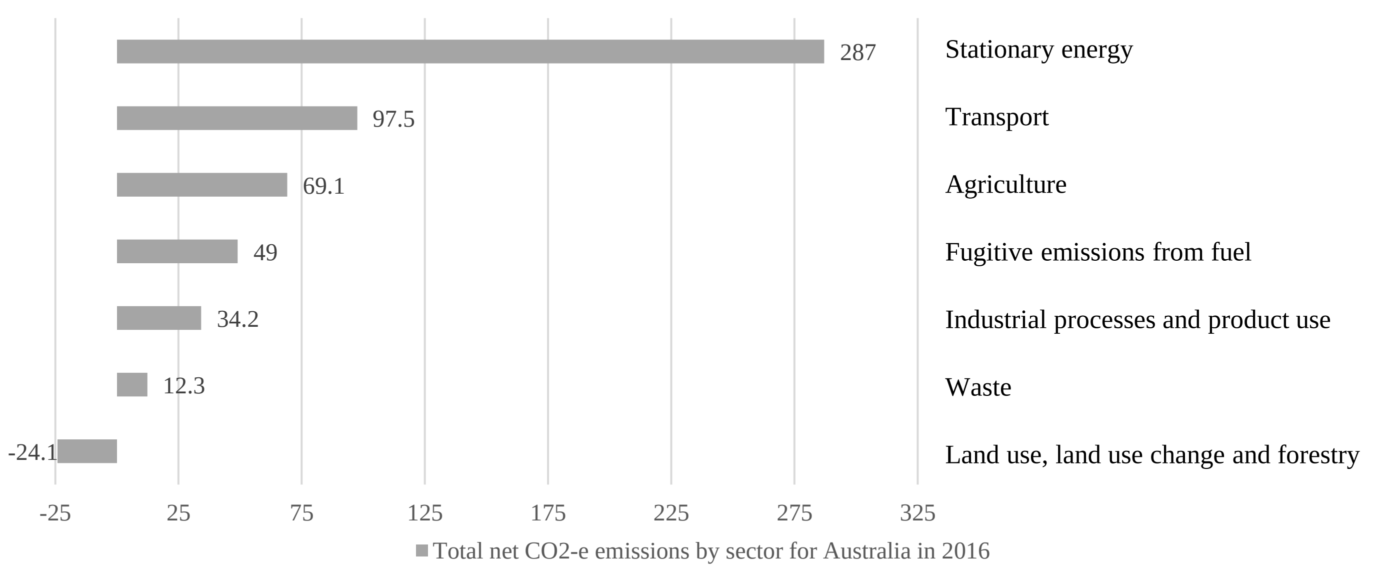

Figure 1. Total net CO_2-eq emissions by sector for Australia in 2016 (Department of the Environment and Energy 2018b).

In Australia, many in the agricultural sector are endeavoring to identify opportunities to reduce emissions. Large agricultural organizations such as Meat and Livestock Australia (MLA) are exploring opportunities to achieve net zero emissions, i.e. carbon neutrality (Meat & Livestock Australia 2017).

The Emissions Reduction Fund

The Emissions Reduction Fund (Department of the Environment and Energy 2018c) is a voluntary scheme that establishes methods which provide incentives for land managers, businesses, local councils and state governments to adopt new practices and technologies that will reduce Australia's GHG emissions. Methods have been developed for improved land management in forests and agriculture, savanna fire management, improved transport efficiency and energy efficiency, facilities, mining and waste to landfill and waste water management practices. Methods may be varied as new technologies become available, to add new eligible activities and to reduce unnecessary regulatory burden.

The Australian Government develops ERF methods that estimate GHG abatement resulting from implementing technologies and management practices (Department of the Environment and Energy 2018c). ERF methods describe: eligible activities that generate abatement by avoiding GHG emissions or sequestering carbon; how to quantify abatement resulting from the activity; and the required compliance measures. Registered projects allow proponents to use approved ERF methods to earn Australian carbon credit units (ACCUs). Once earned, ACCUs can be sold to the Australian Government or to other businesses seeking to offset their emissions.

Methods are legislative instruments and must be adhered to by scheme participants. To ensure ACCUs are credible and the abatement generated contributes toward Australia's emissions reduction targets, ERF methods must comply with the *Carbon Credits* (*Carbon Farming Initiative*) *Act 2011* (Australian Government 2017). Each project must comply with a number of individual project eligibility requirements in that Act along with the *Carbon Credits* (*Carbon Farming Initiative*) *Regulations 2011* (Australian Government 2015) and *Carbon Credits* (*Carbon Farming Initiative*) *Rule 2015* (Australian Government 2018).

An independent Emissions Reduction Assurance Committee (ERAC) provides advice to the Minister for the Environment on whether proposed new methods meet the offsets integrity standards, as specified in Section 133 of the *CFI Act*. The Minister must have regard to any adverse environmental, social or economic impacts, when deciding whether to make an ERF method [Subsection 106(4) *CFI Act*] (Australian Government 2017). Existing ERF methods are reviewed periodically by the ERAC to ensure they continue to meet the offsets integrity standards and other legislative requirements.

These reviews may indicate that an activity that was initially assessed as eligible may no longer be eligible. This may occur if there are changes in other legislation or unforeseen adverse economic, environmental or social impacts occur. Methods can be suspended by the ERAC if they have reasonable evidence that one or more of the offsets integrity standards is not being met. The Minister can also revoke and vary methods.

The Clean Energy Regulator administers ERF projects and contracts (Clean Energy Regulator 2018). Applications can be made for projects to be registered under an ERF method, and for a project to be registered under a method it must meet a number of individual project eligibility requirements. Projects must be new, and not required by law or already funded under a listed government program. There is also a list of 'excluded offsets projects', which could lead to particular adverse impacts, such as the planting of certain defined weed species.

Once projects are registered under an ERF method, proponents are required to undertake the eligible activity or activities and regularly report to the Clean Energy Regulator on the amount of abatement they have achieved. Projects are periodically audited to ensure they are undertaking the activity and estimating abatement as prescribed in the method.

Potential for planting leucaena as an eligible ERF project activity

Planting leucaena in agricultural systems is used here as an example to demonstrate the types of considerations when assessing whether activities would be eligible under an ERF method. This activity is assessed against the offsets integrity standards (s133 *CFI Act*) (Australian Government 2017). There are also other legislative requirements for consideration such as whether the activity is likely to have adverse impacts [Subsection 106(4) *CFI Act*] (Australian Government 2017) – also assessed here. These requirements maintain the integrity of the ERF and ensure that the value of ACCUs remains comparable across sectors. Requirements are:

1. Abatement must be additional to that which would occur in the absence of the project: Emissions Reduction Fund methods cannot permit activities that are likely to occur in the absence of the ERF, such as

being undertaken prior to project application. The combination of method eligibility and individual project eligibility requirements applies appropriate filters, so that only genuinely additional projects can be credited. For leucaena, this means that ERF projects should not be eligible if there is no additional planting of leucaena, or where non-carbon drivers would ensure that leucaena would be planted in the absence of the carbon market.

2. Estimates of net abatement must be measurable and verifiable: Emissions Reduction Fund methods must describe a measured or modelled approach for calculating the net abatement resulting from the project activity. This approach must be supported by robust scientific evidence. Estimates of net abatement must be verifiable by an auditor and the Clean Energy Regulator. In the case of leucaena any approach would need to take into account variables affecting the extent to which methane emissions are reduced, such as preferential grazing (the proportional consumption of leucaena in the diet); and possible variability in enteric methane production between cattle breeds, leucaena species and geographic locations. Calculations must account for natural variability and credit only that abatement resulting directly from the project activity.
3. The net abatement resulting from projects using ERF methods must contribute to Australia's GHG targets: Abatement credited under ERF methods must contribute to Australia meeting its international GHG targets. To achieve this, the change in emissions resulting from the project activity must be evident in Australia's annual GHG accounts. Currently the national accounts do not estimate enteric emissions at a farm scale, and therefore do not detect differences in enteric emissions resulting from local changes to the composition of feed intake. The national inventory would require data on the scope and type of these changes for it to be sensitive to farm-scale differences in feed practices. This accounting approach must be consistent with the IPPC Guidelines for national inventories.
4. There must be clear and convincing evidence that supports the estimates of net abatement: Emissions Reduction Fund methods estimate methane emissions by direct measurement or using models that must provide robust estimates of the net abatement amount. Models must be calibrated with appropriate empirical data.

   Studies to quantify enteric methane emissions from livestock fed different diets have largely been conducted using intensive respiration chambers, where inputs and outputs can be accurately measured (e.g. Hulshof et al. 2012; Newbold et al. 2014; Charmley et al. 2015). In contrast, Tomkins et al. (2018) estimated herd-scale methane fluxes using open path laser technologies and Coates and Dixon (2007) applied faecal NIRS methodologies and $\delta^{13}C$ ratios. These and other studies (e.g. Charmley et al. 2008) have demonstrated there is a reduction in enteric methane and improved emissions intensity resulting from a change in diets for livestock, including livestock change to feeding leucaena.

   It is difficult however to extrapolate these laboratory results to grazing herds, as it is not easy to determine the preferential leucaena or grass grazing practices for herds and individual cattle. Implementing these approaches to estimate net abatement could be complex and costly, thereby reducing the potential for uptake of the activity for generating carbon credits.
5. Methods must account for all material emissions resulting from undertaking the project activity in estimating the net carbon abatement: Performing activities that reduce emissions or sequester carbon may generate additional emissions. Under the ERF, all material emissions that result from the project activity must be accounted for and must be deducted from the abatement resulting from the activity to determine the net abatement amount. For example, for leucaena, GHG emissions resulting from the use of machinery involved with planting and managing leucaena, and the use of irrigation and fertilizer must be calculated and deducted from the gross abatement. Carbon and nitrogen interactions during growth of both grass and leucaena (Conrad et al. 2017) that differ from those occurring before the project was implemented must also be accounted for.
6. Estimates of the net abatement amount must be conservative: It is important that the estimates, projections and assumptions in the calculations in ERF methods do not overestimate the credits that should be issued for a project. 'Conservative estimates' help ensure that estimates of net abatement do not credit more abatement than is evident in Australia's national accounts. That is, when 1 t CO_2-eq is estimated to have been abated due to an ERF project, the national inventory report should also account for at least 1 t CO_2-eq of emissions reduction. All assumptions and estimates for parameters used to calculate abatement must result in a conservative estimate of net abatement. Discounts are sometimes applied to net abatement estimates where there is uncertainty in the science. These discounts may be

reduced over time, with additional research outcomes contributing to more refined estimates of parameters.

7. Methods must address any likely adverse environmental, economic or social impacts from carrying out the project: The Government seeks to avoid activities under ERF methods that result in any adverse environmental, social or economic outcomes [Subsection 106(4) *CFI Act*] (Australian Government 2017). To address any potential unintended adverse outcomes resulting from undertaking ERF projects, methods are assessed at the time of their development and again during periodic reviews. Leucaena is currently classified as an environmental weed as it spreads rapidly and can form dense thickets. In some regions, regulations support appropriate management to prevent or minimize its spread. The potential risk of adverse environmental outcomes as a result of promoting the planting of leucaena under a carbon scheme will need to be periodically reviewed. In addition, the inclusion of leucaena in carbon schemes must consider minimizing the risk of leucaena toxicity to livestock. If the weed classification of leucaena was changed in the future, such that planting it as part of an ERF project activity becomes an excluded offset activity, then new projects would not be eligible under the ERF.

Potential carbon abatement using leucaena

Leucaena is a perennial legume that originates from Central America. It grows best in areas with deep, well-drained, alkaline soils high in phosphorus and receiving more than 600 mm of annual rainfall that occurs throughout the year. Leucaena is more drought-tolerant than most other pasture species, and is relatively frost-intolerant. In Australia, about 125,000 ha have been sown with leucaena (Beutel et al. 2018), the majority being in central Queensland.

Enteric methane emissions from livestock can be reduced by increasing the fermentable crude protein in the diet. Legumes like leucaena are high in crude protein and methane emissions per unit of feed consumed are lower on diets containing legumes (Kennedy and Charmley 2012; McSweeney and Tomkins 2015; Harrison et al. 2015; Vercoe 2015; Conrad et al. 2017). Kennedy and Charmley (2012) demonstrated a 30% reduction in enteric methane produced by livestock fed an optimal leucaena and grass diet relative to a pure grass diet, while Harrison et al. (2015) observed reductions of more than 23%, relative to baseline emissions, in animals fed leucaena.

Liveweight gains are greater when livestock are fed a leucaena-pasture grass combination, compared with many other mixed fodders or pasture grasses (Tomkins et al. 2018). Leucaena provides highly digestible protein and the grass provides a source of roughage and energy. The improved liveweight gains result in earlier turn-off ages or heavier turn-off weights. As a result, the enteric emissions generated per unit of meat production are lower. This is known as the *emissions intensity* for each unit of production.

A reduction in the emissions intensity can be credited under the ERF as is the case for more efficient energy use in the industrial sector (Department of the Environment and Energy 2018d). Eligible activities under the ERF beef cattle herd management method (Department of the Environment and Energy 2018d) include those that promote more efficient liveweight gain in pasture-fed beef cattle herds and increase the weight:age ratio of the herd. Under the ERF beef cattle herd management method the focus is on the outcomes resulting from the activity, rather than identifying specific eligible activities.

Pastures containing a mix of leucaena and grass contain higher crude protein concentration and more biomass than straight pasture grasses. This results in the potential to sustainably increase stocking rates (Harrison et al. 2016). Despite improvements in emissions intensity per animal, an increase in stocking rates has the potential to increase overall emissions from the herd. Emissions Reduction Fund methodologies credit the abatement resulting from improved emissions intensity per animal, but this can be offset by increased stocking rates and hence increased overall emissions by the herd or per unit area.

As a perennial legume, leucaena fixes nitrogen and increases the store of carbon in the soil. For example, Conrad et al. (2017) demonstrated an increase in soil carbon of 280 kg C/ha/yr in the top 30 cm of a vertisol soil in a leucaena-buffel grass grazing system over a 40-year period. Improvements in soil carbon concentrations are most evident when legumes are planted in nitrogen-depleted soils (Conrad et al 2018), and where there are minimal or no deficiencies of soil phosphorus and sulphur (Radrizzani et al. 2016). Where soils are low in P and S, nitrogen fixation and carbon storage can be improved by applying fertilizers. However, where improved management practices focus on carbon abatement, consideration must be given to the potential for additional emissions from this use of fertilizer.

An increase in soil carbon sequestration as a consequence of planting legumes is an eligible activity under the ERF measurement of soil carbon sequestration in agricultural systems (Department of the Environment and Energy 2018d). This method focuses on the outcomes resulting from the activity, rather than defining specific activities that are eligible. Only carbon that is sequestered as a result of undertaking the ERF project activity is considered to be genuine abatement.

Conclusion

Scientific evidence demonstrates that inclusion of leucaena in the diet of cattle in northern Australia can result in improved productivity, reduced enteric methane emissions and improvements in soil carbon levels. If promoting leucaena plantings were to be considered under the ERF, a method of crediting needs to be developed consistent with the offsets integrity standards. Each project would have to meet the individual project eligibility requirements. A key challenge for all potential methods is getting the balance right between accuracy, simplicity and practicality so that genuine projects can be rewarded for their contribution to lowering GHG emissions.

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*ILC2018 Keynote Paper**

Weed leucaena and its significance, implications and control
Leucaena como maleza: Importancia, implicaciones y control

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Abstract

Leucaena (*Leucaena leucocephala*) is widely recognized in many countries as a commercially valuable plant, particularly when used as a nutritious fodder in subtropical and tropical regions. However, it is also considered an environmental weed in some countries due to its ability to form dense infestations in disturbed areas, where it is not proactively managed or grazed. These different perspectives have made leucaena a contentious species. Ideally, landholders and relevant jurisdictions in charge of invasive species need to work together to minimize its spread as a weed and manage existing infestations. To date, the response has been varied, ranging from no action through to some jurisdictions formally recognizing leucaena as an environmental weed within relevant legislation and applying requirements to minimize its impact. Between these extremes, there are initiatives such as an industry Code of Practice (i.e. The Leucaena Network in Australia), recommending that those growing leucaena adhere to certain principles and practices to minimize the risk of spread from their operations. The biology of weed leucaena (e.g. large seed production, relatively long-lived seed banks) and the situations in which it spreads (e.g. roadsides and riparian systems) pose management challenges to landholders and relevant jurisdictions. Adaptive management and experimental research are necessary to identify effective control strategies for a range of situations.

Keywords: Conflict, contentious, ecology, herbicide, management, tree legumes.

Resumen

Leucaena (*Leucaena leucocephala*) es ampliamente reconocida en muchos países como una planta económicamente valiosa, particularmente cuando se usa como forraje de alto valor nutritivo en regiones subtropicales y tropicales. Sin embargo, en algunos países también es considerada una maleza ambiental debido a su capacidad para formar infestaciones densas en áreas perturbadas donde las poblaciones no son pastoreadas ni manejadas en forma proactiva. Estas diferentes perspectivas han hecho de la leucaena una especie contenciosa. Idealmente, los usuarios de las tierras y las autoridades a cargo del control de especies invasoras deberían trabajar juntos para minimizar la diseminación de la especie como maleza y manejar adecuadamente las infestaciones existentes. Hasta la fecha, las reacciones han sido variadas, desde la no acción por parte de algunas autoridades hasta el reconocimiento formal de la leucaena como una maleza ambiental dentro de la legislación existente y la aplicación de normas para minimizar su impacto. Entre estos extremos existen iniciativas tales como el Código de Prácticas desarrollado por la Red de Leucaena en Australia, que recomienda que los que cultivan leucaena se adhieran a ciertos principios y prácticas para minimizar el riesgo de su diseminación. La biología de la leucaena como maleza (p.ej., alta producción de semillas, relativamente larga viabilidad de la semilla en el suelo) y las situaciones en las que se disemina (p. ej., bordes de carretera y sistemas ribereños) plantean

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desafíos de manejo para los productores y las autoridades. Formas de manejo adaptativo e investigación experimental son necesarios para identificar estrategias de control efectivas que deben considerar una variedad de situaciones.

Palabras clave: Conflicto, controversia, ecología, herbicida, leguminosas arbóreas, manejo.

Introduction

Leucaena (*Leucaena leucocephala*) is increasingly recognized around the world for its beneficial properties, particularly as a source of nutritional fodder, timber, fuelwood and shade (Walton 2003a, 2003b; Shelton and Dalzell 2007; Olckers 2011). It has also been used in restoration programs to restore degraded lands, improve soils, reduce erosion and stabilize sand (e.g. Shelton and Dalzell 2007; Normaniza et al. 2008; Roose et al. 2011; Wolfe and Bloem 2012; CABI 2018). Its ability to invade areas where it is not wanted, i.e. may become a weed, is also becoming increasingly recognized (Walton 2003a, 2003b; Shelton and Dalzell 2007; Olckers 2011).

Leucaena production in most countries occupies only a small percentage of the potential area where it could be grown. The risk of it becoming an even more problematic species could therefore increase greatly if steps are not put in place to minimize the risk of it escaping from existing naturalized infestations and cultivated plantations.

In this paper, we discuss the significance of leucaena as a global weed and consider actions and activities that are being or could be implemented to minimize its impacts. Key aspects of the biology/ecology of leucaena and available control options are also discussed in the context of developing management strategies to prevent its spread and/or control infestations having negative environmental impacts.

The significance of leucaena as a weed

While the native distribution of leucaena (i.e. Mexico and Central America) is relatively restricted on a global scale, a combination of deliberate and non-deliberate dispersal has led to it becoming one of the more widely naturalized species around the world (Figure 1). In a comprehensive review of the pest status of leucaena, Walton (2003a) suggested that it could be naturalized in more than 105 countries throughout the world's subtropics and tropics. This number appears to have increased since then to more than 125 countries according to some global invasive species databases (GISD 2015; CABI 2018).

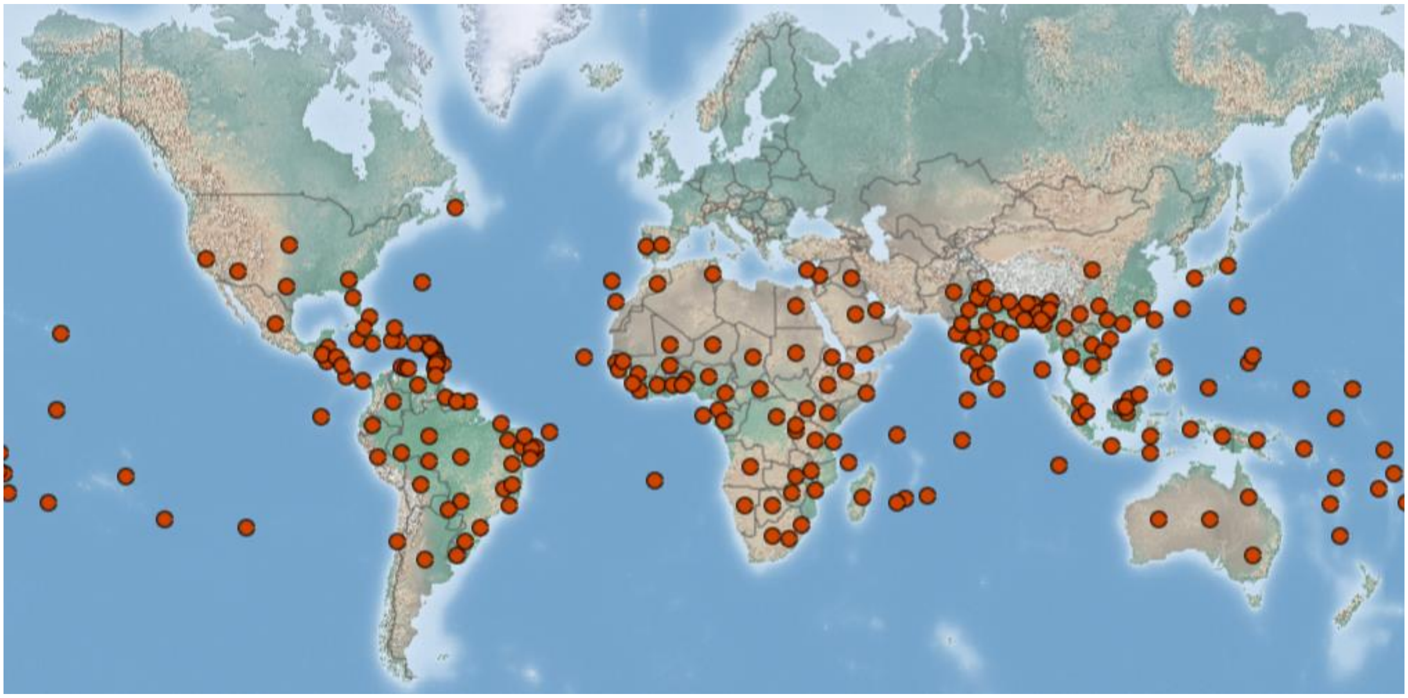

Figure 1. Global distribution of *Leucaena leucocephala*; sourced from the Invasive Species Compendium (CABI 2018). Individual points are representative of either a region, jurisdiction, country or continent. For example, this map shows that in Australia, leucaena is present in Queensland, New South Wales, The Northern Territory and Western Australia, but does not give specific locations of all known infestations.

In terms of world regions, the largest numbers of countries with naturalized populations of leucaena are located in the Pacific Ocean region, Africa, Asia and South America, followed by the Caribbean, Central America, the Indian Ocean region, Australasia, North America and to a lesser extent Europe and the Middle East (Walton 2003a; CABI 2018). Walton (2003a) suggested that leucaena was considered a weed in more than 25 of these countries, while the more recent Invasive Species Compendium database (CABI 2018) lists more than 50 countries where leucaena has been reported to be invasive. Based on a recent review of the potential distribution of 10 invasive alien trees, it appears that leucaena is globally distributed across a large portion of its potential range (Wan et al. 2018). Further expansion of its current range is most likely to occur predominantly through continued spread within already invaded countries.

Not all countries recognize leucaena solely as a weed, with some categorizing it as being a 'contentious' or 'conflict' species (FAO 2009; Clarkson et al. 2010; Olckers 2011). Plants given these classifications are recognized as having some attributes that make them useful or desirable and other attributes that make them problematic (Clarkson et al. 2010; Olckers 2011). Of the 3 subspecies of *L. leucocephala*, subspecies *leucocephala* is generally considered to have the greatest weed potential and is the most widely naturalized. The more recently cultivated *L. leucocephala* ssp. *glabrata* is considered to have fewer weedy attributes but is still recognized as having the potential to become a weed if not adequately managed (Shelton et al. 2003; Walton 2003a; Olckers 2011). Infestations of *L. leucocephala* ssp. *glabrata* have been reported at several locations in Australia (Shelton et al. 2003; Walton 2003a, 2003b).

Leucaena is predominantly recognized as being a weed of roadsides (Figure 2), forest margins, riparian habitats, ruderal areas in peri-urban environments and other disturbed areas (Shelton et al. 2003; Walton 2003a, 2003b; Olckers 2011; CABI 2018). Despite its widespread distribution, its impact is not well documented in the scientific literature. It is generally reported as having an ability to form dense monospecific thickets that could render extensive areas of disturbed ground essentially unusable and inaccessible, reduce biodiversity and potentially threaten endemic species of conservation value (Walton 2003b; Yoshida and Oka 2004; Costa et al. 2015; GISD 2015).

Figure 2. Roadside infestation of leucaena near Brisbane (Australia).

Biology and ecology of leucaena from a weed perspective

Many tetraploid leucaena species such as *Leucaena leucocephala* have biological and ecological attributes that facilitate their ability to become invasive weeds in areas where they are not proactively managed. Plants can live for a relatively long time (>30 years) under favorable conditions, even if regularly grazed (Jones and Bunch 1995; 2000). Once mature, they frequently produce large quantities of seed (Raghu et al. 2005; Marques et al. 2014). Tetraploid plants such as leucaena are self-fertile, with only a small percentage of out-crossing, so even an isolated plant can produce pods with viable seeds and be the source of a new infestation (Walton 2003b; Olckers 2011). While it appears that most seed falls and stays within close proximity to the parent plants, several dispersal mechanisms can facilitate the movement of seeds into new areas, including human activity, animals and water dispersal (Shelton et al. 2003; Walton 2003a, 2003b).The longevity of an established seed bank in the absence of further replenishment becomes important for those tasked with managing infestations. It helps determine the potential duration of control activities, particularly if eradication of the infestation is the end goal (Campbell and Grice 2000; Panetta 2004; Panetta et al. 2011). Having a hard seed coat, leucaena seeds are long-lived with several sources in the literature suggesting periods of 10–20 years and some even potentially longer (Walton 2003a, 2003b; Olckers 2011). In contrast, a study undertaken by Marques et al. (2014) in a Brazilian forest found that leucaena formed a persistent short-lived seed bank (viability 1–5 years). They suggested that under typically hot and humid conditions, such as those experienced at the field site in Brazil, seeds of tropical legumes may break dormancy faster, leading to more rapid depletion of soil seed banks (McDonald 2000).

A study of the potential longevity of seed banks of more than 10 weeds, including leucaena, was initiated in 2009 in the dry tropics of north Queensland. Seeds placed in mesh packets were buried under a range of conditions including different soil types, burial depths and levels of pasture cover [see Bebawi et al. (2015) for details on the methodology]. At 96 months a small percentage (<4%) of viable leucaena seed remained in some treatments if seeds were buried below ground (between 2.5 and 20 cm), but no surface-located seeds remained viable (Figure 3) (F. Bebawi et al. unpublished data). A seedling-emergence trial has also been running conjointly since May 2016. Preliminary results indicate that there have been approximately 9 discrete rainfall periods over the first 2 years that have been favorable for germination and seedling establishment; yet only around 20% of the initial seed has germinated and emerged. The ability of leucaena to germinate multiple times throughout a year while maintaining a persistent seed bank enhances the likelihood of establishment and recruitment occurring over a prolonged period, making it more challenging to control (Campbell and Grice 2000).

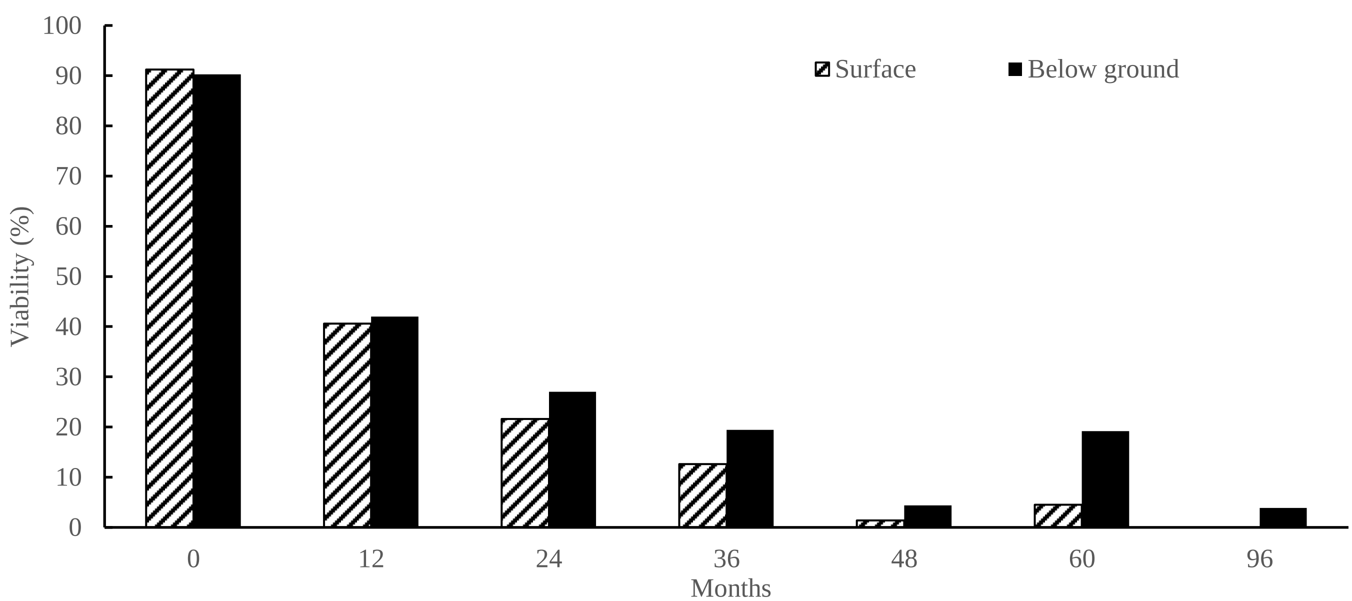

Figure 3. Changes in the viability of *Leucaena leucocephala* seeds over time following placement on the soil surface or burial below ground (2.5–20 cm).

Knowing the time for leucaena seedlings to reach reproductive maturity will aid effective management. Weeds with short timelines to maturity pose greater difficulty, with more frequent control activities required to prevent new plants from reaching reproductive maturity and replenishing soil seed reserves (Campbell and Grice 2000). Leucaena appears to be capable of reaching reproductive maturity within 12 months in many situations, but potentially as quickly as 4 months under ideal conditions (Walton 2003a, 2003b; Olckers 2011).

Control options for leucaena

Up until the present time there has been limited investment into research on control of weedy leucaena with research organizations tending to focus on higher priority species such as those declared under legislation. The main research has been to identify effective herbicides that could be applied to individual plants and scattered infestations (Walton 2003a). Some preliminary investigations into biological control options have been explored in South Africa (Olckers 2011). Some adaptive research has also been undertaken by landholders and natural resource management and community-based organizations trying to deal with specific situations where leucaena has become a problem within their jurisdictions (e.g. Folkers 2010).

Despite limited information on specific control options for weedy leucaena, several of the mechanical and chemical techniques developed for other woody weeds (Vitelli and Pitt 2006) may be relevant. If available, mechanical control would be an appropriate option for treating dense infestations of leucaena using equipment such as bulldozers (with blade, stick-rake or blade-plough attachments) or tractors and excavator-style machinery fitted with mulching devices or other destructive equipment. Any equipment that severs the root system below ground should cause high mortality but, if the plant is cut off at ground level such as during mulching, there is a higher likelihood of significant re-shooting occurring. In a series of control trials undertaken in the Mackay region of Queensland, the use of a cutter bar operating 30 cm below ground resulted in 100% mortality (Folkers 2010). This is likely to be followed by extensive seedling emergence.

Control of re-shooting plants and seedling regrowth can be undertaken with herbicides applied using a few different techniques. However, leucaena is a fairly difficult plant to control with herbicides compared with some other woody weeds, with highest mortality usually achieved by controlling younger plants, particularly if foliar spraying is the preferred method.

The basal bark technique, which involves spraying the stem of plants up to a height of around 30–40 cm from ground-level with herbicides mixed with diesel or oil-based products is consistently one of the most effective treatments on larger plants. Cutting plants off close to ground level and spraying the cut stem immediately afterwards is another effective option (Figure 4) but it is expensive and impractical for large areas unless machinery is used such as a mulcher with the herbicide applied immediately after treatment. In Australia, a triclopyr/picloram- (Access™) based product mixed with diesel is registered for both basal bark and cut stump applications on leucaena (Queensland Government 2016). In Hawaii triclopyr is recommended for basal bark and cut stump applications (Leary et al. 2012).

Figure 4. A roadside infestation of leucaena near Townsville (Australia) treated using the cut stump method.

In Australia, early screening work and more recent adaptive-style trials have shown that foliar applications of glyphosate, clopyralid and triclopyr/picloram-based products can kill leucaena. However, results were often variable, and mortality tended to decrease with increasing plant size (Pest Management Research 2002; Walton 2003a; Folkers 2010). There are no current label registrations for any herbicides to be applied using foliar applications in Australia but permits have been approved previously by the Australian Pesticides and Veterinary Medicines Authority (APVMA) for certain situations. For example, minor use permit PER9395 was issued by APVMA in 2007 for the control of leucaena seedlings on mine rehabilitation sites using a foliar application of triclopyr/picloram (150/50 g a.i./100 L water) (APVMA 2018). In Hawaii triclopyr is recommended for foliar application on leucaena plants that are less than 6 feet tall (Leary et al. 2012).

To increase the range of herbicide options to control leucaena in Australia, a collaborative exercise between industry, producers, government and Dow AgroSciences (now Corteva Agriscience™) resulted in 3 trials being implemented during December 2015 and January 2016 with final assessments undertaken 12 months later. A total of 18 herbicide treatments (including an untreated control) were applied using either basal bark, cut stump, gas gun (low-volume, high-concentration), stem blaze or frill, or the ground application of residual herbicides. The results showed that the registered basal bark techniques (both the traditional and newer thin-line method which involves spraying a more concentrated mix to the bottom 5 cm of stem) using triclopyr/picloram (Access™) consistently gave the best results but some other options also showed promise. In particular, cut stump applications of aminopyralid/metsulfuron-methyl (Stinger™) mixed with water and an aminopyralid/picloram gel (Vigilant™ II) provided greater than 80 and 60% efficacy, respectively. Ground applications of picloram granules (Tordon™ Granules) also showed promise, with limited impact on surrounding grasses and legumes. Ineffective treatments included cut stump applications using glyphosate (Glyphosate 360®) and metsulfuron-methyl (Brush-Off®), gas gun applications using metsulfuron-methyl (Brush-Off®) and aminopyralid/metsulfuron-methyl (Stinger™) and ground applications of tebuthiuron (Graslan®) and hexazinone (Velpar® L). Based on these results, the gas gun application method (low-volume, high-concentration) does not appear to be an effective option for leucaena control, possibly due to the small bi-pinnate leaf and insufficient herbicide translocating into the large biomass of mature plants (M. Vitelli pers. comm.).

A relatively new and novel stem injection technique that uses a specialized applicator and encapsulated dry herbicides is currently showing promise for a range of woody plants, including leucaena. It could have application for treating unwanted plants, particularly in sensitive areas such as waterways and national parks and in areas that are inaccessible to other equipment, such as hillslopes (Goulter et al. 2018). In Hawaii, stem injection applications using aminopyralid are an available option for leucaena control (Leary et al. 2012).

The use of fire as a control option for leucaena has not been formally tested, but warrants investigation. Anecdotal reports are variable, ranging from nil effects (Figure 5) to reasonable mortality, but this could be reflective of variability in the fires implemented. It appears that, if relatively high-intensity fires are imposed, plant mortality is possible, particularly for smaller plants (Wolfe and van Bloem 2012). Nevertheless large-scale seedling regrowth should be expected with seed scarification potentially occurring as a result of exposure to high temperatures for a short period (Walton 2003a). While this has the potential to exacerbate the problem, it can be advantageous as part of an integrated management strategy by increasing the rate of depletion of soil seed reserves, when combined with follow-up control (Campbell and Grice 2000).

Figure 5. Leucaena re-shooting after a fire in Central Queensland (Australia).

Given the benefits of leucaena, biological control has not been a high research priority. A biological control program in South Africa in 1999 resulted in the release of a seed beetle *Acanthoscelides macrophthalmus* Schaeffer, with the aim of trying to prevent establishment/ replenishment of persistent soil seed banks (Olckers 2011). The beetle has now established in another 13 countries (Australia, Benin, Ethiopia, India, Japan, China, Cyprus, Senegal, Taiwan, Thailand, Togo, Vanuatu and Vietnam) as a result of seed contamination or accidental introductions (Raghu et al. 2005; Wu et al. 2013; iBiocontrol 2018). The beetle reduces the viability of seeds, but its effectiveness is variable depending on a range of factors (Olckers 2011; Egli and Olckers 2012; Sharratt and Olckers 2012; Ramanand and Olckers 2013; English and Olckers 2014). In many instances, soil seed banks are still sufficient for seedling recruitment to occur. A sap-sucking psyllid, *Heteropsylla cubana* Crawford, has also been accidentally introduced into many countries, where it is having negative impacts on the productivity of leucaena for commercial purposes, but has not reduced the weediness of leucaena, as infestations are still expanding where the psyllid is present (Olckers 2011).

A range of land management practices can also play an important role in the management of leucaena. It is not an overly competitive species (particularly in the seedling and juvenile stages), so maintaining a healthy pasture within leucaena paddocks and in surrounding areas will greatly reduce seedling recruitment and spread into new areas. Furthermore, if commercial plantings and/or infestations of leucaena are grazed in a manner that defoliates the plants and prevents/minimizes the production of pods, this will greatly reduce the amount of seed that can be dispersed into other areas (Walton 2003a; 2003b). Periodic cutting back of leucaena in paddocks may be required if an increasing proportion of plants grow beyond the reach of livestock and start producing large quantities of seed. Incorporation of grazing as part of management strategies for weed infestations of leucaena is an option that could be explored, either initially to reduce its abundance or as a follow-up technique to utilize the regrowth. The use of goats to control leucaena also warrants further investigation as anecdotal evidence suggests that they will consume not only available foliage but also bark and will keep ring-barking plants, resulting in many eventually dying (M. Shelton pers. comm.). In the absence of grazing, utilization of infestations such as through harvesting for fuelwood and fodder has proven highly effective in minimizing the impacts and spread of leucaena in some countries (e.g. Thailand and parts of Indonesia) (M. Shelton pers. comm.). Nevertheless, given the ecology of leucaena, land managers planning on tackling large established infestations need to be prepared to make a long-term commitment, irrespective of the techniques to be used. Many weed management programs fail because a large area is treated initially. This is often the easiest part, with follow-up treatment being much more difficult, particularly if environmental conditions favor large-scale germination and seedling growth. Control of isolated or small patches before they get the opportunity to spread and establish large and persistent seed banks is the best preventative strategy.

Mitigation strategies

Leucaena has been included in formal weed prioritization and/or risk assessment processes (e.g. Pheloung et al. 1999; Walton 2003a; Nel et al. 2004; Gordon et al. 2011; Reddy 2014) within several countries to determine appropriate strategies to minimize its potential or current impacts at various jurisdictional levels (e.g. local, regional, provincial or national). Depending on its classification or the level of risk, the response has been varied, ranging from no action through to some jurisdictions formally recognizing leucaena as an environmental weed within relevant legislation.

Given the beneficial attributes of leucaena, few countries have used legislative powers as a strategy to prevent, minimize or manage its impacts within their jurisdictions. An exception is South Africa where it is listed as a Category 2 weed under the National Environmental Management: Biodiversity Act 2004 (Act No. 10 of 2004). Category 2 weeds include species that have economic benefits (e.g. agroforestry and fodder species) and are not otherwise prohibited. According to the Act, such species may be imported, harbored, propagated and traded only if a permit is obtained. This classification allows leucaena to be planted and commercially grown in demarcated areas provided steps are taken to control spread (Nel et al. 2004). Outside of demarcated areas, leucaena is considered the equivalent of a Category 1b invasive species, which means that it must be controlled or eradicated where possible (L. Henderson pers. comm.).

While not declared at a national or even a state/territory level in Australia, leucaena has been declared by several local government authorities in Queensland (Walton 2003a; 2003b), which is the equivalent of the third tier of government in a national context. At the higher levels of government, relevant states and territories provide information (e.g. fact sheets) on the potential weed impacts of leucaena as well as options to control infestations. In Queensland, the Biosecurity Act 2014 also legislates that everyone has a general biosecurity obligation (GBO) to take reasonable and practical steps to minimize the risks associated with invasive plants and animals under their control, including leucaena (Queensland Government 2016). In Western Australia, *L. leucocephala* is a permitted species, but it has been classified as a very high environmental weed risk in the Pilbara and Kimberley regions (Revell et al. 2019). Consequently, in these regions leucaena is not approved for use on the extensive areas of pastoral lease (government-owned crown land) but can be grown on freehold land (though this represents less than 2% of the area).

For contentious plants such as leucaena, Clarkson et al. (2010) suggested that a range of non-legislative options could be considered, including the use of codes of practice, subsidies, compensation, bonds, levies or insurance schemes. A voluntary Code of Practice was developed in 2000 by The Leucaena Network, a group of graziers, scientists and extension officers dedicated to advocating the responsible use of leucaena in northern Australia (Shelton and Dalzell 2007; Christensen 2019). It has the key principle that leucaena should be planted only if it is to be proactively managed and if responsibility is accepted to control plants that establish outside planted areas. Eleven recommended practices are identified with a focus on avoiding planting leucaena near potential weed-risk zones, minimizing seed set in grazed stands, diminishing the risk of live-seed dispersal and control of escaped plants from grazed stands. Although voluntary, the implementation of a self-auditing process or some sort of certification measures would be beneficial for the leucaena industry to demonstrate a level of compliance with the Code of Practice.

The recent investment in Australia by industry and government into research aimed at developing sterile leucaena varieties (McMillan et al. 2019; Real et al. 2019) is a positive and proactive initiative. If the environmental risks associated with sterile leucaena can be demonstrated to be minimal, jurisdictions that currently ban or discourage the growing of leucaena, may consider allowing the introduction of sterile varieties in certain situations. This would lead to an expansion of the leucaena industry not only in Australia but also potentially in other countries where weed concerns are preventing it from being grown or promoted for commercial purposes.

Conclusion

Leucaena is a very good example of a contentious plant given its many beneficial attributes, while also having the potential to become a major environmental weed. It has biological and ecological attributes that allow it to disperse from its source and to establish in new areas, particularly disturbed environments. Once it becomes entrenched in an area, the relatively long-lived nature of plants and soil seed banks, combined with an ability for new plants to reach reproductive maturity within a short timeframe, makes successful control a difficult, prolonged and expensive proposition. Legislation at an appropriate jurisdictional level has been used sparingly and often aimed at minimizing the environmental impacts of leucaena, while still allowing its commercial use, albeit with certain restrictions/requirements. For leucaena growers, proactive management of leucaena to minimize spread from their land will greatly reduce the likelihood of new infestations establishing from commercial operations. Practices identified in the Code of Practice, developed by The Leucaena Network in Australia, are a good starting point and could be modified to suit specific situations within different countries. For successful management of weed infestations of leucaena, an integrated approach will be required in most instances to deal not only with the original infestation but also the regrowth/recruitment that will occur so long as there is a viable soil seed bank. Options that could be incorporated, depending on available resources, include utilization (e.g. cutting for firewood, fodder), land-management practices (e.g. competitive pastures and strategic grazing), biological, chemical and mechanical control and perhaps the use of fire in some situations. However, ongoing research to improve control options for a range of situations and to develop sterile leucaena varieties is necessary if future expansion of leucaena is to be allowed in areas where jurisdictions currently restrict/prevent its use due to weed concerns. An on-going dialogue between all organizations with a vested interest in leucaena from both positive and negative perspectives is also critical if industry expansion of leucaena is to occur in a manner that minimizes environmental impacts.

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*ILC2018 Keynote Paper**

A short review of leucaena as an invasive species in Hawaii
Una breve reseña de leucaena como especie invasora en Hawái

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Abstract

Leucaena leucocephala subsp. *leucocephala* was introduced to Hawaii after European settlement and spread widely for cattle fodder and fuelwood. As in many other tropical locations where it has been introduced, it has naturalized and spread in disturbed and drier habitats. While it is common in disturbed areas, it is much less common in intact native dry forests. It is resilient to wildfire and mammalian grazing, which conversely threaten the integrity of remnant native dryland forest. The successional trajectory of areas dominated by leucaena has not been well studied in Hawaii, but it is probable that other non-native rather than native species will replace it. As a result of its widespread distribution, especially on steep slopes, priority for its eradication or control is low. Current biocontrol options are limited in effectiveness. Control of leucaena can and should be given greater priority to protect native dryland forests and inhibit spread of seeds. Restoration of dryland habitats requires intensive, sustained efforts, usually involving volunteers. Combining cultural and/or use values in restoration projects holds promise for stimulating and sustaining community involvement.

Keywords: Forest disturbance, forest succession, shrub legumes, species introduction.

Resumen

Leucaena leucocephala subsp. *leucocephala* se introdujo en Hawái después del asentamiento europeo y se extendió ampliamente para uso como forraje y leña. Como en muchos otros lugares tropicales donde se ha introducido, se ha naturalizado y extendido hacia hábitats perturbados y más secos. Si bien es común su presencia en áreas perturbadas, es mucho menos común en bosques nativos intactos. Es resistente a los incendios forestales y al ramoneo de mamíferos, que, a la inversa, amenazan la integridad del bosque nativo remanente de tierras secas. El proceso sucesional de áreas dominadas por leucaena no se ha estudiado bien en Hawái, pero es probable que otras especies no nativas, en lugar de nativas, la reemplacen. Como resultado de su amplia distribución, especialmente en pendientes pronunciadas, su erradicación o control se considera de baja prioridad. La efectividad de opciones actuales de control biológico es limitada. El control de la leucaena puede y debe recibir mayor prioridad para proteger los bosques nativos de tierras secas e inhibir la dispersión de semillas. La restauración de los hábitats de las tierras secas requiere esfuerzos intensivos y sostenidos, generalmente con la participación de voluntarios. La combinación de valores culturales y/o de uso en proyectos de restauración es una estrategia promisoria para estimular y mantener la participación de la comunidad.

Palabras clave: Introducción de especies, leguminosa arbustiva, perturbación forestal, sucesión forestal.

Hawaii as a model system for studying invasive species

The Hawaiian archipelago is globally the most isolated group of islands from any continental land mass; hence, it has one of the highest proportions of endemic species of any terrestrial location. Despite these isolated and unique characteristics, diversity of soil types and land forms and the wide range in elevation (sea level to >3,000 m) and mean annual precipitation (<250 to 10,000 mm) within and across the islands make it a near-ideal natural laboratory for

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studying patterns of biological and ecological function and adaptation across environmental gradients (Vitousek 2004). Unfortunately, these characteristics also make it extremely vulnerable to the naturalization and spread of introduced plant and animal species.

As in most places in the world colonized by humans, Hawaii has a wealth of introduced plant species adapted to chronic human-associated disturbances, such as land clearing, wildfires, soil disturbance, agriculture and grazing, plus the built environment. Of these one of the most common woody species is *Leucaena leucocephala* subsp. *leucocephala*, known locally by its Hawaiian epithet 'koa haole' (in English 'foreign koa'), given the superficial similarity of seedlings to the native species, *Acacia koa*. As elsewhere in the tropics, leucaena was deliberately introduced to Hawaii, where it was distributed widely as animal fodder and fuelwood. It subsequently became naturalized and spread into disturbed habitats, especially drier forest and scrub habitats. The history and study of its introduction and spread, current geographic distribution, successional status and possible replacement with other species in Hawaii provide a spatial and temporal microcosm to understand and guide the study of other pioneer woody invasive species in the tropics.

Introduction and spread

As in most places in the world, the exact date of first introduction of leucaena to Hawaii is disputed. In his book of Hawaiian plants, *Flora Hawaiiensis*, botanist Otto Degener claims that it was first introduced in 1864 and was widespread 20 years later (Degener 1946). Cuddihy and Stone (1990) cite reports as early as 1837 of deliberate spreading of seed for cattle grazing and fuelwood. Regardless of the exact date of introduction, by the early 1930s, agricultural researchers and extension specialists reported on and recommended the use of leucaena for pastures to improve forage quality (Henke 1929; Ripperton et al. 1933) and to stop erosion of gullies (Zschokke 1931). Zschokke (1931) acknowledged concerns about wind and water dispersal of leucaena seeds down slopes into agricultural fields, where it was considered a major weed. Despite these concerns, he recommended establishment of leucaena on dry hillslopes to replace cactus (no scientific name given but likely prickly pear cactus, *Opuntia ficus-indica*) and lantana (*Lantana camara*) as part of a conversion to pasture for grazing by beef cattle. He reported that large areas on the islands of Kauai and Hawaii had been seeded with leucaena.

Geographic extent and conditions favoring invasion

It is clear from these few reports that the widespread distribution of leucaena in Hawaii today is a combination of deliberate introduction and spread on multiple islands, coupled with naturalization via wind and water dispersal of seeds mostly into disturbed habitats. Leucaena is found primarily at lower elevations (<300 m) and drier habitats in the Hawaiian Islands (Little and Skolmen 2003), especially those that have been subject to chronic disturbance by humans and grazing or browsing mammals. Based on statewide forest inventory estimates, there are approximately 61 million leucaena trees in Hawaii, with stem diameter ranging in size from 2.5 to 22 cm and totaling over 200,000 t of dry matter (USFS 2018). This ranks as the third-most numerous tree in Hawaii but is not in the top 10 in terms of total volume or biomass. It is common or dominant on 10% of the total land area of the state (USGS 2015).

Ecologist Frank Egler described leucaena as common in 3 distinct moisture-elevation zones in Hawaii, sharing dominance with different species in each zone (Egler 1947). All 3 zones experience xeric precipitation regimes, where mean annual precipitation is less than potential evapotransporation, and the majority of rainfall occurs in the cooler autumn and winter seasons. Egler, partly relying on reports from early European explorers, also hypothesized that Polynesian settlers had cleared coastal lowlands extensively and converted them to agriculture, even in dry areas. These conditions would favor the naturalization of a species like leucaena, which is adapted to disturbed sites. It would also encourage deliberate spreading of seeds of leucaena and other useful plants onto sparsely vegetated areas or those covered in 'weeds', i.e. species that were not considered useful, in order to improve them.

Grazing and browsing mammals, including livestock and wild game animals, were introduced soon after European 'discovery' of the islands. Captain James Cook led the first European ship to reach the Hawaiian Islands in 1788. In 1793, Captain George Vancouver gave a few cattle to the chief of the Island of Hawaii as a gift. Harvest of the cattle was forbidden to allow the population to grow, so herd numbers increased quickly and cattle roamed freely on Hawaii and the other islands where they were introduced. Other domestic livestock, such as goats and sheep, and even game animals, like the Eurasian wild pig (*Sus scrofa*), Axis deer (*Axis axis*) and mouflon sheep (*Ovis orientalis*), were introduced to various islands throughout the archipelago. With their lower rainfall and thus productivity, dryland areas suffered most from the population growth of introduced mammals.

The eventual introduction of fencing and active livestock management reduced the damage these animals caused, but also removed the only significant biological control over leucaena and other disturbance-adapted species. While low-lying areas suitable for agriculture soon were sown to pineapple and sugarcane plantations, leucaena and other non-native species spread onto and dominated the dry hillsides. As mentioned by Zschokke (1931), leucaena was regarded as a 'boon' for livestock grazing on these hills but as a 'weed' for the down-slope farmers, who struggled to control it in their agricultural fields. As Hawaii's human population has expanded and the state has become more of a tourist destination, livestock grazing has slowly declined, leaving leucaena completely uncontrolled on hillsides, dry stream beds and abandoned agricultural land. As in many other populated areas of the tropics, leucaena is a common 'roadside weed' and is found more generally along open edges of fields, fence lines, empty urban and suburban lots, riparian forests and similar disturbed but open habitats.

Unlike most native dryland plant species, leucaena benefits from periodic wildfires. Its ability to resprout vigorously from the stump allows it to recover quickly after fire. Its recalcitrant seeds can withstand fast-moving fires common in dry scrub or grassland habitats. In Puerto Rico, Wolfe (2012) observed that leucaena saplings in dryland areas grew better than native saplings in competition with introduced grasses and were less affected by grass-fueled wildfires. Despite its reputation as a verdant tropical paradise, 40% of Hawaii's land surface is classified as either grassland, shrubland or dry forest (USGS 2015). Wildfires in Hawaii annually burn as much area proportionally as any other US state, including those of the western US (Trauernicht et al. 2015). Although these are generally smaller fires, they are concentrated in dry scrub and forest land, the very habitats that favor leucaena dominance. Since most of these fires are a result of human activity, they reinforce the association of leucaena with human-disturbed areas. Native Hawaiian species evolved in the absence of frequent wildfires, as would be caused by lightning strikes. No woody species have evolved the thick bark necessary to survive moderate-intensity fires, and only a few have seeds that are stimulated to germinate in response to wildfire.

Successional replacement

Since leucaena is associated with disturbed, open habitats, it is considered an early-successional pioneer species in forest development. Egler (1942) hypothesized that leucaena and other common non-native species in Hawaii's lowlands would eventually be replaced by native species. Part of his reasoning was that Hawaii's ecosystems are protected from major disturbances such as hurricanes or fires resulting from lightning strikes and, prior to human contact, were free of grazing or browsing mammals. While the islands were created by volcanic uplift, only Hawaii Island has active volcanoes at present. Therefore, Hawaii should have a diversity of late-successional native species. In the Caribbean island of Martinique, Egler (1942) observed leucaena in similar dry lowland environments; however, it was much less dominant than in other environments and it appeared that it was being replaced by native species. Thus, given adequate protection from human-associated disturbances, including grazing mammals, native Hawaiian species should eventually replace non-native pioneers like leucaena.

A related hypothesis proposed by Hatheway (1952) was that native Hawaiian dryland forest should be resistant to invasion by non-native species in the absence of major disturbances. He surveyed a native dryland forest within a protected reserve on Oahu that already included non-native woody species. He hypothesized that over time the native species should be able to maintain their dominance and even expand into the surrounding forest dominated by non-native species within the reserve. Resurveys of this area in 1970 and again in 2016 showed a slow decline in native species dominance and a subsequent increase in non-native species (J. Hibit pers. comm.). There also was no evidence of spread of native species into the surrounding forest dominated by non-natives.

While present in each of the surveys, leucaena was not one of the dominant species. Its abundance declined over time, but surviving trees grew larger, suggesting little, if any, successful reproduction was occurring. This agrees with observations by this author that leucaena can persist in the understory of dry to mesic forests but does not produce seed or grow into the overstory in the absence of large openings in the forest canopy. More generally, it suggests that other non-native rather than native species are likely to replace leucaena in Hawaii's dryland forests. Where wildfires and mammalian grazing persist, these successional changes are likely to be inhibited or reset, and leucaena will continue to be a dominant species in these ecosystems.

Priorities and options for control

Leucaena leucocephala is listed as one of the "100 Worst Invaders" globally (ISSG 2010), and is classified as a highly invasive species in Hawaii (HPWRA 2018). Olckers (2011) classified it as a 'conflict species' because of the tension between its value for human use and its propensity to naturalize and spread in dry and disturbed habitats. In Hawaii, its abundance throughout the islands causes authorities to give it a low priority for eradication or control. Newly introduced species, those with limited spatial distribution or those that invade and disrupt native ecosystems or threaten native species are higher priorities for control (HISC 2018).

Manual or mechanical eradication of leucaena is challenging. Its resilience to repeated and frequent grazing means that livestock or wild game animals can at most control its vegetative growth and production of seeds. Indeed, one reason Zschokke (1931) recommended it for control of gully erosion was the well-founded belief that, once established, it could survive and function under regular grazing pressure. Leucaena is resistant to many common herbicides but is sensitive to others, in particular triclopyr and picloram (Jim and Santo 1990; Cook et al. 2005). Recommendations are generally for basal bark or cut stump application of a herbicide mix or repeated applications of glyphosate to resprouting shoots.

Natural or assisted biocontrol of leucaena has been studied in Australia (Raghu et al. 2005) and South Africa (Olckers 2011). The leaf-sucking leucaena psyllid (*Heteropsylla cubana*) is now widespread globally and can cause slow growth or dieback of growing shoot tips. However, its effects tend to be seasonal and are usually not sufficient to kill established trees or prevent seed production during at least part of the year. A seed-boring bruchid beetle, *Acanthoscelides macrophthalmus*, is relatively specific to leucaena and is common in many areas of leucaena infestation. It was introduced to South Africa, evaluated for host specificity and eventually released in 1999 (Olckers 2011). It established well in the area of release, but appears incapable of achieving consistent and adequate seed predation to prevent spread of leucaena. The fact that leucaena coexists with both *H. cubana* and *A. macrophthalmus* throughout much of its range and is still considered an invasive species suggests these options are unlikely to be effective in most places. Both natural observations and management recommendations emphasize that grazing and browsing are more effective measures to control growth and seeding of leucaena.

Given the scale of leucaena coverage in Hawaii and the intensity of control measures required, eradication and replacement or restoration of native vegetation will have to be highly prioritized. Hillsides dominated by leucaena will be a low priority. Clearing fire breaks, riparian zones and the edges of remaining native dry forest habitat should be given higher priority to reduce wildfire risks, inhibit its movement into native forests after disturbance and provide a buffer along waterways to reduce seed dispersal. The leucaena Code of Practice (The Leucaena Network 2018) provides practical guidelines to reduce seed production and the likelihood of spread off farms and pastures that mirror these general recommendations.

Finally, dryland forest restoration is inherently more difficult than in mesic areas because of the low rainfall and thus relatively slow growth of naturally colonizing or planted native species. Wildfire risks are also higher, especially when surrounded by invasive grasses and shrubs that are adapted to fire. In Hawaii, efforts have focused on protection of remaining native forest combined with small-scale restoration of high-priority areas. Such efforts can be successful in reducing non-native species cover, establishing healthy populations of native species and encouraging natural recruitment of native seedlings. This usually requires years of effort by professionals and coordinated volunteers, and it is usually confined to just a few hectares in areas that are reasonably accessible (e.g. Medeiros et al. 2014). However, given that leucaena is associated with human-disturbed habitats, there are many areas in drier parts of the state close to both remnant native forest and residential neighborhoods that could be sites for community-based restoration. Successful examples of such projects often include important cultural aspects, such as perpetuating cultural history or practices (HFI 2016) or reviving traditional agricultural and land management systems as part of a larger watershed restoration and management strategy (Ka'ala Farms 2018).

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ILC2018 Keynote Paper*

Leucaena leucocephala introduction into a tropical pasture in the Chaco region of Argentina. Effects on soil carbon and total nitrogen

Introducción de Leucaena leucocephala *en una pastura tropical en el Chaco argentino. Efectos en el carbono y nitrógeno total del suelo*

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Abstract

The introduction of leucaena (*Leucaena leucocephala*), apart from increasing animal production, improves soil fertility through biological nitrogen (N) fixation and its deep-rooted system. There is limited information on carbon and N dynamics in hedgerow silvopastoral systems, particularly in the subsoil profile. The concentrations and vertical distribution of organic carbon (OC) and total N , and their fractions (particulate and associate forms) in the profile (0–100 cm) of a 4-year-old leucaena stand in a *Urochloa brizantha-Chloris gayana* pasture were compared with those in the adjacent pure tropical grass (*U. brizantha*) pasture. Leucaena introduction increased the OC concentration in the subsoil (20–100 cm) by 45%, particularly the stable form (associate OC) in the deepest horizon (50–100 cm). This was attributed to a greater abundance of leucaena roots deeper in the profile than for grass. Leucaena also enhanced by 7.6% the N concentration (from 0.131 to 0.141%) in the topsoil (0–20 cm) associated with an increment in the labile form (particulate organic N), due to leaf deposition, recycling of animal feces and nodule-N turnover from N fixation. Leucaena establishment has the potential to improve soil fertility and hence availability of N to companion grass growth, and can be utilized as a greenhouse gas mitigation strategy.

Keywords: C sequestration, leguminous trees, soil carbon fractions, tropical grasses.

Resumen

La introducción de leucaena (*Leucaena leucocephala*), además de incrementar la producción animal, aumenta la fertilidad del suelo por fijación simbiótica de nitrógeno (N) y por sus raíces profundas. Existe poca información sobre la dinámica de carbono y N en sistemas silvopastoriles, particularmente en el subsuelo. La cantidad y distribución vertical de carbono orgánico (CO) y N total, y sus fracciones en el perfil del suelo (0–100 cm) de una pastura de leucaena de 4 años de edad en asociación con *Urochloa brizantha* y *Chloris gayana*, fueron comparadas con una pastura adyacente de *U. brizantha* en monocultivo. Leucaena incrementó en un 45% la concentración de CO (0.98 a 1.42%) en el subsuelo (20–100 cm), particularmente la forma estable (CO asociado) en el horizonte más profundo (50–100 cm), efecto atribuido a sus raíces profundas. Leucaena también acrecentó en un 7.6% la concentración de N (de 0.131 a 0.141%) en el horizonte superficial del suelo (0–20 cm), asociado al incremento de la forma lábil (N orgánico particulado), atribuido a deposición de hojas, reciclado de excreta animal y descomposición de nódulos. La implantación de leucaena tiene el potencial de mejorar la fertilidad del suelo, la disponibilidad de N para gramíneas asociadas, y puede ser una estrategia de mitigación de gases de efecto invernadero.

Palabras clave: Secuestro de carbono, árboles leguminosos, fracción de carbono, pastos tropicales.

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Introduction

Sustaining or enhancing soil organic carbon (OC) and total nitrogen (TN) in grazing systems is essential for maintaining the chemical, biological and physical properties of soils, as well as mitigating greenhouse gases emitted by agriculture (Franzluebbers and Stuedemann 2009). Tropical grass pastures are typically constrained in their capacity to store soil C due to limited plant-available N in soils under pure grass pastures and frequent overgrazing, which leads to low primary biomass production and OC losses (Dalal and Carter 2000). Legume introduction in mixtures with grasses increases soil OC and TN in grazing systems (Fisher et al. 1994; Peoples et al. 2001; Tarré et al. 2001). Planting the multipurpose forage tree legume, leucaena (*Leucaena leucocephala* ssp. *glabrata*), has been reported to improve topsoil fertility in hedgerows in silvopastoral systems (Radrizzani et al. 2011; Conrad et al. 2017) and to increase livestock productivity (Radrizzani and Nasca 2014). Although there is some information in the Chaco region on carbon sequestration in tropical grass pastures (Banegas 2014) and in silvopastoral systems (Corbella et al. 2015), there is no published information on changes in soil OC and TN levels and their fractions (particulate and associate forms) under grazed leucaena pastures. Particulate organic carbon (POC) comprises OC particles <2 mm and >53 µm in size (Cambardella and Elliot 1992). POC is biologically and chemically active and is part of the labile (easily decomposable) pool of soil organic matter. Associate organic carbon (AOC) comprises OC particles <53 µm in size, and is chemically and physically protected from microbial degradation, being more stable and persistent in the soil. The quantity and vertical distribution of OC and total nitrogen (TN) stocks, and their fractions (particulate and associate forms), in the soil profile (0–100 cm) of a 4-year-old leucaena-grass pasture, were compared with those in soil of the adjacent pure tropical grass pasture in the Chaco region of Argentina.

Materials and Methods

Site description

This study was carried out at the Animal Research Institute of the Semi-arid Chaco Region (IIACS), operated by the National Institute of Agricultural Technology (INTA), located at Leales, Tucumán (27º11' S, 65º14' W; 335 masl), in the west of the Chaco region, Northwest Argentina. The climate is subtropical sub-humid with a dry season from April to September and average annual rainfall of 880 mm (75% in October–March). Average maximum/minimum temperatures are 32/20 ºC in January and 22/7 ºC in July; on average 16 frosts occur each year, with an average ground surface temperature of -2.2 ºC and minimum temperature of -7 ºC. Mean evaporation exceeds mean rainfall in all months. Soil type is Fluvaquentic Haplustoll, US Soil Taxonomy System (Soil Survey Staff 1999).

Pasture description

The soil samples were collected from 4 parcels of 1 ha each: 2 parcels with pure grass pasture (PP) and the other 2 parcels with leucaena-grass pasture (LP). These 4 parcels had been established with a pasture of *Urochloa brizantha* (syn. *Brachiaria brizantha*) cv. Marandú (brachiaria) in 1995. In December 2009, leucaena cv. K636 was planted in 2 of these 4 brachiaria parcels, selected at random, to evaluate the effect of leucaena introduction into ageing pure grass pastures. Leucaena seed was zero till-planted in double row hedgerows (1 m apart) with 5 m between the twin hedgerows. Eight months after leucaena establishment, high grazing pressure was imposed to avoid leucaena plants growing too tall (Radrizzani and Nasca 2014), which caused a decline in grass cover and production (visual observation but not measured in this study) in the inter-row space. In December 2011, the inter-row pasture was cultivated and overseeded with *Chloris gayana* cv. Finecut (Rhodes grass) forming a brachiaria-Rhodes grass pasture. Thereafter, the high stocking rate regime continued to maintain a dense leafy canopy within browse height. Both pastures (PP and LP) have been rotationally grazed at a variable stocking rate, according to fodder availability from early spring (October) to late autumn (June). For most of the grazing periods, LP was heavily grazed with a stocking rate around 3 times that in PP in order to restrict height growth of leucaena, leading to overgrazing of the inter-row grass.

Soil sampling

Soil samples were collected in both pastures in March 2014 from 12 transects 10 m in length (3 in each parcel; 6 per pasture). In the leucaena pasture, transects were placed obliquely from leucaena hedgerows to the middle of the inter-row (2.5 m from the hedgerow) following the sampling procedure described by Radrizzani et al. (2011). Along each transect, 5 soil cores (0 to 1 m deep) divided into 3 depths: 0–20 cm, 20–50 cm and 50–100 cm, were collected at equal distances along the 2.5 m (i.e. in the leucaena pasture: 0, 0.63, 1.25, 1.88 and 2.50 m from hedgerow). The 5 soil samples collected for each depth were mixed to form 1 composite sample per depth and transect (3 and 6 composite samples per parcel and pasture, respectively). The assumption underlying the comparisons was that both the LP and PP pastures had similar soil properties before leucaena establishment. Therefore, the difference in soil fertility parameters between pastures could be attributed to the introduction of leucaena into the pure grass pasture.

Measurements and analytical techniques

Soil samples were air-dried (40 °C), and coarse fragments (>2 mm) including gravel, plant residues and roots were removed before grinding samples to pass a 2-mm sieve. Organic carbon (OC) concentration was determined by Walkey Black (Nelson and Sommers 1996). Total nitrogen (TN) concentration was determined by Kjeldahl (Bremner 1965). Fractions of OC and TN were measured in 50 g of each composite sample through particle size analysis, following the technique described by Cambardella and Elliot (1992); organic carbon associated with particles <53 µm was entrapped into clay and silt, and therefore, considered as associate organic carbon (AOC), with a similar arrangement for associate total nitrogen (ATN). Particulate organic carbon (POC) was calculated by subtracting AOC from OC, and particulate total nitrogen (PTN) was determined by subtracting ATN from TN.

Statistical analyses

Analysis of variance of soil fertility parameters (OC, POC, AOC, TN, PTN and ATN) and mean comparisons (Tukey, $P<0.05$) within pastures were performed to assess the effects of leucaena introduction. All statistical analyses were carried out using InfoStat software (Di Rienzo et al. 2016).

Results

Total organic carbon (OC)

In both pastures, stratification of OC was observed in the soil profile, with higher levels in the topsoil (0–20 cm horizon) than in the subsoil (20–50 cm and 50–100 cm horizons) (Figure 1A). This stratification was more pronounced in soil supporting PP than in soil supporting LP, since OC concentrations continued to decline with depth in PP but no differences were observed between subsoil depths in LP. In the topsoil horizon, OC concentrations were similar for LP and PP (1.25±0.05% vs. 1.31±0.06%, respectively). However, in the subsoil horizons, OC concentrations were higher for LP than for PP (0.71±0.07% vs. 0.58±0.03% in the 20–50 cm horizon; and 0.71±0.05% vs. 0.40±0.05% in the 50–100 cm horizon). For LP and PP soils, 53% and 43%, respectively, of the total OC in the first meter of soil was contained in the combined subsoil horizons (20–100 cm depth).

Particulate organic carbon (POC)

Concentrations of POC were also stratified in both pasture soil profiles but stratification was different from that for OC (Figure 1B). In contrast with OC concentrations, POC was higher in PP than in LP in the topsoil horizon (0.48±0.08% vs. 0.40±0.05%, respectively) and represented 61.5% of total POC for PP and 45.5% of total POC for LP. In the 20–50 cm horizon, POC was higher in LP than in PP (0.28±0.08% vs. 0.17±0.04%, respectively) and in the 50–100 cm horizon POC was again higher in LP than in PP (0.20±0.05% vs. 0.13±0.03%).

Associate organic carbon (AOC)

Concentrations of AOC were also stratified, but differences between pasture soils were restricted to the 50–100 cm horizon where AOC was higher in LP than in PP (0.51±0.03% vs. 0.27±0.05%, respectively) (Figure 1C). The topsoil horizon contained 47.5% of total AOC for LP and 55% of total AOC for PP.

Total nitrogen (TN)

Concentrations of TN followed a similar trend to OC (Figure 1D). However, TN was higher in LP than in PP only in the topsoil horizon (0.141±0.0039% vs. 0.131±0.0035%, respectively). In the subsoil horizon, no differences were observed between LP and PP (20–50 cm depth: 0.070±0.0030% vs. 0.069±0.0033%, respectively; and 50–100 cm depth: 0.054±0.0040% vs. 0.050±0.0038%, respectively).

Particulate organic nitrogen (PON)

Concentrations of PON were also stratified in both pasture soil profiles but followed different patterns from those for the TN concentrations in the subsoil (Figure 1E). In the 0–20 cm horizon, PON was greater in LP than in PP (0.08±0.002% vs. 0.06±0.003%, respectively), showing that most of the TN in this horizon was in the labile ON form. A similar result was observed in the 20–50 cm horizon, where PON was also higher in LP than in PP (0.04±0.001% vs. 0.02±0.001%). In contrast, PON was higher in PP than in LP in the 50–100 cm horizon (0.02±0.002% vs. 0.01±0.002%).

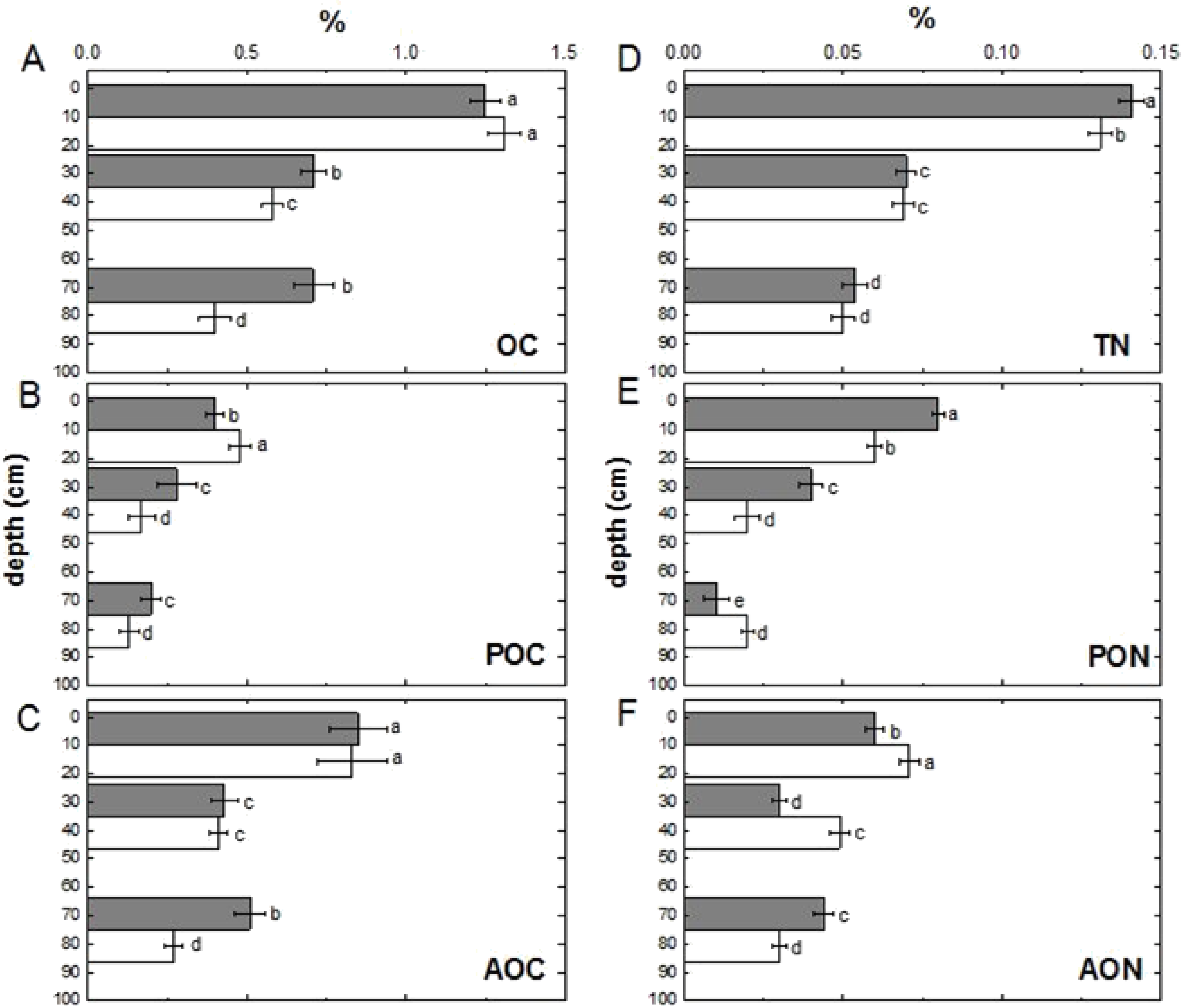

Figure 1. Concentrations of: **A**, organic carbon (OC); **B**, particulate OC (POC); **C**, associate OC (AOC); **D**, total nitrogen (TN); **E**, particulate organic nitrogen (PON); and **F**, associate organic nitrogen (AON), in relation to soil depth (0–20, 20–50 and 50–100 cm horizons) in soils under leucaena-grass pasture (filled squares) and pure grass pasture (open squares) at IIACS-INTA. Means followed by different letters are significantly different (P<0.05); bars represent standard error.

Associate organic nitrogen (AON)

Concentrations of AON were also stratified as were TN and PON but the relationships were the mirror images of those for PON (Figure 1F). AON was higher in PP than in LP in the 0–20 cm (0.071±0.003% vs. 0.06±0.002%, respectively) and 20–50 cm (0.049±0.003% vs. 0.03±0.001%) horizons. In contrast, AON was higher in LP than in PP in the 50–100 cm horizon (0.044±0.004% vs. 0.03±0.003%).

Ratios of carbon to nitrogen (OC:TN, POC:PON and AOC:AON)

The OC:TN ratio increased with depth in the LP pasture, while it decreased with depth in the PP pasture (Table 1a). While this ratio was higher in PP than in LP in the surface horizon, the reverse was the case in the 20–50 cm and 50–100 cm horizons. The POC:PON ratio also increased with depth in LP and decreased in PP (Table 1b). While the ratio was narrower in LP than in PP for the 0–20 and 20–

50 cm horizons, the reverse was the case in the 50–100 cm horizon, with a very high ratio for LP. The AOC:AON ratios declined with depth under both pastures and were higher in LP than in PP for all soil horizons (Table 1c).

Table 1. Organic carbon:total nitrogen (OC:TN), particulate organic carbon:particulate organic nitrogen (POC:PON) and associate organic carbon:associate organic nitrogen (AOC:AON) ratios in soils for leucaena-grass pasture (LP) and pure grass pasture (PP) at IIACS-INTA. Means within parameters followed by different letters are significantly different (P<0.05).

Soil depth (cm)	LP	PP
a) Mean OC:TN ± s.e.		
0–20	8.9±0.19c	10.0±0.15b
20–50	10.1±0.35b	8.4±0.32c
50–100	13.2±0.18a	8.0±0.22c
b) Mean POC:PON ± s.e.		
0–20	5.0±0.33d	8.0±0.38b
20–50	7.0±0.29c	8.5±0.68b
50–100	20.0±1.24a	6.5±0.44c
c) Mean AOC:AON ± s.e.		
0–20	14.2±0.77a	11.7±0.61b
20–50	14.3±0.81a	8.4±0.48c
50–100	11.6±0.55b	9.0±0.38c

Discussion

This study generated data from a real grazing system that described the effects on soil properties of the introduction of a forage tree legume into a tropical grass pasture. However, a lack of an accurate baseline measurement of the initial pasture soil properties did prevent rigorous statistical comparison before and after leucaena introduction. Results demonstrated the increase in OC concentration in the subsoil (20–100 cm depth), particularly the stable OC form (AOC) in the deepest horizon (50–100 cm), 4 years after leucaena introduction into a grass pasture. Results also showed that the introduction of leucaena enhances the TN in the topsoil associated with an increment of the labile ON form (PON).

Changes in organic carbon and its fractions

Overall, OC concentrations for leucaena-grass pastures were similar to values reported by Banegas (2014) in similar soil types of the same area. The 43% of the total OC in the subsoil (20–100 cm depth) of the pure grass pasture was similar to the percentages reported by Banegas (2014) in grazed pure grass pastures in the same area and by Babujia et al. (2010) in Brazilian oxisols with tropical grass pastures. Within 4 years from planting, leucaena increased the percentage of total OC contained in the subsoil from 43% to 53%, and most of this OC was in the most stable form (AOC). Similar increments in subsoil OC have been reported by Carter et al. (1998) in leucaena and *Stylosanthes* spp. pastures in northern Australia; 10 years after the woody forage legumes were introduced, they had accumulated more OC in the 20–65 cm soil horizon than the adjacent native grass pastures. Comparable results were observed 9–16 years after *Desmodium ovalifolium* (Tarré et al. 2001) and *Stylosanthes capitata* and *Arachis pintoi* (Fisher et al. 1994) were oversown into tropical grass pastures.

Although it is known that leucaena establishment can enhance OC concentrations in topsoil via its N contribution, which increases tropical grass growth, litter recycling and humus formation (Radrizzani et al. 2011; Conrad et al. 2017), in this study the most labile C form (POC) was lower in topsoil for LP than for PP. This unexpected result could be mainly attributed to two causes: a) the higher stocking rate imposed on the leucaena-grass pasture in comparison with the pure grass pasture (Radrizzani and Nasca 2014) caused overgrazing and a decline in the inter-row grass cover (visual observation but not measured in this study), hence reducing grass litter deposition and grass root turnover; and b) the cultivation done in December 2011 (only in LP pasture) might have accelerated mineralization of the labile OC form (POC) and 2.5 years might have been insufficient time to recover the original value (POC in PP pasture) in the inter-row area.

The high concentration of the stable OC form (AOC) in the deepest horizon (50–100 cm) is consistent with studies that show that root turnover in deep soil enhances the pool of less-labile soil OC (Fisher et al. 1994; Follett et al. 2003). This increment of stable C in the subsoil could be attributed to leucaena's deep-root system (not measured in this study), since a larger proportion of fine roots (>60%) of leucaena have been observed below 40 cm in soil compared with the adjacent grass pastures (Radrizzani 2009). Pachas et al. (2018) determined abundance of roots of leucaena and Rhodes grass (*Chloris gayana*) and found that leucaena had a greater abundance of roots deeper in the profile than the grass. Moreover, it is known that defoliation promotes significant turnover of fine roots (Jayasundara et al. 1997; Franzluebbers and Stuedemann 2005). Root carbon turnover would have contributed significantly to the increment in subsoil OC, particularly under the high stocking rate applied in this leucaena pasture (Radrizzani and Nasca 2014).

Although sampling up to 3 or 4 m depth is recommended to assess OC in systems where shrubs or trees grow (Jobbágy and Jackson 2000), in this study available funds did not permit collecting deeper soil samples. Consequently, the sampling depth to a meter underestimated the OC concentrations, particularly in the leucaena pasture where the OC concentration did not decline from 20 to 100 cm (Figures 1A, 1B and 1C); additional soil OC might be accumulated below the top meter. Therefore, in further surveys of silvopastoral systems soil samples should be collected to a depth of at least 3–4 meters to take account of the whole OC contribution from leucaena.

Changes in total nitrogen and organic nitrogen fractions

Overall, soil TN concentrations and organic nitrogen fractions for leucaena-grass pastures and grass pastures were within the range reported in the same area by Banegas (2014), Corbella et al. (2015) and Conrad et al. (2018). Like soil OC concentrations, soil TN declined with depth in both pastures, since most of the N (~90%) was bound up with OC in organic matter. However, in leucaena pasture, TN did not follow the same trend as soil OC concentrations, associated with the great increase in the labile PON form in both the 0–20 cm and 20–50 cm horizons. This result is consistent with higher soil TN concentrations in topsoil (0–15 cm) reported by Radrizzani et al. (2011) and Conrad et al. (2018) in leucaena pastures in comparison with adjacent pure grass pastures in northern Australia. A similar result was reported by Mahecha et al. (1999), who observed significant increases in TN concentration in topsoil (0–20 cm) of leucaena silvopastoral systems relative to pure grass pastures in the Valle del Cauca region, Colombia.

The increase in N concentration in the topsoil of leucaena-grass pasture, mainly in the labile PON form, could be attributed to deposition of leucaena leaf which is high in N (e.g. frost causes leucaena leaf shedding), leaf recycling via animal feces (e.g. high grazing pressure) and nodule-N turnover from biological N fixation. Grazing management (e.g. rotational, seasonal or continuous grazing) and weather conditions (e.g. frost and drought) can influence the quantities and the proportions of leucaena leaf fall and leaf recycled via dung (Burle et al. 2003). In the 20–50 cm horizon, the greater proportion of PON compared with AON could be attributed mainly to nodule-N turnover from biological N fixation.

Changes in carbon:nitrogen ratios

Overall, soil C:N ratios for leucaena-grass pastures and grass pastures were within the range reported in the same area by Banegas (2014) and Corbella et al.(2015). Results showed that C:N ratio increased with depth in the leucaena pasture but decreased with depth in the grass pasture, showing inverse relationships between C:N ratio and soil depth for the 2 pastures. In the leucaena-grass pasture, higher inter-row grass production and quality than in the pure grass pasture could be expected. It is known that biomass production of pure grass pastures is limited due to soil N being immobilized in litter and soil organic matter (Graham et al. 1981; Robbins et al. 1989). The increase in TN of topsoil via deposition of N-rich leaf and biological N fixation by leucaena might enhance available N for grass growth, leading to an increase in inter-row grass yield and quality.

In relation to the ratios of various parameters, the main contribution of leucaena was in the PON (labile N form) in the top 50 cm of the LP soil profile (0–20 and 20–50 cm horizons), with lower POC:PON ratios than in the deeper soil (50–100 cm). Similar findings were reported by Luce et al. (2013) with significant increases in the labile fractions of N attributed to both recycling of N-rich residues and biological N fixation after legume introductions; they highlighted that PON is the N form most sensitive to management-induced changes and has the potential to predict N availability for plant growth. Furthermore, Griffin and Porter (2004) showed that the inclusion of red clover as a cover crop in 2-year potato (*Solanum tuberosum*) rotations increased the proportion of total soil N as PON by 1,320% compared with rotations that did not contain a legume cover crop. In the deepest soil horizon (50–100 cm) of the leucaena-grass pasture, POC:PON ratio was considerably higher than in other treatments associated with the high POC concentration that might be formed by deep roots of leucaena.

The high ratios of the associate fractions (AOC:AON) in the topsoil of both pastures and the low variability with depth of these ratios, is consistent with the high stability of the associate fractions.

Conclusions

Introduction of leucaena into a grass pasture promoted substantial capture of OC in the subsoil (20–100 cm), especially the most stable form (AOC), which has minimal susceptibility to mobilization in the deepest horizon (50–100 cm), attributed to a greater abundance of leucaena roots deeper in the soil profile than of the grass.

Leucaena introduction also enhanced N concentration in the topsoil (0–20 cm), particularly the most labile form (PON) that promotes improvement in grass growth and quality, attributed to N-rich leucaena leaf deposition, leaf recycled via animal feces and nodule-N turnover from biological N fixation.

Accordingly, the establishment of hedgerow leucaena silvopastoral systems can increase cattle production directly through the diet, as well as improving soil fertility and hence availability of N to companion grasses. Through the increased growth rates of animals and greater production per head and per unit area, this strategy can serve as a long-term greenhouse gas mitigation strategy.

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*ILC2018 Keynote Paper**

Adoption, profitability and future of leucaena feeding systems in Australia

Adopción, rentabilidad y futuro de sistemas de alimentación con leucaena en Australia

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Abstract

Leucaena (*Leucaena leucocephala* ssp. *glabrata*) is a highly palatable and productive forage used mainly by beef producers on extensive properties in northern Australia. When sown into native or sown grass pastures, leucaena provides significant production, economic, environmental and social benefits. Adoption of leucaena was slow initially due to a range of technical, agronomic and landscape factors. These have now been largely overcome through extensive research, development, producer experience and other advances, resulting in around 130,000 ha of cultivated leucaena being utilized across northern Australia.

A range of aspects will need to be addressed if the adoption of leucaena is to be accelerated into the future. These include environmental concerns, especially potential weediness, and a range of technological needs, including soil nutritional requirements, grazing and toxicity management, opportunities for companion fodder systems and conservation options. Advances in technology and the ongoing need for a high-quality, profitable and sustainable perennial forage will ensure the continued adoption of leucaena across northern Australia for the foreseeable future.

Keywords: Improved feeding systems, legume-grass systems, liveweight gain, tree legumes.

Resumen

Leucaena (*Leucaena leucocephala* ssp. *glabrata*) es un forraje muy palatable y productivo que es utilizado principalmente por productores de ganado de carne en extensas áreas del norte de Australia. Una vez establecida en pasturas nativas o sembradas, la leucaena proporciona significativos beneficios de producción, económicos, ambientales y sociales. Inicialmente la adopción de leucaena fue lenta debido a una serie de factores técnicos, agronómicos y otros relacionados con la vegetación nativa y el suelo. Estos se han superado en gran medida gracias a extensas actividades de investigación y desarrollo, experiencias a nivel de productor y otros avances, resultando en que actualmente se están utilizando alrededor de 130,000 ha de leucaena en el norte de Australia.

Si se quiere acelerar la adopción de leucaena, será necesario abordar una serie de aspectos. Estos incluyen consideraciones ambientales, en particular el potencial de leucaena como maleza, y una gama de factores tecnológicos que incluyen aspectos nutricionales de la planta, manejo del pastoreo y de la toxicidad por mimosina, oportunidades para sistemas forrajeros asociados y opciones de conservación de forraje. Se considera que avances tecnológicos y la continua necesidad de un forraje perenne de alta calidad, rentable y sostenible, garantizarán la continua adopción de leucaena en un futuro previsible en el norte de Australia.

Palabras clave: Ganancias de peso vivo, leguminosas arbóreas, sistemas de alimentación mejorados, sistemas leguminosa-gramínea.

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Introduction

Leucaena (*Leucaena leucocephala* ssp. *glabrata*) is a high-quality perennial forage used primarily in extensive beef production systems across tropical and subtropical environments in northern Australia. When sown with native or exotic companion grasses, leucaena provides significant production, economic, environmental and social benefits to grazing businesses. Owing to suitable climate and extensive areas of fertile soils, leucaena has been sown predominantly in Queensland, where the majority is found in the central region of the state (Fitzroy River basin). When successfully established and appropriately managed, adding leucaena into rundown grass-only sown pastures in tropical and subtropical environments can improve both stocking rate and animal liveweight gain by up to 100%, providing up to 4 times higher total beef production per hectare per year (Dalzell et al. 2006; Bowen et al. 2018).

Incorporating leucaena into grass-only pastures also produces considerable environmental benefits, such as: (i) improved soil health with higher carbon and fertility levels through nitrogen fixation (Radrizzani et al. 2011; Conrad et al. 2017); (ii) minimization of water movement through the soil profile and subsequent mobilization of salts in particular soils due to the deep and extensive root system (Poole 2003; Pachas et al. 2016); (iii) greater water infiltration, in association with reduced run-off and soil loss during heavy rains due to higher ground cover and water-receptive soil conditions (Pachas et al. 2016); (iv) reduction in methane production (g/kg digestible organic matter intake) as the proportion of leucaena in the diet increases (Kennedy and Charmley 2012); and (v) a significant reduction in greenhouse gas emissions intensities per unit of beef produced (Harrison et al. 2015; 2016).

The long-term economic benefits of perennial pasture grazing systems with leucaena are also substantial, even when the high cost of establishment is included. Gross margins per hectare can be doubled (Bowen et al. 2018) compared with grass-only pastures, and whole-farm profitability (annualized net present value) for a breeding and finishing enterprise containing around 1,500 adult equivalents (AE = 450 kg dry animal at maintenance) can be improved by more than $40,000/annum for 30 years when compared with the same grazing business without leucaena (Bowen and Chudleigh 2018a; 2018b).

Despite grazing cultivars being available since 1962 (Gray 1968) and subsequent research demonstrating the production, profitability and environmental benefits of leucaena when sown into perennial grass pastures, the adoption of leucaena by graziers in northern Australia has been slow (Wildin 1981; Lesleighter and Shelton 1986; Middleton et al. 1995; Larsen et al. 1998; Shelton and Dalzell 2007). The area of cultivated leucaena currently utilized by graziers across northern Australia is estimated at 130,000 ha, with the majority in central and southern Queensland (Beutel et al. 2018). However, this area is small compared with the potential area suitable for growing leucaena (Peck et al. 2011; Beutel et al. 2018). The most recent study into the current and potential adoption of leucaena (Kenny and Drysdale 2019) indicates a doubling of the existing area sown in central and southern Queensland would be achievable within 20 years of the commencement of a new extension program.

This paper reviews the current adoption, profitability and future of leucaena feeding systems in northern Australia.

Adoption of leucaena feeding systems across Australia

While leucaena was first recorded in Australia at the end of the nineteenth century (Hutton and Gray 1959), interest in leucaena as a forage plant for grazing occurred only some 50 years later in the 1940s and 1950s (Gray 1968). Testing of germplasm by CSIRO started in the mid-1950s and by 1967 more than 100 accessions had been examined (Gray 1968). The initial cultivars, Peru and El Salvador, were released in 1962. Despite the availability of these productive cultivars, only 24 ha of commercial leucaena was established by 1979 (Wildin 1993). This initial slow adoption rate was due to: (i) a general lack of awareness of the plant; (ii) concerns about the negative effects of mimosine and DHP toxicity on animal performance; (iii) poor knowledge of soil, climatic and management requirements of leucaena; (iv) a lack of confidence in the production potential of leucaena; and (v) a high rate of establishment failure (Lesleighter and Shelton 1986; Pratchett and Triglone 1989; Middleton et al. 1995). Once the success of early leucaena plantations was reported (Wildin 1986) and mimosine and DHP toxicity issues were overcome (Jones and Megarrity 1986), sowings of commercial plantations expanded to an estimated 8,000 ha by 1985 (Wildin 1986), 20,000 ha by 1992 (Wildin 1994), 35,000 ha by 1995 (Middleton et al. 1995) and 100,000 ha by 2005 (Mullen et al. 2005). Despite the reporting of an estimated 150,000 ha of established leucaena in 2007, and a projected expansion to 300,000–500,000 ha by 2017 (Shelton and Dalzell 2007), a recent study estimated the area sown to leucaena and utilized by graziers in the main growing areas of central and southern Queensland was approximately 123,500 ha (Beutel et al. 2018). Added to this is an estimated 2,500 ha of sown leucaena in north Queensland (Mark Keating pers. comm. 2018) and about 500 ha in the Northern Territory (Peter Shotten pers. comm. 2018). While an appreciable area of leucaena was sown in the Kununurra district (Ord River irrigation area) of Western Australia, most if not all of this has been replaced by higher value crops (Clinton Revell pers. comm. 2018). Therefore an estimate of the total area sown to leucaena and utilized by graziers in northern Australia is currently around 130,000 ha.

A range of studies have estimated the area suitable for leucaena establishment across Australia. These projected areas have varied considerably based on the choice of climatic conditions and soil parameters included in the analysis as being suitable for leucaena: 78 million ha in coastal and subcoastal Australia (Hutton and Gray 1959); greater than 13 million ha in Queensland (Shelton and Dalzell 2007); 8.4 million ha in Queensland (Peck et al. 2011); and 25.4 million ha in northern Australia (Kenny and Drysdale 2019). On the basis of the above estimates of 126,000 ha of cultivated leucaena currently established across Queensland and using the (conservative) potential area of 8.4 million ha, only 1.5% of the total area suitable for leucaena in Queensland has actually been sown at present. Further, if the total area sown in northern Australia is around 130,000 ha, and the potential area is 25.4 million ha, then only 0.5% of the potential area has actually been sown. The logical conclusion must be that there is huge, yet to be realized, potential for leucaena sowings across northern Australia.

Central Queensland

Containing large areas of suitable soils plus favorable climatic conditions, central Queensland is now known as the heartland of leucaena in Australia. However before the availability of heavy machinery to clear areas of trees, a large proportion of the suitable soils for leucaena in central (and southern) Queensland supported native woodlands of brigalow (*Acacia harpophylla*). This lack of cleared land on suitable soils impeded the initial sowing of leucaena. Leucaena competes poorly with other species in the seedling stage and to achieve reliable establishment seed must be sown into the soil. However achieving this is problematic when trees and other vegetation hinder the use of machinery and compete with leucaena seedlings for soil nutrients and moisture. During the period following the clearing of large areas of these woodlands, when productive grazing cultivars were released (1960s and 1970s), the freshly sown grass pastures were very productive in terms of both pasture and animal performance (Walker and Weston 1990). This meant adoption of leucaena remained slow. When attempts to establish leucaena did occur, a general lack of agronomic understanding and inappropriate practices caused high failure rates (Buck et al. 2019). Legumes typically failed when incorporated into highly productive pastures owing to the competition (predominantly for moisture) from the established sown grasses (typically *Chloris*, *Megathyrsus/ Panicum* and *Cenchrus* spp.) (Peck et al. 2011). These establishment issues were not overcome until the 2000s when research and grazier collaboration provided the technology to formulate extension packages detailing agronomic techniques for reliable establishment (Dalzell et al. 2006; Shelton and Dalzell 2007). Today, when graziers follow the recommended practices, leucaena establishes reliably across a range of pasture and landscape situations.

A lack of animal performance data stifled adoption during the early development of leucaena feeding systems in central Queensland, but adoption increased as research was conducted to demonstrate responses in animal production during the 1980s and results were communicated to the grazing industry (Wildin 1986). Nonetheless, the high cost of establishment (exacerbated by failures) was still a barrier to adoption well into the 1990s (Larsen et al. 1998). Even today the high establishment costs of leucaena, compared with other forage options, remain an impediment to leucaena adoption (Stuart Buck unpublished data 2018).

An extensive area of leucaena sown into fertile clay soils in the Fitzroy River basin of central Queensland.

Cattle grazing leucaena with buffel grass (*Cenchrus ciliaris*) pasture in central Queensland.

Other regions in northern Australia

Adoption of leucaena in north Queensland, Northern Territory and northern Western Australia has been significantly lower than that in central and southern Queensland, with only an estimated 2,500 ha sown in north Queensland (Mark Keating pers. comm. 2018). In the Northern Territory, approximately 700 ha has been planted since the early 1990s, primarily in the Douglas Daly and Victoria River districts, with leucaena stands now surviving across ~500 ha (Peter Shotton pers. comm. 2018). In northern Western Australia 400 ha of leucaena was being utilized for beef cattle production in the Kimberley in the late 1980s (Pratchett and Triglone 1989), and this quickly expanded to around 2,000 ha after the threat of mimosine toxicity was solved by the release of rumen inoculum containing the detoxifying bacterium *Synergistes jonesii* (Petty et al. 1994). However the area of leucaena has declined since that time and the legume has been fully replaced with other high value crops (Clinton Revell pers. comm. 2018).

Impediments to leucaena adoption in north Queensland (Mark Keating pers. comm. 2018; Craig Lemin unpublished data 2018), Northern Territory and Western Australia include: (i) a predominance of extensive breeding enterprises not focussed on producing slaughter cattle; (ii) poor awareness amongst producers of the production benefits of leucaena combined with a corresponding lack of farming expertise and confidence; (iii) the general unsuitability of the landscape (shallow and/or infertile soils, thick vegetation or standing timber); (iv) the monsoonal climate (intense wet season, long dry season) and associated establishment risks; (v) high prevalence of competition from weeds; (vi) high cost of establishment including foregone grazing for up to 12 months and the need for prepared seedbeds; (vii) relatively favorable climate for proliferation of psyllids; (viii) limited availability of suitable machinery; (ix) a lack of qualified advisors or other specialists with agronomic knowledge and skills; (x) high transport costs of inputs to property; and (xi) the lack of local marketing options for store or finished cattle. When leucaena production systems are attempted in these environments, these constraints often translate to lower economic performance compared with the more favored localities in central and southern Queensland (Chudleigh et al. 2018).

Owing to these constraints, other tropical perennial legumes have been commonly promoted and adopted by graziers across the top end of northern Australia, especially north Queensland and Northern Territory. For example shrubby and Caribbean stylos (*Stylosanthes* spp.) were initially developed and promoted at a similar time to leucaena and have been widely sown due to ease of establishment without soil preparation and significant productivity gains achieved on infertile soils. However stylos are not suited to highly-productive soils with moderate to high clay content, and research and development studies in the 1990s demonstrated the benefits of leucaena in the monsoonal environments of north Queensland. Since the 2000s adoption of leucaena has expanded into north Queensland's seasonally dry tropics, the Atherton Tableland and coastal zones (Innisfail-Mackay), where there is a combination of sufficient annual average rainfall and suitable soils. The uncleared inland basalt provinces (Mount Surprise to Charters Towers) and cleared alluvial soils (Gilbert and Burdekin catchments) are also emerging areas for establishing leucaena. The impetus for this expansion followed the successful Producer Demonstration Site (PDS) at 'Meadowbank' station (Middleton 1998, 1999; Hasker 2000) in the 1990s, where increased carrying capacity and cattle performance (annual liveweight gain) on leucaena were double those observed on native pastures alone (Kernot 1998). More recently, a co-ordinated research, development and extension (RD&E) program has been in place to raise the profile of leucaena in north Queensland and includes: (i) an experiment comparing the palatability of new psyllid-resistant breeding lines and commercial leucaena cultivars (Wondergraze and Cunningham), which led to the selection of the psyllid-resistant Redlands variety (Shelton et al. 2016); (ii) producer demonstration sites to show local graziers the benefits of sowing leucaena on both cleared country and uncleared basalt woodlands; (iii) a 61 ha grazing trial comparing the performance of cattle grazing Redlands with that of cattle grazing Wondergraze; and (iv) trial areas of Redlands on commercial properties across northern coastal areas, Atherton Tableland and seasonally dry tropics sites (supported by MLA).

In order to increase leucaena adoption rates across northern Australia, ongoing RD&E programs must focus on: (i) improving the farming skills and confidence of graziers; (ii) quantifying long-term competitive effects of native woodland species on the productivity of leucaena-grass pastures established in uncleared basalt woodlands; (iii) helping graziers understand the cost-benefits of sowing leucaena; and (iv) quantifying the marginal productivity gains of leucaena established on the Atherton Tableland relative to existing highly productive pastures achieving annual liveweight gains up to 250 kg/hd. Local government declarations of leucaena as a weed and competing land uses in higher rainfall coastal zones will potentially influence adoption in the region.

There are specific districts in northern Australia where leucaena has been highly productive, and there is significant scope for further adoption, particularly following the release of the highly psyllid-tolerant cultivar Redlands. These districts include the coastal and seasonally dry tropical zones in north Queensland (cleared coastal and Atherton Tableland soils, fertile alluvials, basalt and possibly red duplex soils), the Douglas Daly region of the Northern Territory (red loam soils) and the Kununurra district of northwest Western Australia (heavy clay soils). While cattle marketing options are now more diverse than in the past, these areas all face the same constraints, including: the seasonally dry monsoonal climate; limited access to specialist advisors; difficulties and costs associated with accessing and transporting machinery; and increased input costs linked to geographic isolation. However, if soils and rainfall are suitable for leucaena establishment, capable and motivated producers and industry personnel will overcome these challenges.

Leucaena with native grass pasture in north Queensland.

Leucaena and predominantly Mulato II (*Urochloa* hybrid) grass pasture in the Douglas Daly region of Northern Territory.

Leucaena sown into native grass pasture and open Eucalypt forest in north Queensland.

Leucaena sown into native pastures at Meadowbank, north Queensland.

Young leucaena, planted into fully cultivated seedbed prior to grass inclusion, in southern Queensland.

Leucaena with buffel grass, southern Queensland.

New South Wales

The adoption of leucaena in New South Wales has been virtually non-existent due to persistent views that leucaena is suited to tropical climates and would therefore be unproductive in temperate climates or subtropical climates with long cold winters. However, following recent successful establishment and production of leucaena in southern inland Queensland (Antonio 2019; Ogg and Ogg 2019), an investigation into the establishment, persistence and comparative performance of leucaena in inland northern New South Wales indicates leucaena is both productive and persistent and compares favorably with other perennial tropical legume options such as desmanthus (*Desmanthus* spp.) in this environment (Boschma et al. 2018). Despite the demonstrated ability of leucaena to persist with regular frosting and produce significant forage yields during extended periods of low rainfall, it will not be recommended to graziers until sterile cultivars are available to mitigate the weed risk in this region (Boschma et al. 2018).

Productivity and profitability of leucaena feeding systems

When sown into highly-suitable situations and with appropriate management, leucaena feeding systems are highly-productive and profitable. In central Queensland, leucaena-grass pastures can be 2.6 times more productive (kg/ha liveweight gain) and 1.9 times more profitable ($/ha gross margin) than grass-only pastures (Bowen et al. 2018). Further, whole farm economic analyses indicate that a profitable outcome from leucaena establishment can be generated over a 30 year period in suitable growing regions of northern Australia, even when high establishment costs are taken into account, including: (i) fallowing land prior to sowing; (ii) seed, fertilizer, chemical and machinery inputs; (iii) foregone income from absence of grazing during the leucaena establishment phase; and (iv) ongoing inputs such as mechanical pruning and fertilizer (Bowen and Chudleigh 2018a).

In north Queensland, well-managed leucaena sown into suitable landscapes can be very productive. Cattle performance data from the Meadowbank PDS near Mt Garnet indicate leucaena sown at 8–10 m inter-row spacing with perennial native pastures (*Themeda* and *Heteropogon* spp.) in the inter-row spaces on basalt soils significantly boosts annual liveweight gains. In this study, 30 Charbray steers grazing leucaena-grass pasture during June–November 1997 (167 days during the dry season) gained an average of 0.84 kg/hd/d or 141 kg/hd (Middleton 1998; Hasker 2000). In July 1998, despite significant psyllid damage, the 12-month (366 days) weight gains by 25 Charbray steers from this same cohort averaged 235 kg/hd or 0.64 kg/hd/d (Middleton 1999). Unpublished data for 2005 indicate daily liveweight gains of Charbray steers during the wet season and the full year were 1.16 and 0.7 kg/hd, respectively (Table 1), which were double the weight gains observed on native pastures alone (Kernot 1998).

An additional advantage was that in this study stocking rates increased from one Adult Equivalent/5 ha on native pastures to one AE/3.2 ha on native pastures with leucaena. Subsequent herd modelling using the Breedcow Dynama package (Holmes 2013) suggested gross margins for the total enterprise could improve by 25% if 2,000 ha of leucaena was established on a typical 25,000 ha breeding and fattening beef operation on basalt soils in north Queensland (Bernie English and Joe Rolfe unpublished data 2018).

Since only limited research has been conducted, the general lack of long-term productivity data in north Queensland, Northern Territory and Western Australia has meant a scarcity of published information on the profitability of leucaena feeding systems for these regions (Fred Chudleigh pers. comm. 2018). Generating productivity data is a priority, as the potential for leucaena to transform beef industry profitability in northern Australia has been boosted with the release of the Redlands cultivar, which may be significantly more productive in these tropical environments, in part because of its psyllid resistance. To drive future adoption, further research is needed to: identify the most productive landscapes; develop practical and cost-effective cultural methods; refine reliable establishment techniques; and improve grazing management to maximize cattle and system performance.

Table 1. Average liveweight gains of steers grazing leucaena-native pastures on Meadowbank Station (Mount Surprise) in north Queensland in 2005. Approximate stocking rates of 1 Adult Equivalent (AE) to 3.2 ha were applied to leucaena-native pastures compared with traditional stocking rates of 1 AE to 5 ha on native pastures alone.

Grazing period (days)	No. of steers (average entry weight, kg)	Average total weight gain (kg/hd)	Average daily weight gain (kg/hd/d)
19/12/2004 – 17/04/2005 (119)	48 (243)	139	1.16
20/04/2004 – 17/04/2005 (362)	9 (403)	256	0.7

In the cooler southern Queensland environment, strategic placement of leucaena on higher, warmer sites on the northeastern Darling Downs can significantly boost production and economic outcomes compared with grass-only pastures in a similar location. In a study conducted over 2 years, leucaena-grass pastures produced an average economic return (partial return on livestock capital, which is the value added by the stock less the variable and some overhead costs) of 22% compared with grass-only pasture of 6.5% (Emery and Sneath 2015). This was bettered in the same study only by the average economic return (partial return on livestock capital) of 27% delivered by cattle finished in a feedlot during the same period. While increases in capital value are generally not included in economic modelling scenarios, an increase in property values is considered, and often realized, by graziers who establish significant areas of leucaena on their properties.

As previously discussed, research data regarding the productivity of leucaena pasture systems in more southerly environments (New South Wales) were limited until the recent completion of an empirical research study into the productivity of tropical legume and grass species in inland New South Wales (Boschma et al. 2018). Owing to the recent nature of this study, there has not been sufficient time to develop and undertake research to fully understand the economic performance of leucaena feeding systems in these colder subtropical regions.

Future of leucaena feeding systems in Australia

Adoption

Leucaena feeding systems already add significant value to the northern Australian beef industry. Expanding these industry benefits will rely mainly on lifting leucaena adoption rates through concerted RD&E activities. The influence of a recent RD&E campaign in north Queensland is evident as the number of producers utilizing leucaena has increased from 3 prior to 2000 to 15 at present (Joe Rolfe and Bernie English unpublished data). There were 127 landholder inspections of local leucaena research sites in north Queensland during 2014–2018. Many of these were repeat visits by local producers highlighting the appeal and insights provided by on-property trials and demonstrations (Coutts and Roberts 2003).

There is now extensive advisor and producer knowledge of the productivity and profitability of leucaena feeding systems in central, and to a lesser extent, southern Queensland. In these regions, there are ample suitable soils for leucaena and research highlights the economic advantages of sowing leucaena into rundown sown grass pastures. While leucaena is still being planted, adoption rates to date remain modest compared with the potential area suitable for leucaena. Why many graziers have not adopted leucaena in these preferred locations should be determined so that research and extension programs can address these issues to overcome the road-blocks and unlock the production potential across large areas. Some graziers have planted all sections of their property suitable for leucaena, whereas others are reluctant to plant additional areas until their stock numbers and turnoff increase sufficiently to finance the establishment of additional paddocks. Other reports indicate some graziers, primarily located in non-frost-prone locations, are still developing grazing management techniques to effectively control the height of their current leucaena stands and to reduce seed production, weed spread risk and the need for mechanical trimming.

Across north Queensland and the Northern Territory a range of research projects/demonstrations are required in areas suited to leucaena to overcome local challenges and boost future adoption. Investigations should include the collection of data on leucaena and cattle production across a range of locations and seasons. Economic analyses of production systems in these environments will enable advisors and graziers to evaluate how incorporating leucaena can improve the profitability of existing production systems. While more research investment is required, an existing project aims to measure and compare the liveweight gains of weaner steers grazing the psyllid-resistant cultivar Redlands and the most recently released psyllid-susceptible cultivar Wondergraze near Mount Garnet in north Queensland (Lemin et al. 2019). Outcomes from this grazing trial will broadly improve the understanding of leucaena establishment, management, fertilizer requirements and production economics in northern environments. While there are limited data on the economics of incorporating legumes generally into grass-only pasture systems in northern Australia, a recent desktop modelling analysis by Ash et al. (2015) clearly demonstrates that legume incorporation is the most profitable strategy for adoption by graziers.

In recent years, high seed prices combined with shortages of seed and appropriate rhizobium have constrained leucaena plantings. Unfortunately the relatively small demand for inputs such as seed and rhizobium, compared with other legumes like lucerne (*Medicago sativa*), which is regularly re-sown, means these issues could re-emerge in the future. Although rhizobium is now readily available, seed supply of some leucaena varieties is still limited. The anticipated future expansion of leucaena across Australia will place increasing pressure on industry suppliers to match the demands for critical inputs. This could result in structural changes to business models, for example the emergence of dedicated seed producers of openly traded cultivars rather than opportunistic harvesting of seed, to ensure reliability and continuity of supply.

Environmental considerations

Leucaena is considered an environmental weed by many local government and natural resource management organizations. Managing the real and perceived weed risk of leucaena is critical for ongoing adoption through industry and community acceptance. The Leucaena Network (TLN) was formed by graziers in 2000 to promote the sustainable adoption of leucaena while minimizing unplanned spread. A Code of Practice (CoP) was released by TLN in 2000 to encourage the responsible planting and management of leucaena and is regularly reviewed and updated (Christensen 2019).

While leucaena is regarded as a weed by many, several important environmental benefits for grazing landscapes are critical to the future adoption of leucaena. Benefits include: (i) improved soil health and fertility through increased organic carbon levels; (ii) higher sustainable pasture utilization through increased biomass production (Bowen and Chudleigh 2018c); (iii) ground-cover maintenance, particularly during dry conditions; (iv) reduction in methane production per unit of beef production; and (v) potential for carbon sequestration and payments through associated accreditation schemes. These benefits could be potentially overlooked unless strongly advocated by the industry. The recently instigated project 'Development of a sterile Leucaena to enhance red-meat production in new regions of Australia' (MLA donor company project code P.PSH.0884), if successful, could result in the removal of restrictions on leucaena plantings across many areas of Australia, particularly in Western Australia and New South Wales.

Nutritional requirements

There is an emerging need to improve understanding of the nutritional requirements of leucaena and determine the timing, placement and quantity of fertilizer applications for existing leucaena-grass pasture stands. A considerable area of leucaena has been sown into nutrient-depleted paddocks previously utilized for dryland cropping. In this situation leucaena production is restricted by limited availability of soil nutrients rather than rainfall received. Considerable improvements in annual dry matter production, pasture quality and stocking rates can be made when adequate soil nutrients (particularly phosphorus and sulfur) are available to the pasture system (Radrizzani et al. 2010). For new leucaena sowings, it is critical to determine soil nutrient levels prior to sowing to determine appropriate fertilizer application rates and placement in relation to the planted rows. In existing stands, measurements of plant nutrient status (leaf analyses) together with soil nutrient stores are required before fertilizer rates, placement and application frequency can be determined.

The basalt provinces in north Queensland are an emerging establishment area for leucaena. Fertilizer applications are essential to overcome inherent sulfur deficiencies on these soils, both at planting and in the longer term. Practical methods for fertilizer application in these timbered and rocky landscapes, as well as the frequency and optimum rates, all require further investigation.

Filling feed gaps with winter forages

Business enhancements might arise from the production of high-quality feed throughout the year by incorporating annual winter forages into a perennial leucaena-pasture system, either during years with high winter rainfall or where irrigation is available. One of the perceived issues with a leucaena-grass pasture in the tropics and subtropics is poor grass growth, pasture quality and weight gains during the drier (and cooler) winter months. One concept being investigated by industry practitioners is to sow annual winter forages, e.g. oats (*Avena sativa*) in the inter-row spaces, either direct drilled into the dormant grass or sown after cultivation. This system has the potential to fill the winter feed gap to maintain high weight gains for close to 12 months of the year, compared with only 7–9 months without winter forages. While field research into the productive capacity and resulting economic outcomes of such systems needs to be undertaken, economic analysis of a system, involving grazing cattle on oats in the winter months and leucaena-grass pasture for the remainder of the year in central Queensland (Bowen and Chudleigh 2018b), indicates costs of establishing and managing the winter forage could out-weigh the increased weight gains and additional income potential from marketing heavy cattle earlier. Without irrigation, such a system may have production merits only in higher rainfall years. Unfortunately the ability to accurately predict these suitable years is difficult with current seasonal forecasting tools and, while irrigating leucaena could guarantee adequate soil water for optimum forage growth, this could come at a prohibitive cost.

Fodder conservation

Techniques to improve the utilization efficiency of leucaena, especially in irrigated situations, could be critical to future profitability. Innovative graziers are already exploring effective techniques to either ensile or pelletize leucaena to increase the utilization efficiency and conserve fodder for use at a later date. Young, fresh leucaena biomass has been cut and wrapped into silage bales with reasonable success (Stuart Buck unpublished data 2018). Other innovators have attempted to pelletize the same material (Ernie Young pers. comm. 2015). Undoubtedly feeding such material during the dry season will improve weight gains, but the costs associated with cutting, wrapping-pelletizing, handling, transporting and feeding may exceed the benefits and must be analyzed.

Grazing management

Future research must include a focus on refining grazing management of leucaena-grass pastures to ensure sufficient pasture supply to maximize dietary selection and liveweight gains. Research into dietary selection by cattle through fecal analysis over a number of years has provided important insights into the quantity and timing of leucaena intake in a mixed pasture sward. Specifically, multiple on-farm trials in central and southern Queensland environments with stock on leucaena and predominantly buffel grass pastures indicated leucaena can comprise about 50% of dietary intake on average during the year (Bowen et al. 2018). However intakes can range from around 10% to greater than 80%, depending on time of year, supply of edible leucaena and quantity and quality of the companion grasses. Therefore, graziers and advisors need to look beyond the notion of an 'ideal' level of leucaena intake (30% is commonly asserted), and recognize leucaena consumption by cattle will, and should, fluctuate significantly with grass quality and seasonal conditions. As such, management of the leucaena-grass pasture system should aim to maximize the supply of edible leucaena at times of high leucaena intake (typically when grass quality is low in autumn and spring) and ensure adequate grass forage is available when grass consumption is high (typically when grass quality is high in summer). To this end there will be important implications for pasture (grass and leucaena) budgets, stocking rates, grazing periods, row widths, row direction to minimize grass shading, fertilizer requirements and selection of companion grass species in new plantings and existing stands.

Toxicity to grazing animals

Considerable research into leucaena toxicity, dynamics of rumen microflora and management in recent years (Dalzell et al. 2012; Davis et al. 2012; Graham et al. 2013; Halliday et al. 2013, 2019) indicates a range of bacteria other than *Synergistes jonesii* are capable of degrading dihydroxypyridine (DHP) and may already be present in the rumen of grazing animals in Australia. In addition other metabolic processes (conjugation) may allow cattle to consume high levels of mimosine yet still grow at levels expected on a particular dietary intake and composition (Halliday et al. 2013). These investigations must continue to provide graziers with recommendations for practical management options to minimize production losses associated with toxicity.

Plant breeding

Innovative plant breeding technologies will ensure new leucaena cultivars are developed by introducing specific traits into existing cultivars. While a new project in Western Australia is endeavoring to breed a sterile leucaena, the opportunity and feasibility of breeding a cold- or frost-tolerant cultivar should also be investigated. This could expand the area suitable for leucaena in both the colder areas of existing growing regions, and importantly the colder climates of New South Wales, where leucaena is currently not sown, mainly due to temperature limitations. Ultimately it may be desirable to have a cultivar which has multiple attributes such as psyllid resistance, sterility and cold tolerance. These combined attributes would enable high production from leucaena plantations extending from the northern regions of Australia through to southern latitudes where cooler winter temperature patterns are dominant.

Cattle management technologies

Some of the production enhancements previously discussed will be made easier or enabled through advances in electronics. Electronic ear tags with global positioning systems (GPS) capability will revolutionize the ability to manage individual animals within large mobs of cattle. Walk-over-weighing and auto-drafting systems are already commercially available and can provide significant management and time-saving advantages, including: sorting of similar weight groups of cattle for marketing purposes; targeting cost-effective supplementation programs; and grouping similar-sized animals for breeding or pasture-budgeting purposes.

Conclusions

While leucaena is already making a significant contribution to the level and profitability of beef production in northern Australia, there is potential for enormous increase in the area sown. Research will continue to develop superior cultivars and refine the methodologies for establishing and utilizing this valuable legume in the years ahead. With continual improvements in agronomy and grazing systems, and the ongoing need for graziers to improve productivity while meeting more stringent market specifications, leucaena-grass pastures will continue to be one of the most economical and sustainable feeding systems for northern Australian beef producers.

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(Note of the editors: All hyperlinks were verified 9 August 2019.)

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ILC2018 Keynote Paper*

Current and future adoption of leucaena-grass pastures in northern Australia

Adopción actual y futura de pasturas de leucaena-gramíneas en el norte de Australia

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Abstract

The leucaena-grass pastures and target markets for adoption project was commissioned by Meat & Livestock Australia (MLA) to examine the scope for further adoption of leucaena-grass pastures in northern Australia. Drawing upon stakeholder and producer interviews, focus groups, mapping of biophysical factors critical to growing leucaena and a review of existing literature, regional adoption profiles were developed using the ADOPT model. This work outlines the current and future potential for adoption of leucaena in northern Australia and recommends 5 interrelated strategic actions designed to support the ongoing adoption. These actions have been designed to address the complex technical, social and biophysical requirements for successful adoption and will require collaboration between investors, The Leucaena Network, producers, government agencies and the private sector to be effective.

Keywords: ADOPT, beef, central Queensland, extension, technology transfer.

Resumen

Meat & Livestock Australia (MLA) encargó este estudio con el fin de examinar las perspectivas de incrementar la adopción de pasturas de leucaena-gramíneas en el norte de Australia. Con base en entrevistas con productores individuales y en grupos, y con personal de agencias gubernamentales, mapeo de factores biofísicos críticos para el cultivo de leucaena y una revisión de la literatura existente, se desarrollaron perfiles de adopción regionales utilizando el modelo ADOPT. Este trabajo describe el potencial actual y futuro para la adopción de leucaena en el norte de Australia y recomienda 5 acciones estratégicas interrelacionadas, diseñadas para apoyar la adopción en curso. Estas acciones fueron diseñadas para abordar los complejos requisitos técnicos, sociales y biofísicos para una adopción exitosa. Para ser efectivas, requerirán la colaboración entre inversionistas, la Red de Leucaena (The Leucaena Network), los productores, agencias gubernamentales y el sector privado.

Palabras clave: ADOPT, extensión, ganado bovino, Queensland central, transferencia de tecnología.

Introduction

The northern Australian beef industry

More than two-thirds of Australia's beef herd is located in northern Australia, covering subtropical northern New South Wales (NSW) (6%), Queensland (QLD) (47%), Northern Territory (NT) (10%) and the rangelands area of Western Australia (WA) (5%) (ABS 2017). These northern production systems are based in the summer-dominant rainfall zones, with highest stocking densities in southeast Queensland decreasing further north and into the Northern Territory, the Kimberley and Pilbara.

Cattle production and turnoff across the north are tailored to a variety of 'production sectors' from breeding and sale of weaners or store yearlings through to backgrounding and finishing for specific domestic and

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export markets (Ausvet 2005). A key challenge faced by northern producers is to obtain the rapid weight gains required to meet market specifications because of the relatively poor nutritional value of tropical grass pastures.

Leucaena as a forage option

Amidst the search for more nutritious species the forage legume leucaena, used in combination with grass pastures, was reported by Dalzell et al. (2006) to be the most productive, sustainable and profitable system for producing grassfed beef in northern Australia. These pronouncements of the virtues of leucaena were reinforced by Bowen et al. (2015) in a study of forage systems on 24 producer sites in the Fitzroy region. The study found that leucaena-grass pastures resulted in the highest average total beef production and highest gross margins. Production/ha from leucaena-grass pastures was 2.6 times greater than the average annual beef production from perennial grass pastures and 1.6 times higher than the next most productive legume pasture, with less variability between sites and years in total beef produced.

Leucaena, while being highly productive and profitable, presents significant challenges to establish and manage, and is suited to only a particular range of soil and rainfall zones in northern Australia. Producer Demonstration Sites (PDS) and research projects have demonstrated the challenges involved in managing and establishing leucaena, highlighting a 3–7 year payback time to recover establishment costs for leucaena-grass systems (Bowen et al. 2015). In summary, the strengths and weaknesses of leucaena as defined by Dalzell et al. (2006) are:

Strengths

- Very high nutritive quality for ruminant livestock.
- Highly productive on suitable soils.
- Drought-tolerant, retaining leaf during dry periods.
- Long life meaning lower lifetime cost overall.
- Enables targeting of higher value markets.
- Reduces soil erosion and prevents rising water tables due to deep root system.
- Reduces greenhouse gases via carbon sequestration and reduced methane production.

Limitations

- Poorly adapted to acid and infertile soils.
- Grows poorly at low temperatures and is susceptible to frosting.
- Poorly competitive in seedling stage and slow to establish.
- Susceptible to psyllids in humid/coastal conditions.
- Costly to establish.
- Mimosine toxicity requiring additional management.

Objectives and method

The purpose of the leucaena-grass pastures adoption project is to inform the development of an industry strategy to increase the adoption of leucaena-grass pastures across suitable regions of northern Australia. This study was commissioned with 4 objectives:

1. Describe the potential for future leucaena production in northern Australia;
2. Examine current production levels of leucaena-grass pastures in Australia;
3. Explore the barriers and incentives to adoption (scope) and the return on investment Meat & Livestock Australia (MLA) can expect from its RD&E investments into leucaena; and
4. Make recommendations on a strategy to increase the adoption of leucaena-grass pastures.

Throughout this paper we refer to 5 regions in northern Australia, each with a unique combination of adoption characteristics. These regions differ in one or more key elements critical to the potential adoption of leucaena, namely: farming system types; psyllid risk; access to markets; and producer density/critical mass. The regions are central Queensland, the Queensland High Rainfall Coastal zone, Queensland Gulf Country, Northern Territory and Western Australia.

To understand the geo-climatic potential for leucaena in these regions, we reviewed the published literature. From this review, the geo-climatic potential of leucaena was mapped, based on soil depth >1 m and pH >5.5 as per the methodology of Beutel et al. (2018) and annual rainfall ≥400 mm. To determine the upper limit of beef properties and cattle numbers in suitable areas, Australian Bureau of Statistics (ABS) SA2 polygons that fall within Natural Resource Management (NRM) regions were used, with counts being apportioned based on the percentage of area within an NRM region where boundaries do not align.

In terms of actual adoption, the paper draws on the work of Beutel et al. (2018) in central Queensland and input from local operatives in the other zones to assess the extent of current plantings. The next component of this project was to explore barriers and incentives to adoption. This was assessed by multiple 'data' sources including: producer interviews and focus groups in central Queensland; discussions with R&D personnel involved with leucaena; review of literature on the attributes of leucaena; and an analysis of MLA producer segmentation work. These data were then incorporated into the ADOPT model (Adoption and Diffusion Outcome Prediction Tool; Kuehne et al. 2017) to better understand the potential scope and rate of adoption.

Upon developing these adoption 'profiles' for each region, a rationale for investment in extension and adoption activities was developed, with 5 interrelated strategic actions being recommended to support the consolidation of knowledge associated with leucaena management and ongoing adoption.

Results

Scope for leucaena

Geographic potential for leucaena production is dependent upon 4 key biophysical elements: 1) growing temperature; 2) frost incidence; 3) annual rainfall; and 4) soil type, as described by Dalzell et al. (2006):

1. Temperature – growth slows when daily maximum temperatures fall below 25 °C in autumn, and stops when minimum temperatures fall below 10 °C. Soil temperatures need to be above 18 °C for leucaena seed to germinate rapidly.
2. Frost – can kill seedlings of all cultivars; however mature plants recover after leaf drop caused by mild frosts (0 to -3 °C) and after death of above-ground stems from severe frosts (below -3 °C).
3. Rainfall – can tolerate and produce leaf during dry spells and droughts; however performs best in areas that receive >600 mm annual rainfall. Above 800 mm rainfall psyllid insect damage becomes problematic with current varieties. The new psyllid-tolerant Redlands variety has potential to address this issue.
4. Soils – grows best on deep, fertile, well-drained, neutral to alkaline soils.

From these data, the following can be concluded with regard to the geographic potential of leucaena across northern Australia:

- The 600–800 mm rainfall zone is likely to provide greatest potential so long as soil and temperature conditions are suitable. The 400–600 mm zone may also be suitable, depending upon annual rainfall distribution, but is deemed 'marginal' in terms of its appropriateness.
- The 800 mm plus rainfall zone offers huge production potential with the new Redlands psyllid-tolerant variety; however a greater prevalence of acid soils, opportunities for higher-value crop production, perceptions in coastal areas of leucaena being a weed and establishment and management challenges mean that these areas are also seen as marginal for adoption.
- Average minimum temperatures and frosts are unlikely to be a barrier in northern Australia, except for a small area around Charleville.
- Soil depth >1 m and pH >5.5 appear to provide a best-bet option for land suitability.
- Suitable areas in NSW fall into Local Government Areas (LGAs) which prohibit the use of leucaena.

In order to quantify the upper limit with regards to potential area in northern Australia suitable for growing leucaena, data from the CSIRO National Soils Grid for pH($CaCl_2$) and soil depth, along with Bureau of Meteorology (BoM) annual rainfall data were collated to form maps and data tables and results are represented in Table 1 and Figure 1 below.

From these data it can be seen that:

- 16% of northern Australia or 88,106,354 ha fits the broadest temperature/rainfall/soils requirement for growing leucaena;
- only 5% or 25,351,588 ha fits the ideal rainfall and soil characteristics; and
- of the total ideal area suitable for leucaena, 5% is in NSW, 14% is in the NT, 79% is in Queensland and 2% is in WA.

Table 1. Total area suitable for growing leucaena in northern Australia.

State	Total area (ha)	% of ideal area	Rainfall zone area[1] with suitable soils[2] (ha)		
			400–600 mm	600–800 mm	>800 mm
New South Wales	10,103,329	5	543,964	1,218,044	145,696
Northern Territory	134,735,520	14	2,697,013	3,523,638	11,344,726
Queensland	172,935,408	79	36,125,260	20,106,218	8,765,528
Western Australia	220,803,174	2	16,235	503,689	3,116,343
Total (ha)	538,577,432				
Total potential (ha)	88,106,354		39,382,471	25,351,588	23,372,294
Total potential (%)	16		7	5	4

All areas are calculated using GDA 94 Albers Projection.
[1]Rainfall based on BoM 30 year annual mean from 1976 to 2005.
[2]Suitable soils based on a combination of soil depth >1 m and pH($CaCl_2$) >5.5 (in soils >1 m); data sourced from CSIRO - National Soils Grid of Australia (90 m resolution).

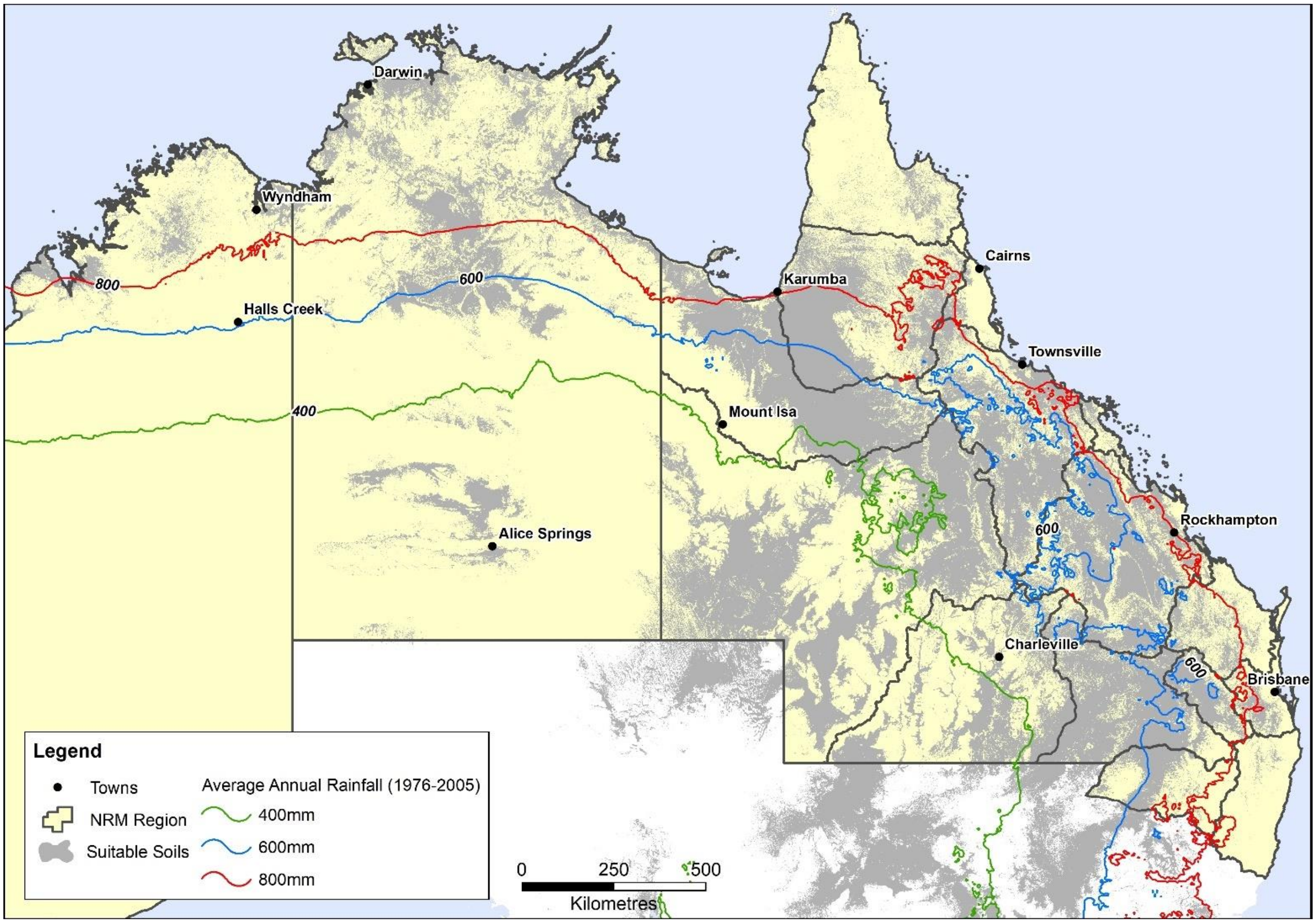


Figure 1. Soils suited to leucaena (depth >1 m with pH >5.5) in rainfall zones across northern Australia.

Beef enterprises and cattle numbers in areas suited to leucaena

The beef industry across northern Australia encompasses almost 16,000 producers and over 15 million cattle. In order to estimate beef cattle numbers and the number of beef properties in areas suited to leucaena, we have mapped the distribution of cattle and producers across the 17 NRM zones in northern Australia. We then overlaid the area with the rainfall and soil suitability characteristics in order to evaluate the upper level of producers who may adopt leucaena, along with the number of cattle this represents. Figures 2 and 3 show the cattle producers and cattle numbers for each NRM region and Tables 2 and 3 show overall producer and cattle numbers for each state and in areas potentially suited to leucaena.

From these data we concluded that:

- 40% of properties comprising 42% of cattle in northern Australia have the potential to grow leucaena. This represents 6,266 properties and 6,329,606 head of cattle;
- 20% of properties and 16% of cattle are in the 'ideal' zone for leucaena with regard to rainfall and soils. This equates to 3,080 properties and 2,377,086 cattle; and
- Queensland is the dominant area with regard to ideal conditions for leucaena, containing 92% of properties and 91% of all cattle in areas highly suitable for growing leucaena.

In summary:

- 16% (88,106,354 ha) of northern Australia fits the broadest temperature-rainfall-soils requirements for growing leucaena, comprising 6,048 properties and 6,302,595 cattle;
- 5% (25,351,588 ha) of northern Australia fits the ideal requirements for growing leucaena, comprising 3,080 properties and 2,377,086 cattle; and
- 79% of the ideal area is in Queensland, which equates to 20,106,216 ha, 92% of properties (2,835) and 91% of all cattle (2,168,123) in areas highly suitable for growing leucaena.

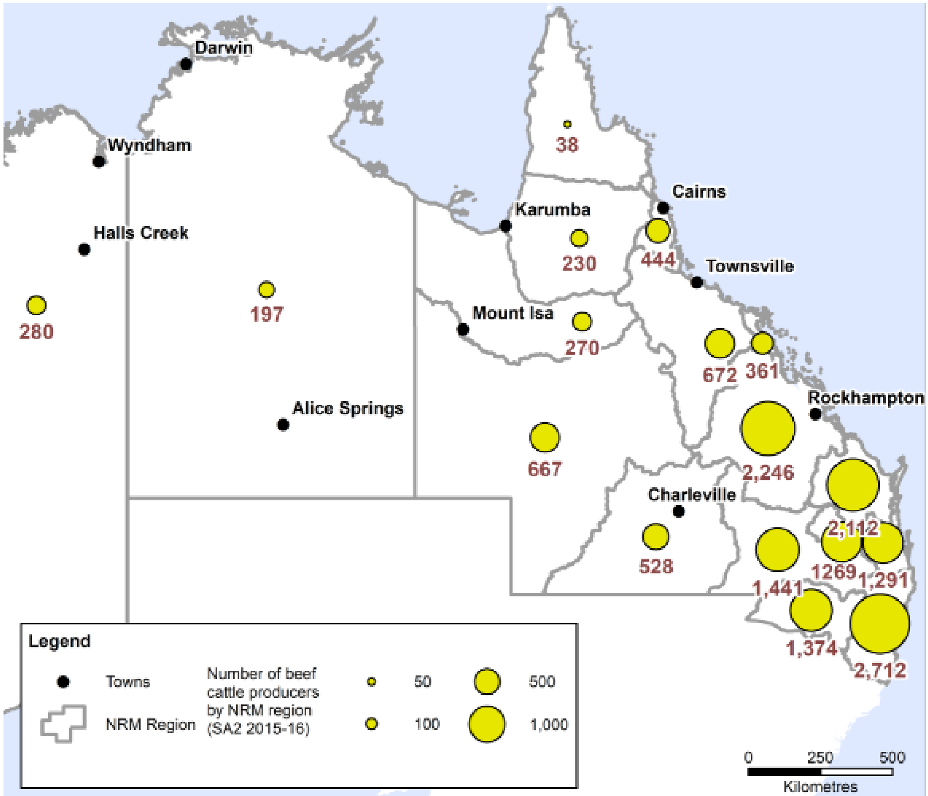


Figure 2. Number of beef cattle producers in NRM regions across northern Australia.

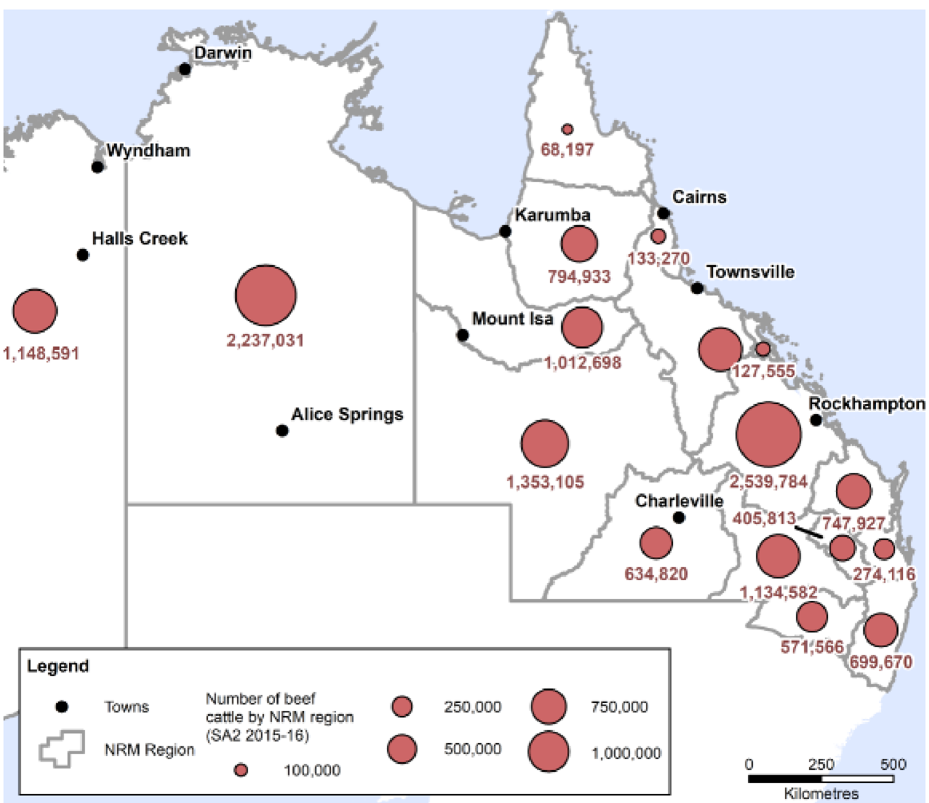


Figure 3. Number of beef cattle in NRM regions across northern Australia.

Table 2. Beef cattle properties suitable for growing leucaena in northern Australia.

State	Beef cattle properties[1]	% ideal properties	Beef cattle properties[1] in rainfall zone areas[2] with suitable soils[3]		
			400–600 mm	600–800 mm	>800 mm
New South Wales	4,086	8	68	238	85
Northern Territory	197	0.2	3	7	35
Queensland	11,125	92	2,131	2,835	860
Western Australia	280	0	0	0	4
Total properties	15,688				
Total potential properties	6,266		2,202	3,080	984
Total potential (%)	40		14	20	6

[1]Counts are based on ABS SA2 polygons that fall within NRM regions, rainfall areas and combined rainfall/suitable soils areas. Note that SA2 areas do not coincide with NRM regions. ABS counts have therefore been apportioned based on the percentage within an NRM region.
[2]Rainfall based on BoM 30 year annual means from 1976 to 2005.
[3]Suitable soils based on a combination of soil depth >1 m and pH($CaCl_2$) >5.5 (in soils >1 m); data sourced from CSIRO - National Soils Grid of Australia (90 m resolution).

Table 3. Beef cattle numbers in areas suitable for growing leucaena in northern Australia.

State	Beef cattle numbers[1]	% cattle in ideal zone	Beef cattle numbers[1] in rainfall zone area[2] with suitable soils[3]		
			400–600 mm	600–800mm	>800 mm
New South Wales	1,271,236	4	25,214	92,770	21,457
Northern Territory	2,237,031	5	75,727	107,773	220,657
Queensland	10,387,505	91	3,024,138	2,168,123	541,025
Western Australia	1,148,951	0.4	170	8,420	44,132
Total cattle	15,044,723				
Total cattle in potential zone	6,329,606		3,125,249	2,377,086	827,271
Total potential (%)	42		21	16	5

[1]Counts are based on ABS SA2 polygons that fall within NRM regions, rainfall areas and combined rainfall/suitable soils areas. Note that SA2 areas do not coincide with NRM regions. ABS counts have therefore been apportioned based on the percentage of area within an NRM region.
[2]Rainfall based on BoM 30 year annual means from 1976 to 2005.
[3]Suitable soils based on a combination of soil depth >1 m and pH($CaCl_2$) >5.5 (in soils >1 m); data sourced from CSIRO - National Soils Grid of Australia (90 m resolution).

Exploring adoption of leucaena using regional segmentation

The vast majority of leucaena plantings in northern Australia are in what is variously known as the Brigalow (*Acacia harpophylla*) belt, central Queensland, or the Fitzroy/Mary/Burnett region of Queensland. In addition to this we have identified 4 other primary geographic zones in northern Australia, i.e. High Rainfall Coastal zone, Gulf Country, Northern Territory and Western Australia. These 5 zones differ in 1 or more key elements critical to the potential adoption of leucaena, namely: farming system types; psyllid risk; access to markets; and producer density/critical mass. The following section will outline the current understanding of the history and extent of leucaena adoption in each of these geographic zones. The central Queensland section is naturally larger than the others, given the history of leucaena production in this region.

Central Queensland

For the purposes of this study we have used the geographical boundary defined by Beutel et al. (2018) to describe the central Queensland beef region. This area comprises the Fitzroy, Burnett Mary, Border Rivers Maranoa Balonne, Condamine and the western subregion of the southeastern Queensland NRM regions. Bray et al. (2014) described the climate of this region as subtropical to tropical, varying from humid near the coast to semi-arid inland. The wet season occurs in summer with frequent flood events after cyclones and monsoonal downpours. Brigalow and buffel grass (*Cenchrus ciliaris*) are synonymous with central Queensland but many other land types and native grasses exist in the region. Approximately 95% of the area is utilized by agriculture, with 87% grazing and 8% cropping (Cobon and Toombs 2007).

To examine the extent of leucaena plantings in the region, Beutel et al. (2018) mapped the geographic potential in the region using a combination of rainfall and soil attributes. In addition they mapped the actual distribution of leucaena stands which provides an ideal test of actual locations against recommended parameters. From this work the following can be noted:

1. *Temperature*. The majority of plantings of leucaena are in areas which have minimum average temperatures of 6 °C or above. The average minimum temperature in the coldest month within the study area falls to 6 °C, which is below the 10 °C minimum threshold for winter growth. The limited prevalence of leucaena in these cooler areas suggests that, while producers may push the limits of leucaena's temperature tolerance, it is not a common occurrence.
2. *Frost.* The majority of leucaena is planted in areas which are least frost-prone. While some plantings occur in the moderate frost-prone area southeast of Charleville (10–20 frosts of less than 0 °C), more-severe frosts of less than -2 °C are less likely to occur in this band.
3. *Rainfall.* Three-quarters of leucaena plantings were found in the 'ideal' 600–800 mm zone, with almost a quarter of plantings occurring in the 'suboptimal' rainfall zone of less than 600 mm. This suggests that a significant proportion of producers value leucaena in more marginal areas. As could be expected, no leucaena plantings were located in the >800 mm zone, which Beutel et al. (2018) suggest reflects challenges to leucaena production in wetter parts of the study area, which include: a) susceptibility to psyllid predation; b) acidic soils with high exchangeable aluminum levels; c) opportunities for higher-value crop production; and d) higher weed burdens during crop establishment.
4. *Soils.* Cultivated leucaena was not found in more acid soils of pH <5.5 comprising 11.3% of the study area, and was under-represented on shallow soils, with only 1.2% of the leucaena cultivation occurring on 31.6% of the study area. Not surprisingly, 98% of all leucaena was found on the 'ideal' soils with depth greater than 1 m and pH >5.5.

Beutel et al. (2018) detected leucaena on 94 quadrats, which included 103 cadastral sites in southeast Queensland using a random sampling of aerial images, where presence was confirmed before image inspection. Based on ABS data, there are 8,359 beef properties located across these 5 NRM regions with 2,640 in the ideal rainfall-soil zone and 1,289 in the marginal zone (rainfall of 400–600 mm). Given the 103 properties successfully identified by Beutel et al. (2018), this equates to:

- 3.9% of properties (103) adopting leucaena in the study area;
- 2.9% of these properties (80) being in the 'ideal' zone with 600–800 mm rainfall; and
- 1.0% of properties (24) being in the <600 mm zone.

Views from adopters in central Queensland. To gain greater context for the adoption of leucaena in central Queensland, field work was conducted in the region, which involved meetings with Queensland Department of Agriculture and Fisheries staff at Toowoomba, Biloela and Rockhampton, and with members of The Leucaena Network, who provided insights and helped arrange focus groups and property visits from Millmerran to Wandoan and Taroom, then south of Banana, west to Moura and east to Thangool. Interviews were conducted with individuals or in focus groups from 20 cattle properties in central Queensland. Leucaena is currently grown on 15 of these and owners are advocates for the technology (adopters). Three owners do not currently have any leucaena and have reservations about it (non-adopters), while 2 have purchased properties where it was sown many years ago, is out of control and efforts to eradicate it or get it back into rows have been unsuccessful. In addition, the views of 6 individuals involved in either leucaena R&D or extension were also garnered and recorded.

Benefits and advantages. Those interviewed had planted leucaena on 3–44% of their properties with a mean planting of 18%. The majority considered the best economic advantage gained from leucaena-grass pastures was through finishing weaner cattle and weight gains of 1–1.3 kg/d were regularly quoted with production gains of 30–100%. Gains of 0.7 kg/d were recorded in older cattle. The ability to meet target markets was enhanced and young cattle could be regularly turned off 12 months earlier than off grass pastures.

Leucaena was most often used on lighter country with low soil nitrogen levels as the legume raised protein production. With the introduction of vegetation clearance laws leucaena was also seen as a way of getting increased production from existing land without further purchases. Leucaena's ability to provide nutritional feed after grasses mature and diet quality tapers off and its ability to fill the autumn-winter feed gap were widely recognized.

Drawbacks and limitations (potential barriers to adoption). The high cost of establishment, including the cost of land being out of production, and the associated risks of establishment failure were important considerations, although many felt the risks of failure were greatly reduced by hiring contractors and were less likely with experienced croppers. Leucaena has a weak seedling that competes poorly with weeds and grasses, which means a long lead time in preparation and attention to detail with establishment.

The frost impact on production reduces the benefits but planting on higher ground and utilizing the leaf prior to frosts were common strategies to overcome this issue.

The region's history of land clearing and difficulties in maintaining the land free of regrowth (suckers) has produced a mindset in some against trees, e.g. leucaena. "*Grandfather and father spent their lives clearing this country and I'm not going to be putting trees back."*

Grazing management is important and requires proper infrastructure, e.g. fences and watering points, which is seen as too much additional work and expense by some. *"It is a big decision and almost a lifetime commitment, which cannot be reversed and reduces land flexibility. If not managed appropriately leucaena can get away and get out of control and this is almost impossible to rectify."*

Much of the Brigalow belt suffers from scrub regrowth, which requires blade-ploughing from time to time and people consider this will be difficult in leucaena stands and scrub will reinfest their land. Along with this, leucaena is perceived as not being as profitable as cropping and does not produce the cash flow on arable country that cropping does, so it is often confined to less-fertile soils and production decline is being witnessed.

Learnings from experience. Early extension recommendations were to plant twin rows 1 m apart with an inter-row spacing of 6 m. A common theme emerging from experience is that many prefer much wider inter-row spacing, commonly 12–15 m. There are several reasons behind this thinking. Flexibility is mentioned in terms of management of the inter-row space, e.g. slashing or cultivation of the space for weed control and even cropping this space, requiring sufficient width to operate appropriate implements. However, some think leucaena is too 'thirsty' for this, i.e. it draws too much moisture from the soil.

The leucaena-grass balance is of significant interest and is seen as a key to maximizing production. While this issue is unresolved, approaches by different graziers differ. Some graziers consider that the area sown to leucaena should be limited or inter-row spaces should be wide, especially in areas with lower rainfall. Others consider that leucaena is the most nutritious component of available forage so the more leucaena the better. Sowing with an inter-row spacing of 6 m or less can mean that grass is overgrazed if stock numbers are high enough to prevent leucaena from becoming too tall. In addition, leucaena is very competitive for nutrients and moisture and can shade the grass, the combined effects limiting grass growth.

The third issue relating to paddock preparation is more complex and views are divided. Some graziers strongly advocate that paddocks should be ploughed fence-to-fence after which leucaena is planted in rows, with careful attention to weed control; it is only when plants are established that grass should be sown in the inter-row spaces. This extends the time before the paddock reaches full production and is more costly because of the opportunity cost of grazing forgone. The alternative view held equally strongly is to plant into established grass pasture, by treating strips (with herbicide and cultivation) and then sowing leucaena into the prepared seedbed. Wider inter-row spacings would increase the probability of success with this approach. One grower suggested the amount of nitrogen that leucaena contributes to the soil may be over-estimated, and said it does not share its N with grasses like other legumes, while it also extracts a lot of moisture from the soil at the expense of the grasses.

Cunningham, Tarramba and Wondergraze were the 3 varieties commonly grown in the study area. As a general comment several producers preferred Cunningham, considering it was more palatable, and more easily controlled through grazing. One producer thought Tarramba was more productive, while cold tolerance of Wondergraze was seen as an advantage by some.

Several landowners mentioned that leucaena was initially thought to be useful as a drought reserve, but in practice it is not. Certainly, it 'hangs on' after the grasses dry off and fills a feed gap but in extended dry periods it drops its leaves and is unproductive. Two of the non-land owner professionals we spoke to had examined phosphorus depletion under leucaena; they considered that, as it was often planted on poorer soils and P removal was significant, without fertilizer application this was a potential and emerging issue.

High Rainfall Coastal zone

The High Rainfall Coastal zone can be categorized as areas with greater than 800 mm average annual rainfall (AAR), on the coastal fringes of northern Australia, stretching from Cooktown in the north to Maryborough in the south. The region currently supports approximately 2.5 million cattle on 817 properties. Current levels of leucaena production in this zone are hard to define accurately, but anecdotal evidence would suggest that it is very small in comparison with plantings in central Queensland. A key reason for this is the susceptibility of current cultivars to psyllid damage. The psyllid, which appeared first in Australia in 1986, is a leaf-sucking insect specific to the leucaena genus, feeding on the growing tips of susceptible cultivars (Bray 1994). Psyllid damage can reduce production by 50–70% in humid regions and 20–50% in subhumid environments (Bray 1994; Mullen and

Shelton 2003), and as such is a significant impediment to leucaena production in the high rainfall zone. Shelton et al. (2017) suggest that the availability of a psyllid-resistant variety could increase the range of adaptation of leucaena by 30%. The current 'Redlands for Regions' project is exploring the establishment of the new Redlands variety on 5 properties in the High Rainfall Coastal zone and is providing data for clarifying key establishment and management requirements.

Gulf Country

The Northern Gulf region comprises the catchments of the Norman, Gilbert, Staaten and Mitchell River systems, all of which flow into the Gulf of Carpentaria. Around 60% of the region is contained in the Northern Gulf Plains bioregion, while the remaining 40% falls within the Northern Einasleigh Uplands bioregion (Sattler and Williams 1999). There are approximately 196 grazing businesses, covering an area of about 12.4 M ha. These businesses rely on (principally) native pastures to turn off about 260,000 head of cattle per year with a value of approximately $180 million. A range of markets are targeted including live export, the store market, the US grinding beef trade and the transfer of weaners to growing and fattening areas in southern and central Queensland. Total herd size in the Northern Gulf Region is approximately 834,000 head, of which about 520,000 are breeders and heifers 12 months and older. Rolfe et al. (2016) found that high female mortalities, poor reproductive performance and low annual liveweight gains are commonly recorded with low annual liveweight gain (70–90 kg/hd) being a major constraint for those production systems located solely in the northern Gulf savannas. Low profitability and debt-servicing pressures in these areas make pasture improvement and the installation of additional infrastructure unaffordable for most businesses. It is therefore not surprising that currently leucaena plantings in the Gulf country are limited despite large areas being in the 'ideal' zone agroclimatically. Current estimates suggest there is in the vicinity of 700 ha either recently planted or being planted as of December 2018 (Rolfe et al. 2019; J. Rolfe pers. comm.).

Northern Territory

The Northern Territory has 197 beef cattle properties with approximately 2,237,031 beef cattle. In areas with soils suitable for leucaena (>1 m deep and pH >5.5), most properties (35) are in the >800 mm zone, with 7 properties in the 600–800 mm zone. Three properties are in the 400–600 mm zone.

Lemcke and Shotton (2018), in their Agnote on leucaena, reported that the deep sandy red Kandosols (Blain soils) and deep clay red Kandosols (Tippera soils) of the Douglas Daly and Katherine regions appear most suitable for growth and production of leucaena [see Smith and Hill (2011) for soil characteristics]. In contrast they note that, on the gravelly laterite soils further north and closer to the coast, severe leaf fall occurs within 4–6 weeks following the last of the wet season rains, and suggest that supplementary irrigation would be needed during the dry season on those soils. They note that the deeper red earth soils in the north may be more successful.

Research at Douglas Daly Research Farm (AAR = 1,200 mm) has focused on the production of introduced pastures for many years. Grazing trials indicated that best liveweight gains came from grass-leucaena pastures with an average of 200 kg/hd/yr @ 1.25–1.5 hd/ha. Over 12 months straight buffel grass produced LWG of 171 kg/hd (179 kg LWG/ha), while buffel-leucaena produced LWG of 222 kg/hd (278 kg LWG/ha) (Shotton 2012). The irrigated grass-leucaena results (non-replicated) were about 0.5 kg/hd/d or 2.7 kg/ha/d (P. Shotton pers. comm. 2018).

According to Peter Shotton (pers. comm. 2018), despite interest being shown in establishing leucaena, very few graziers have taken up the opportunity, with only relatively small areas of leucaena planted in the Katherine-Daly Basin and Victoria River District. Best estimates are that less than 1,000 ha has been planted in the Territory to date, many as small plantings which have been neglected or superseded by horticulture or forestry.

Western Australia

In Western Australia, leucaena can be found near wetlands and riverine sites in Halls Creek, Kununurra, Cockatoo Island, Christmas and Coolan Islands, Broome and Derby (Hussey et al. 1997; Cowan 1998). Leucaena has been planted as a pasture in the Ord River Irrigation Area of the Kimberley (Larsen et al. 1998), since CSIRO plantings in the 1970s. After the discovery of the DHP-detoxifying bacteria, an industry began to develop, and more than 2,000 ha of cv. Cunningham was planted and grazed; however this area has declined in recent years, with several properties removing the planted trees and converting to horticultural crop production. Leucaena has spread over 60 km along the Ord River, between the Ord River Dam and the Diversion dam and downstream from the Diversion dam, to create dense riparian thickets. Currently there are no commercial plantings of leucaena in WA and current regulations prevent any new plantings on leasehold land (basically all of WA).

Exploring potential adoption of leucaena in northern Australia using the ADOPT model

ADOPT is an acronym for 'Adoption and Diffusion Outcome Prediction Tool', which was constructed to quantitatively predict adoption to assist in planning agricultural research, development, extension and policy (Kuehne et al. 2017). Based on past research and conceptual thinking, the ADOPT model identifies and utilizes variables that are considered to contribute to either Peak Adoption Level (scope) and/or Time to Peak Adoption (rate) using both characteristics of the population and the practice of interest described below (Figure 4).

Peak Adoption Level driven by 'Relative Advantage'

- Relative advantage for the population – including business and environmental orientation, planning horizon and financial constraints (Q's 1–6).
- Relative advantage of the practice – including profitability, risk level, upfront costs, reversibility and ease of management (Q's 14–22).

Time to Peak Adoption driven by 'Learning of Relative Advantage'

- Population-specific influences on the ability to learn about the practice – such as advisory support, group involvement, additional skills required and general awareness of the practice (Q's 10–13).
- Learnability characteristics of the practice – such as trialing ease, observability of benefits prior to use and complexity of evaluating benefits after use (Q's 7–9).

Input to the ADOPT model was provided by population data interpreted from MLA's producer segmentation survey and 'innovation-practice' response data derived from literature on leucaena (MLA 2016). An example of reasoning used for each element is outlined in Tables 4 and 5.

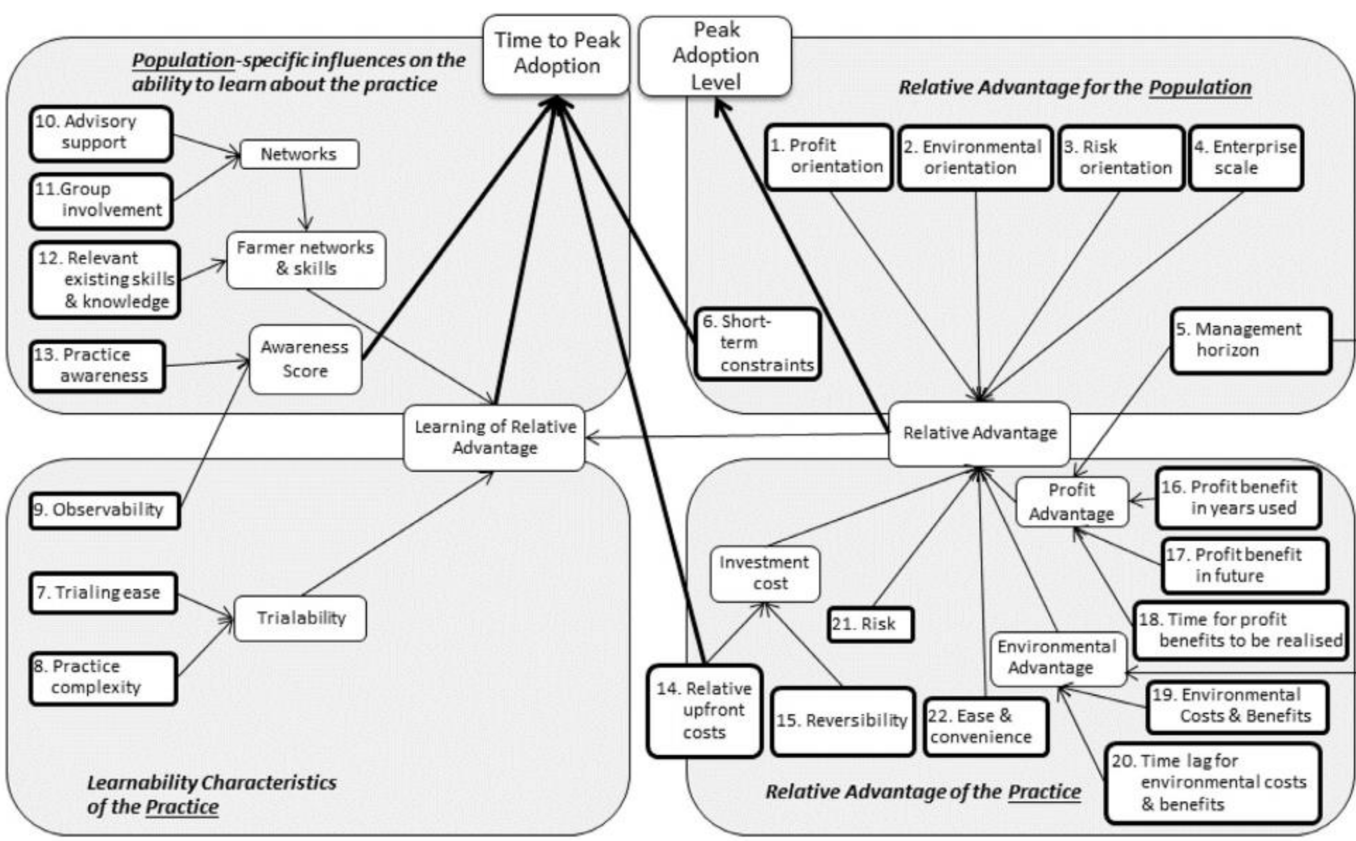


Figure 4. The conceptual framework of influences on peak adoption level and time to peak adoption (from Kuehne et al. 2017).

Table 4. Example input for factors affecting level of peak adoption.

Question	Response	Reasoning
Relative advantage for the population		
1. Profit orientation	3. About half have maximizing profit as a strong motivation	Based on weighted scaling of MLA producer segmentation category 'Commercial orientation'
2. Environmental orientation	2. A minority have protection of the environment as a strong motivation	Based on weighted scaling of MLA producer segmentation category 'Environmental benefits'
3. Risk orientation	2. A minority have risk minimization as a strong motivation	Based on weighted scaling of MLA producer segmentation category 'Risk attitude'
4. Enterprise scale	4. A majority of the target farms have a major enterprise that could benefit	Assumes producers in the climatic zones could benefit
5. Management horizon	3. About half have a long-term management horizon	Based on weighted scaling of MLA producer segmentation category 'Five year outlook'
6. Short-term constraints	4. A minority currently have a severe short-term financial constraint	Based on weighted scaling of MLA producer segmentation category 'Relevant financial outlay'
Relative advantage of the practice		
14. Relative upfront cost of practice	3. Moderate initial investment	Requirement for specialized sowing equipment/ contracting
15. Reversibility of practice	3. Moderately difficult to reverse	Removal of plants would require spraying and possibly cutting, taking time and money
16. Profit benefit in years that it is used	7. Large profit advantage in years that it is used	Significantly more profitable than other species on areas planted
17. Future profit benefit	5. Small profit advantage in the future	Assume small specific additional profits such as carbon sequestration
18. Time until any future profit benefits are likely to be realized	3. 3–5 years	Takes 3–7 years to reach full potential
19. Environmental costs & benefits	2. Moderate environmental disadvantage	Specific need to manage to the Code of Practice considered to be an 'environmental disadvantage'
20. Time to environmental benefit	3. 3–5 years	Environmental disadvantage relates to spread of seeds from this age onwards
21. Risk exposure	6. Moderate reduction in risk	Leucaena more likely used to increase growth rates/fatten, but drought tolerance offers degree of risk reduction
22. Ease and convenience	2. Moderate decrease in ease and convenience	More difficult to manage than pastures alone, tending to leucaena and managing stock access/timing to access

Table 5. Factors affecting rate of peak adoption.

Learnability characteristics of the practice		
7. Trialable	2. Difficult to trial	Trialing requires specialized sowing equipment, seeds need inoculating, specialized animal, weed and pest management
8. Practice complexity	4. Slightly difficult to evaluate effects of use due to complexity	Benefits should be reasonably self-evident so only slightly difficult to evaluate performance
9. Observability	4. Easily observable	Fairly easy to observe on other producer properties
Learnability of population		
10. Advisory support	3. About half use a relevant advisor	Based on weighted scaling of MLA producer segmentation category 'Paid consultants'
11. Group involvement	3. About half are involved with a group that discusses farming	Based on weighted scaling of MLA producer segmentation category 'Networks'
12. Relevant existing skills & knowledge	1. Almost all need new skills and knowledge	Requires a whole new suite of cropping and pasture management skills and animal management
13. Practice awareness	4. A majority are aware that it has been used or trialed in their district	Based on weighted percentages of MLA producer segmentation category attending 'Field days'

Sensitivities within the ADOPT model

The model predicts that 4 key aspects of leucaena's 'relative advantage' have the largest impact on adoption with Profitability (Q16, Q17 and Q18) being the standout, while Reduction in risk exposure (Q21), Ease and convenience (Q22) and Environmental costs/benefits (Q19, Q20) also significantly impact the model's output.

Regarding those producers most likely to adopt leucaena, Profit orientation (Q1) is an important precursor for adoption and based on MLA producer segmentation, about half have 'Maximizing profit' as a strong motivation. However, within this profit-motivated farmer cohort the Enterprise scale (Q4), more broadly interpreted as enterprise fit or farming systems fit, has huge potential to influence adoption because of:

- Technology 'fit' in the system re: scale, intensity, farm layout, labour, machinery and access to markets; and
- Property-specific attributes of leucaena on profitability, risk exposure, ease of use and integration within the system, plus environmental considerations.

Note 'systems fit' is not adequately addressed through the model with this function being rather coarse in its application.

Factors impacting time to peak adoption

Major factors affecting time to peak adoption include characteristics of leucaena which limit the capacity of producers to learn about the technology. These include:

- Learnability characteristics of using leucaena, particularly trialing ease and complexity of evaluating benefits after use (Q7 and Q8);
- Social learning including advisory support, group involvement, additional skills required and general awareness of the practice (Qs 10–13); and
- Short-term financial constraints (Q6) combined with upfront costs (Q14).

Exploring upper limits of adoption at a regional level

In this section, we explore the upper limits of adoption at a regional level, using sensitivities in the ADOPT model described above. Table 6 summarizes the way in which we adjusted the model for sensitivities on a regional basis along with the model output for upper levels of both rate and scope. Note that all other factors apart from these sensitivities remained constant within the model and did not change from region to region.

In central Queensland (CQ) we can see that high profitability, combined with excellent enterprise fit and social learning support, has the highest predicted upper adoption level of 18% and shortest time to peak adoption of 14 years. Note that the percentage for scope should be applied to those properties within the 'ideal' zone identified previously. Compared with CQ the 2 key adoption drivers of profit and enterprise fit are considerably lower, moderated in areas where leucaena offers greater risk reduction [Gulf country, NT and WA]. A key qualifier here is the lack of information on farm systems profitability in areas outside of CQ.

Areas other than CQ, particularly more remote areas, have considerably reduced social learning opportunities in terms of advisory support, group involvement and general awareness of leucaena, and typically have a lower base knowledge and skills for leucaena management, all extending the time to peak adoption.

While weed-related considerations confer a small environmental disadvantage in CQ, the Gulf and possibly the NT, risks are higher in Higher Rainfall Coastal (HRC) and totally exclude leucaena in most of WA. Across all regions, altering the model to have no net environmental disadvantage has potential to increase adoption by about a third, and double adoption in more environmentally sensitive areas.

Building a rationale for investment in extension

Rationale for investment in extension essentially revolves around the benefit:cost ratio of the intervention, where benefits are characteristically economic but also take into account social and environmental impacts arising from the intervention. Extension benefits are derived from the combination of per-farm benefits and the defined scope of adoption.

Table 7 reports the estimated 'scope' for leucaena adoption based on the ADOPT model output and uses property data based on ABS SA2 polygons that fall within NRM regions and combined rainfall-suitable soils areas. Note that SA2 areas do not coincide with NRM regions. ABS counts have therefore been apportioned based on the percentage of area within an NRM region.

Regional- and industry-scale economic benefits of leucaena adoption

Industry-scale economic benefits are a product of adoption rates and per-farm benefit, both of which will differ between regions. In this section we explore regional benefits based on the data above and summarize by collating these into an industry-scale benefit.

Table 6. Regional ADOPT output accounting for the key sensitivities within the model.

	Central Queensland	High Rainfall Coastal	Gulf Country	Northern Territory	Western Australia
Profit	+++	+++	+?	+?	+?
Environment	X	XX	X	?	XXX
Enterprise fit	+++	++	+?	+?	+?
Risk		+	+++	+++	+++
Social learning	+++	XX	XXX	XXX	XXX
Scope (peak adoption)	18%	6%	8%	8%	5%
Rate (time to peak)	14 yr	15 yr	17 yr	20 yr	21 yr
Seedless (remove envt disadvantage)	23%	10%	9%	9%	9%

The + symbols indicate enabling influence on adoption, whereas the X symbols depict restraining influence on adoption.

Table 7. Estimated scope for leucaena adoption based on ADOPT model output for regional segments.

	Central Queensland	High Rainfall Coastal	Gulf Country	Northern Territory	Western Australia
Peak adoption % as predicted by ADOPT	18%	6%	8%	8%	5%
Estimated no. properties with ideal rainfall/soils	2,640	817	124	42	4
Estimated no. properties to adopt leucaena	475 (371*)	49	10	3	0
Time to peak adoption (yr)	14	19	22	25	36

*371 is the number of properties yet to adopt leucaena allowing for the estimate of current adoption from Beutel et al. (2018).

Central Queensland

If we take the modeled farm assessment of net annualized benefit per farm from investing in leucaena of $40,336 (Chudleigh et al. 2018), and multiply this by the 371 properties in CQ based on our ADOPT model output, which represents the upper scope for additional leucaena adoption in CQ, a total maximum, annualized benefit of $15 million is calculated.

If we then consider the upper level for the time to peak adoption generated by the ADOPT model of 14 years, an annual increase in properties adopting leucaena of 27 per year would be required to reach peak adoption in this time frame, which would deliver an annualized benefit of $1.1 million. This equates to a cumulative value over the expected time to peak adoption (14 years) of $115 million.

Taken together, the large pool of likely adopters and robust estimates of significant per-farm benefits, coupled with significant existing extension support, suggest reliable returns from investment into appropriate adoption strategies for central Queensland.

High Rainfall Coastal zone

Approximately 817 properties with suitable soils are located in the HRC zone. Up until now leucaena usage has been restricted because of likelihood of yield reductions due to psyllid damage. However, the recent release of the psyllid-resistant variety Redlands has paved the way for increased leucaena usage in this zone. Based on our modeling and the associated assumptions, it is estimated that 6% of these properties, i.e. 49 properties, are potential adopters.

Regarding per-farm economic benefits, current trials show early indications of psyllid resistance and impressive forage growth; however there is still a lack of cattle production data on which to base reliable estimates of economic benefit.

The industry-scale benefit in the HRC zone is therefore based on a significant pool of producers likely to adopt if farm trials prove profitable, and if appropriate extension support and strategies are delivered. Further investment into extension in this zone calls for a stepped approach, with the first step aimed at establishing farm-level profitability and systems fit.

Gulf and Northern Territory

The Queensland Gulf country contains significant areas of land suitable for leucaena, encompassing an estimated 124 properties. There are also some 42 properties on suitable soils in the NT. Based on our modeling and the associated assumptions, we estimate that 8% of properties in both regions are potential adopters, which equates to approximately 10 properties in the Gulf and 3 in the NT.

Although leucaena has been used on some properties in the Northern Territory, and is being trialed on a handful of properties in the Gulf, there is a lack of reliable data on the farm systems fit and management of leucaena and its profitability in these environments. Notwithstanding a lack of real-world data on the performance of leucaena in these regions, there has been considerable interest, particularly from corporate enterprises. These entities may 'go it alone' on minimal information; however opportunity exists for some form of funded support to enhance success as discussed in the next section.

Western Australia

In contrast to the NT and the Gulf, leucaena has been used successfully on a number of farms in the Ord River district but it has since been replaced by alternative land uses in this area. Suitable soils and climate for leucaena do exist outside the Ord catchment, but virtually all properties are on leasehold land (from the Government), where growing of leucaena is forbidden. Given this scenario, it is difficult to mount a case to support these extremely limited opportunities for leucaena under current state legislation.

Discussion – Systems fit adoption considerations

Throughout this review, the complexity of integrating leucaena into farming systems has become increasingly apparent, with potential adopters needing to firstly be convinced of its suitability for their properties (soils, climate, profitability), assess its fit within the farm system (marketing approach, labor and resources), and have the skills and equipment to establish and manage it. Other key considerations, based on field work and discussions with regional experts, which may impact on ADOPT outputs and therefore need to be addressed via strategy, are:

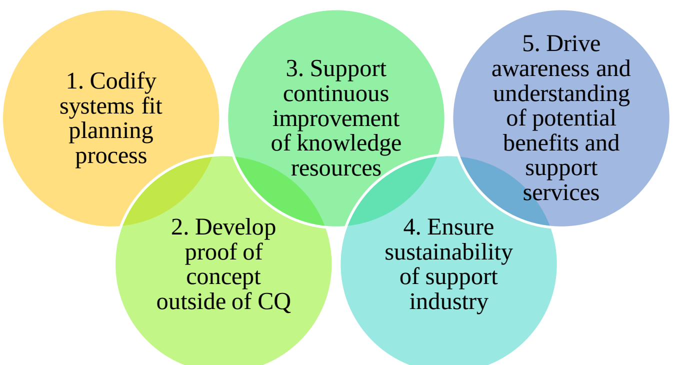
- Competition for land: high land prices and suitability for alternative high-value crops and timber species have reduced the portion of potential areas sown to leucaena in the Ord and parts of the NT and this is likely to be the case in the HRC zone.
- The need for the 3 Cs, i.e. cashflow to survive the production gap that new-sown leucaena could present; capital to invest in the machinery to develop land; and capability to 'farm' – the fear of farming as a barrier to adoption seems to increase with distance from cropping country.
- Perceptions associated with key management and grazing issues – agronomy, rotational grazing, height management, broad-leaf weed control and cattle mustering – may have a negative impact on adoption to a greater extent in areas with less exposure to farming, i.e. Gulf, parts of the HRC and NT.
- The availability of cleared country outside of CQ is a clear limitation to leucaena's use, given the Queensland vegetation management laws (bit.ly/2MEuSWP).
- The harshness of the climate in both the Gulf and NT means that, while soils may be suitable and AAR suggests moisture will not be limiting, extremes of heat and periodic inundation increase the risks of sowing failures and the overall perceptions of how risky it is to plant leucaena (Rolfe et al. 2019).
- Extension and expertise: CQ is in the fortunate position of having a pool of leucaena knowledge gained over many years and embedded in advisory personnel, growers and The Leucaena Network. Knowledge, support and grower experience are far more limited and fragmented in other areas.
- The precarious position of many beef businesses across northern Australia means that they are not well placed to cope with establishment, market and climatic risks in the absence of significant advisory support and 'proof-of-concept'.
- The fact that 25% of adoption in CQ has occurred in the 400–600 mm rainfall zone is significant, as all assessment to date has focused on the 600 mm+ rainfall zones. This factor may balance out the negative aspects of the considerations above.
- The lack of marketing options in WA, NT and parts of the Gulf is an issue as the traditional market for cattle in NT is the live cattle export trade. The Livingstone meatworks established 50 km south of Darwin around 2015 reportedly processed about 500 head of cattle a day (ABC 2018) presenting some opportunities for marketing stock, but has recently suspended operations owing to lack of profitability. Yeeda abattoir in the Kimberley has recommenced operations and has a similar capacity to the Livingstone meatworks, offering some access to the slaughter market for northwest WA. Without such access to slaughter markets the benefits of leucaena may not be fully realized.

Clearly the fundamental challenge is to enable property owners and their advisors to balance the pros and cons of planting leucaena, compare it with other alternatives and make decisions based on how they envisage the future of their business. In CQ where there is a growing pool of expertise and experience based on 30 years of RD&E, this challenge is largely process-based, i.e. development of strategic forage plans. For regions outside of CQ, there is also a requirement for detailed forage planning; however these property owners lack the basic inputs to support such

a process. As such, further investment is required to 'prove and codify' the fundamental aspects of a profitable leucaena system for these regions. Given this, we see 2 primary tasks for the strategy:
1. Codification of the process to explore systems fit for the new generation of adopters; and
2. Enhancing the understanding of what constitutes systems fit in regions where little or no experience with leucaena exists.

Conclusions and Recommendations for action

The combined effects of the comments listed above lead to 5 interrelated strategic actions designed to support ongoing adoption of leucaena. As can be seen from the diagram below, these actions have been developed to address the 2 primary tasks outlined in the previous section.



The logic of the 5 actions can be understood as follows:

- Action 1 is designed to support the process of analysis at the property level to assess the appropriateness or otherwise of changes to the forage base. This action aims to address the key issue of systems fit identified at multiple stages in this report. It is intended that investment in this action would be a discrete period and that the process itself would become embedded in practice over time.
- Action 2 will deliver the fundamental elements necessary to enable Action 1 to be implemented in areas outside of CQ. Key elements of systems fit such as establishment best practice, weight gain potential across various stock classes, realizing benefits of leucaena through systems change and risk associated with establishment and management are yet to be adequately codified for the HRC, Gulf and NT. Investment in this action would also be for a discrete time period as, by definition, once the concept is 'proved', producers can then move confidently on to investment and implementation.
- Action 3 is a critical component of any 'knowledge' system and has been occurring to a certain extent already, albeit not in a strategic and coordinated fashion. An ongoing investment linked to broader strategic objectives at an industry scale is required to ensure rigor around knowledge resource management.
- Action 4 is critical to the longevity of the leucaena industry given the ongoing decline in publicly-funded extension. Given the potential for leucaena to deliver significant value to producers, it is highly likely that once Actions 1–3 are achieved the viability of private support services will be enhanced. Required however is an ongoing investment in the skills and capability of the support sector, given the well-known limitations of many service providers to invest in skill development. An additional requirement is ongoing investment in the integrity of key elements of the leucaena supply chain, particularly seed production and distribution.
- Action 5 will ensure that current and future investments in leucaena RD&E are realized and leveraged for industry benefit over the long term.

The critical next step for investors is to work closely with The Leucaena Network and other stakeholders to plan further action designed to support the enhancement of adoption and management of leucaena in Australia.

The key questions to consider are:

1. Do the potential benefits of investment warrant the actions outlined in this paper?; and
2. What systems will be put in place to monitor progress to ensure the adoption targets linked to these benefits are tracked and the strategy is modified if they are not being met?

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ILC2018 Poster and Producer paper*

The Leucaena Network and The Leucaena Code of Practice
La Red de Leucaena y el Código de Prácticas para el cultivo de leucaena

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Keywords: Environment, extension, research, responsibility.

Introduction

The Leucaena Network was formed in July 2000 by a group of producers and industry representatives who wished to progress the leucaena industry and address environmental concerns.

The organization's aim is to "promote the responsible development of leucaena in productive and sustainable ecosystems to build stronger rural communities".

In September of that year, the Network developed The Leucaena Code of Practice to promote responsible management of the legume in response to the environmental concerns (reproduced at the end of this paper).

Today, The Leucaena Network is a leading producer group in the grass-fed beef industry in Queensland. Members include livestock producers, leucaena and pasture seed growers, researchers and extension personnel. The Network remains true to its message, continuing to focus on the responsible management of the legume while working to promote the industry and provide current and relevant information and research to its members.

The Network encourages everyone who is involved with the leucaena industry to take up Network membership to foster ongoing activities and research to assist the industry to prosper.

Currently due to demand, much of The Leucaena Network's focus is on the promotion of strategies for successful leucaena establishment for new producers. However, the Network continues to strive to provide established producers with research and extension information. A linchpin of The Leucaena Network's information provision is its website, www.leucaena.net.

Current Research Projects

Currently, The Leucaena Network is partnering with Meat & Livestock Australia (MLA) and Queensland Department of Agriculture and Fisheries (QDAF) in the MDC/PIFT 'Redlands for Regions' establishment trials; the Wandoan-based 'Improving the Productivity of Leucaena in Grass Pastures with Fertiliser' Producer Demonstration Site (PDS); and the provision of input into the UQ/UWA sterile leucaena project (Figures 1–3). The feasibility of research projects into the management and maintenance of established leucaena is currently being investigated.

Figure 1. QDAF, MLA and Leucaena Network representatives join 'Redlands for Regions' producers at Quincan Springs.

Figure 2. QDAF officer Bernie English joins 'Redlands for Regions' producers Rob Ahern and Gerard Lyons at 'The Four Mile'.

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*Poster presented at the International Leucaena Conference, 1–3 November 2018, Brisbane, Queensland, Australia.

Figure 3. Leucaena irrigated under centre pivot at Theodore, Central Queensland.

The Code of Practice

The key message of The Leucaena Code of Practice for producers is to plant leucaena ONLY if you intend to manage it and are prepared to accept responsibility to control leucaena that establishes outside the planted area on your property, including watercourses.

Producers are advised that this can be achieved by adopting the following practices:

1. Do not plant leucaena in areas where rivers, creeks and flood channels can disperse seed pods/seed. If leucaena becomes a restricted or regulated plant under a Wild Rivers declaration, growers must comply with the relevant Wild Rivers Code.
2. Keep leucaena at least 20 m away from external fence lines.
3. Maintain a buffer strip of strong grass pasture between leucaena plantings and creeks or boundary fences.
4. Fully fence leucaena paddocks to avoid the unlikely risk of stock spreading ripe seed.
5. Graze or cut leucaena to keep it within the reach of animals and minimize seed set.
6. Chemically manage leucaena escapees with Access® (currently the only registered herbicide for use on leucaena).
7. Establish and manage vigorous grass in the inter-rows to:
    a. provide competition to minimize establishment of volunteer leucaena seedlings;
    b. minimize the risk of seed being transported during heavy rain;
    c. productively utilize fixed nitrogen the system produces; and
    d. maintain ground cover and prevent soil erosion.
8. Maintain the practice of:
    a. regularly monitoring creeks and major watercourses to detect any escaped leucaena seedlings and plants; and
    b. controlling all plants detected adjacent to property boundaries on creek banks and other adjoining areas where cattle do not normally have access, and on public roadsides (after first obtaining a permit from Main Roads Department or Shire Council).
9. Comply with local laws (weed declarations etc.) and assist Local Government agencies to identify any escaped leucaena so that action can be taken to control it.
10. Promote the responsible management of leucaena in accordance with this Code.
11. Keep abreast of best-practice developments in the management of leucaena.

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*ILC2018 Poster and Producer paper**

Evaluating leucaena in timbered northern basalt country in Queensland, Australia

Evaluando leucaena bajo cobertura arbórea en el norte de Queensland, Australia

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Keywords: Grazing, Queensland Gulf Country, tree legumes, Wondergraze.

Introduction

Introduction and successful establishment of leucaena (*Leucaena leucocephela*) has the potential to increase annual liveweight gains of grazing cattle and improve enterprise gross margins by up to 25% in a sustainable way (Buck et al. 2019). However, there has been low adoption of leucaena in northern Queensland (<2,500 ha established) despite well-established protocols in central and southern Queensland. Impediments to leucaena adoption include: reduced productivity following psyllid infestations; high establishment costs; lack of existing cleared sites; and low producer confidence and experience with plant establishment in the region. The fertile, free-draining basalt soils in northern Queensland (~2 M ha between Charters Towers and Mt. Garnet) are well suited to leucaena production. Two demonstration sites were established to evaluate the establishment, productivity and performance of leucaena on lightly timbered basalt sites located at Whitewater and The Brook Stations in far north Queensland. An additional aim of these demonstrations was to increase producer awareness and adoption of leucaena-based pastures in the region.

Materials and Methods

Whitewater Station

A Producer Demonstration Site was established at Whitewater Station (18.1467º S, 144.3183º E; 600–700 masl), which covers an area of 25,200 ha. The land types on Whitewater are broadly red duplex-based soils; red basalt (60%), granite (35%) and black basalt (5%) soils. Average annual long-term rainfall is 796 mm with 70% falling between December and March. The enterprise supplies Brahman cross (*Bos indicus* × *Bos taurus*) and Droughtmaster (stabilized *Bos indicus* × *Bos taurus*) cattle to live export (280–350 kg) and local store markets. Typical stocking rates are one Adult Equivalent (AE = 450 kg dry animal at maintenance) to 7 ha with opportunistic rotational spelling.

Site. A 33 ha lightly timbered site was selected on well drained, red basalt soils with high P and low S concentrations. Predominant pasture species included naturalized Indian couch (*Bothriochloa pertusa*), *Stylosanthes* spp. and native grasses. Strips were ripped in November 2013, nominally at 10 m spacings, following a 'line of least resistance' through the standing trees and rock outcrops to prepare a seedbed.

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*Poster presented at the International Leucaena Conference, 1–3 November 2018, Brisbane, Queensland, Australia.

Due to insufficient rainfall in the 2013/14 wet season, planting was deferred until the following wet season (2014/15). Wondergraze leucaena was planted (1.5 kg/ha) in single rows in January 2015. Gran-am® (24% S, 20% N) fertilizer was applied (30 kg/ha) either side of the row at the same time. All rows were sprayed with glyphosate herbicide (570 g/L; 2 L/ha) before planting and Verdict® (haloxyfop at 520 g/L) was applied at 100 mL/ha after sowing for grass control. Low rainfall following sowing resulted in a failed establishment and planting strips were re-ripped in October 2015. Re-planting occurred in January 2016 at a seeding rate of 1.5 kg/ha but no additional fertilizer was applied. A mix of glyphosate and Spinnaker® (active ingredient 700 g/kg imazetaphyr applied at 140 g/ha) was applied immediately after planting. Granulated sulphur (90% S) was applied in September 2016 (50 kg/ha) and again in August 2017 (140 kg/ha). Adequate follow-up rainfall ensured there was favorable leucaena emergence and establishment (Figure 1).

Figure 1. Tom Saunders (Whitewater) inspecting young leucaena seedlings (top) in February 2016 and mature leucaena in the standing timber in 2018 (bottom).

Grazing. Grazing of the site (leucaena) began during the 2017 dry season (July–October). Initial grazing was at a heavy stocking rate and cattle were removed prior to the 2017/18 wet season. No weight gain data were recorded. The paddock was spelled up to July 2018, when 18 weaner steers (average 228 kg) were introduced for comparison with similar animals (average 231 kg) grazing on pastures in a neighboring paddock. Stocking rates between the 2 paddocks were identical and cattle in both paddocks had access to a weaner supplement.

The Brook

The breeding, backgrounding (molasses production feeding), agistment and trading enterprises on The Brook cover 21,000 ha and include a mix of red (85%) and black (15%) basalt country. Average annual rainfall is 650 mm. The Brahman breeder herd on The Brook is crossed with Brangus (Brahman × Angus), Angus and Brahman bulls. Infrastructure development is advanced with 62 paddocks and greatest grazing distances to water of approximately 2 km. Salt and sulphur supplements are fed in the wet season, while a water medication unit delivers dry season urea supplementation to animals in some paddocks. A walk-over weighing unit is also used to monitor cattle weight gains and assist with the trading enterprise and marketing decisions.

Site. A 400 ha site on The Brook was deep-ripped using a bulldozer in October 2017. In order to establish a legume-grass pasture in the wide inter-rows, seed of Seca stylo (*Stylosanthes scabra* at 1 kg/ha) and granulated sulphur (90% S at 60 kg/ha) were aerially applied across the whole paddock in November 2017. Following early season storm rains, strips were sprayed with glyphosate (570 g/L; 2 L/ha) in December 2017. Both Redlands (350 ha) and Wondergraze (50 ha) were planted (twin rows 1.8 m apart; 12–15 m inter-row spacing) at a seeding rate of 1 kg/ha during January and February 2018 using a custom-made planter (Figure 3). A glyphosate (1.5 L/ha) and Vezir® (700 g/kg imazethapyr; 140 g/ha) mix was applied at planting for knockdown and pre-emergent weed control.

Figure 3. Single-pass twin-row planting (with custom-built planter) and herbicide application at The Brook.

Results

Whitewater

At Whitewater, leucaena was successfully established over approximately 75% of the site by the end of the

2016/17 wet season. Average daily weight gain of steers grazing pasture only at Whitewater during the 2018 dry season was 0.06 kg/d versus a gain of 0.48 kg/hd/d for steers in the leucaena paddock at the same stocking rate (Table 1). A corn-based weaner supplement was fed in both paddocks (10.5 MJ ME/kg; crude protein 14%; crude protein equivalent 11%); intakes (as fed) in the leucaena paddock were 0.57 kg/hd/d compared with 0.93 kg/hd/d in the pasture paddock. Without the daily intakes of weaner supplement some weight loss would have been expected in weaners in the pasture paddock.

Table 1. Comparison of live weights (LW; kg) and average daily gains (ADG; kg/hd/d ± s.d.) over 63 dry season days of weaner steers grazing either pasture only or leucaena + pasture at Whitewater station.

	LW 20.07.2018	LW 21.09.2018	ADG
Pasture only	231 ±19	237 ±20	0.06 ±0.08
Leucaena + pasture	228 ±20	258 ±21	0.48 ±0.13

The Brook

Planting conditions, particularly in January 2018, were hot and dry and establishment success was limited with leucaena sparsely established across 300 ha. However the establishment of Seca stylo has been very encouraging. Controlling access by kangaroos, deer and cattle to the leucaena paddocks was challenging. Overall seedbed preparation was not ideal and planting depth could have been reduced. Planting such a large area when embarking on a leucaena development program is problematic. In future plantings the O'Brien family would plant a smaller area and implement a pest management plan, combined with complete repair of electric fence and traditional fencing, to limit access by marsupials, deer and cattle. An additional 100 ha of Redlands will be planted in the 2018/19 wet season using a similar twin-row configuration and inter-row spacing.

Discussion and Conclusions

Results at the Whitewater site have demonstrated that the challenges of establishing leucaena in lightly timbered but fertile basalt country can be overcome. This indicates that it is feasible to establish leucaena on the large areas of basalt country in north Queensland. While paddocks were not replicated, the marked differences in initial animal productivity data confirm the anticipated benefits of leucaena over existing native pastures even at relatively low levels in the diet. Further work is required to determine the long-term productivity and economics of leucaena in such situations, including overcoming practical constraints imposed by the standing timber (e.g. competition for moisture and on-going fertilizer requirements in fully mature leucaena).

In contrast with the results at Whitewater, the poor leucaena establishment at The Brook highlights the inherent risks with establishing leucaena in northern environments. Particular issues are the need for adequate seedbed preparation and planting techniques and the problems associated with keeping leucaena seedlings free from grazing during establishment in the north, where cleared areas are relatively few compared with central Queensland and there is a long dry period coupled with variable soils and rainfall. At The Brook, observations will continue to determine how well the legumes persist and produce in a range of seasons and how this is reflected in terms of animal production.

Acknowledgments

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*ILC2018 Poster and Producer paper**

Pioneer of leucaena development in Queensland, Australia: Nyanda, Carnarvon Gorge

Pionero en el desarrollo de leucaena en Queensland, Australia: Nyanda, Carnarvon Gorge

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Keywords: Establishment, management, tree legumes.

Background and history of leucaena production

We (John and Del O'Neill; Figure 1) first planted leucaena (*Leucaena leucocephala*) on our property 'Nyanda' in 1982 and these original paddocks still look green and lush after summer rain, with no sign of nutrient deficiency (Figure 2). We were part of a small group of original innovative graziers supported by Department of Primary Industries extension champion John Wildin. The group were the pioneers of commercial use of leucaena in Australia.

Nyanda is 15,200 ha, much of it mountainous. A total of 600 ha on the more arable areas was planted with variety Peru. We would plant more if we had suitable areas and intend to plant 20 ha of Redlands when seed becomes available. Some graziers in the Carnarvon area have planted Tarramba but it is not popular as it grows too tall. To date we have not tried Wondergraze.

Figure 1. John and Del O'Neill with Max Shelton in 2017.

Figure 2. 30-year-old leucaena, recovered from burning, now under-grazed and about to be frosted.

Environment

The Carnarvon location is excellent for leucaena with deep soils, especially on the creek flats, where soil phosphorus levels can reach 120 ppm. No leucaena has ever been fertilized on Nyanda.

Frost is an issue and most paddocks are frosted every year. The degree of damage varies from leaf fall to stems being frosted to ground level, which has a major influence on the amount of available leucaena in spring. With severe frosting it can take a few months for a significant amount of regrowth to occur from the base of the plants. After 25–30 years of frosting the leucaena plantations are still productive.

Establishment and management

We have observed that, to ensure establishment success, it is best to plant into fully cultivated paddocks in December-January.

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We tried planting directly into a grass paddock but the resulting leucaena growth and production were very poor. We plant leucaena in single rows only and inter-row cultivate during the first summer. Initial plantings were at a row spacing of 4.5 m but later we increased the spacing to 6 m. We spray a 1 m wide band of a mixture of herbicides [Basagran® (bentazone) and Fusilade® (fluazifop-P) at 2 kg a.i./ha for each herbicide], directly over young leucaena rows for control of broad-leaf weeds and grass. This was effective on both emerging leucaena, where young weeds were killed, and on older leucaena (up to 75 cm tall), where weeds were not fully controlled, but their growth was arrested, allowing the leucaena plants to gain advantage in uptake of water. If leucaena plants are sufficiently advanced at the end of autumn, we feed the area off before winter as leaf will be lost from frosting anyway.

Height management

I, John, consider that leucaena should be cut while still at a manageable height when the contractor's machines can travel through at a reasonable speed. These contractors were not around when we started and the leucaena became virtually out of control in some areas. In those cases, excess height of leucaena was controlled by driving along the rows with a bulldozer every 5 years. A neighbor of ours pulled a heavy scrub chain over some of his leucaena paddocks to reduce the height and in subsequent years followed up with mechanical cutting.

Burning

Some paddocks have been burnt accidently with varying outcomes. While most recovered quickly, one paddock, which carried a large amount of tall frosted grass and lots of old dead branches, received a very hot burn. The bases of the leucaena plants were burnt to 2–3 cm below ground level and plants took about 3 years to recover.

Inter-row grasses

For the initial plantings we planted green panic and buffel between leucaena rows. However, competition from the highly vigorous growth of leucaena and the heavy stocking rates employed have weakened the grass.

Psyllids

In some years infestations of the leucaena psyllid (*Heteropsylla cubana*) are quite bad and their sticky secretions reduce the palatability of the plant to cattle. For the first 15 years after planting, infestations of psyllids were severe every year, but recently infestations have been greatly reduced owing to a succession of dry years.

Weed leucaena

Leucaena plants have spread between rows but we control them by blade-ploughing. Some spread has also occurred to lane ways, as well as to Consuelo creek, where green panic and leucaena protect creek banks.

Animal management and marketing

Plants in most paddocks have been frosted every year, but not over-grazed, and are still productive after 25 years (Figure 3). We recognize the need to spell leucaena each year to allow recovery after heavy grazing or frosting.

One paddock has deteriorated dramatically as a result of overstocking at 2.5 animals per ha almost all year combined with annual frosting. Plants in this paddock have woody bases with leafy regrowth coming out like a bonsai plant, but have lost vigor (Figure 4).

Figure 3. Well-grazed 30-year-old leucaena.

Figure 4. Heavily-grazed 30-year-old 'bonsai' leucaena.

We use a rotational grazing system (one block having 5 cells and others 2 cells), which gives all paddocks 6–8 weeks of recovery. The original leucaena is still in good condition, but perhaps not quite as good as in the beginning. Water points are fenced off and spear traps are used to muster cattle.

Toxicity

Leucaena toxicity was an issue initially but the frequency of occurrence seems to have lessened. In the past, when steers first grazed leucaena in December, they would all lose hair from their tail and sheath, prior to being sent for slaughter. At that time, there was only a small area of leucaena, which was quite lush. However, no cases of hair loss have been seen since cattle were first inoculated with *Synergistes jonesii* in 1984-85.

On more than one occasion young maiden heifers were joined with bulls while grazing on fresh leucaena and conception rates were very low. A neighbor also experienced low calving percentages in heifers. Our current policy is to grow heifers on leucaena after weaning followed by grazing in a grass paddock for 6 months prior to joining. We keep bulls on leucaena right up to mating with no observed negative effects on their fertility. Calves are weaned in May and grazed on leucaena, when it is often frosted and therefore not so much leucaena leaf is available.

Target markets

We target the 'Jap Ox' market with steers at 30–33 months old, usually ranging from 340 to 360 kg dressed weight, often closer to 360 kg, with 70% of animals having a maximum of 2 permanent incisor teeth. However, in 2017 and 2018, average dressed weight was 375–380 kg with 70% of animals showing milk or 2 permanent teeth. Some are down-graded at the abattoir for having more than the optimal subcutaneous fat cover on the rump (P8 fat maximum 22 mm).

For the past 9 years, we have developed a small-scale Droughtmaster stud (a stabilized Brahman × Shorthorn cross). While leucaena pastures can be used for all classes of cattle, we consider that leucaena is best used for fattening, although we put our weaner heifers onto leucaena before moving them onto grass prior to joining.

Concluding statement

Leucaena has been a major factor in the viability of Nyanda and we would be delighted to have more areas suitable to plant more leucaena!

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ILC2018 Poster and Producer paper*

Leucaena production in the Fitzroy River catchment, central Queensland, Australia

Producción de leucaena en la cuenca del río Fitzroy, Queensland central, Australia

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Keywords: Cattle, establishment, grazing, liveweight gain, management, tree legumes, Wagyu.

Background

My wife and I own Sunland Cattle Co. Pty. Ltd., which operates 2 central Queensland cattle properties, Old Bombandy and Ten Mile Stations. Old Bombandy is situated on the Isaac River near Middlemount (11,308 ha) and Ten Mile is positioned on the Mackenzie River near Duaringa (6,868 ha). We are first-generation primary producers operating a Wagyu Stud and selling many fullblood Wagyu bulls. From our Wagyu breeding operation, we sell steers (400–450 kg) to feedlots and retain females to upgrade our herd (more than 10,000 fullblood and purebred Wagyu). We carry out numerous embryo transfer (over 1,150 embryos this year) and artificial insemination programs each year. Currently, we have a surplus of Wagyu females as we have reached our required breeding number. Another property was leased recently to increase cattle numbers. Our aim is to continue to improve our herd genetics. An area of 6,000 ha of leucaena spread over the 2 properties has proven to be an integral part of our beef business (Figure 1).

Our leucaena history

We became interested in leucaena in the early 1960s when we observed cattle near our home town of Rockhampton doing well on leucaena that was growing wild. We collected some seeds, planted them and this developed into a small patch. While the stand grew thickly but not very tall, a couple of isolated leucaena plants grew to about 8 m high. Our observations had shown that plants growing wild along roadways or creeks usually do not reach that height, potentially due to high plant populations and competition for moisture. By the late 1970s we had planted a small area of leucaena on a 900 ha property north of Rockhampton. While the leucaena established and grew, it was not impressive owing to the infertile soil type and frost incidence.

Figure 1. Leucaena at Sunland Cattle Co.

In the early 1990s we planted cultivar Tarramba leucaena at Old Bombandy and later at Ten Mile using seed treated with boiling water to improve germination (today all seed is mechanically scarified). A good plant population was achieved but the seedlings gradually died off and disappeared. This was due to wireworms and false wireworms chewing the roots underground, while other insects attacked the seedlings above the ground. Establishment success improved after a row of navy beans (white *Phaseolus vulgaris*) was planted each side of the leucaena rows as a decoy crop for the insects and worms. Beetle baits are now routinely used at planting to kill worms and insects that attack the small plants. Initially, we ploughed strips in the paddocks and planted single

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rows of leucaena, but subsequently switched to ploughing whole paddocks and planting leucaena in twin rows (1 m apart; 6 m inter-row). While we are satisfied with this inter-row spacing, opinions vary on the optimal spacing for varying conditions. In a dry climate, we consider wider inter-row spacing is preferable so leucaena can obtain sufficient moisture for maximum growth.

Establishment 'best bets'

Overall, while planting leucaena in summer with good soil moisture has proved successful, with good seed germination, heat wave conditions at this time can burn off seedlings. Spring planting is preferred so seedlings can grow and become established, being less affected by summer heat waves. Frost is common in the area and a couple of bad frosts followed one planting in early July. We expected the planting to be a failure, but fortunately the seeds had not germinated before the frosts and warmer weather which followed resulted in good germination and establishment. We spray with Spinnaker® (700 g/kg imazethapyr) as per label across a 3 m strip (leucaena and 1 m either side of the grass) when planting to suppress grass growth in the leucaena strips and treat seed with chemical to deter insects. Grass is not sown in the inter-row spacing as grass seed germinates naturally when the effects of Spinnaker® decline. The grass varieties grown are: buffel (*Cenchrus ciliaris*), green panic (*Megathyrsus maximus*; syn. *Panicum maximum* var. *trichoglume*), Bambatsi panic (*Panicum coloratum* var. *makarikariense*), Urochloa (*Urochloa mosambicensis*) and Rhodes Grass (*Chloris gayana*) (Figure 2). To determine if soil phosphorus levels were adequate, we applied superphosphate fertilizer at 250 kg/ha to a couple of rows and observed no production benefit in the leucaena. Soil tests have been conducted since then, which revealed that there was considerable variation in fertility between paddocks, and fertilizer will be applied to more paddocks to test possible further production responses.

Figure 2. Grass inter-row between the leucaena rows.

Leucaena in our business

We aim to manage the leucaena by matching cattle numbers to carrying capacity of paddocks to consume the leucaena rather than having to use mulching to control it. In very good seasons around 1,300 steers from Old Bombandy (in addition to the current cattle grazing the leucaena paddocks) have been introduced on to Ten Mile to manage leucaena height. When significant areas of our leucaena reached heights and stem diameters above those which private contractors could successfully mulch to the desired height with their machines, we designed and employed engineers to build a large mulcher (Figure 3) to reduce the height to what we desired. This has been quite successful. We also purchased a small leucaena cutter to mulch our smaller leucaena. Our current aim is to manage the height of leucaena so cattle can access all of it and prevent it from seeding. My philosophy is: 'When cattle eat the leucaena, we make money but when we have to mulch it, it costs us money'. If our cattle eat 100% of the leucaena produced during times of high growth and grow well, it can eliminate mulching.

Figure 3. The mulcher we designed and had built for mulching Tarramba.

At Old Bombandy an area of about 5,000 ha is fenced and managed using 'cell grazing' (high intensity-short duration grazing) including the leucaena paddocks. We consider that cell grazing is an effective management strategy which provides a rest or spell for pastures so that lush feed is available when cattle next return to a paddock. We plan to extend this management system to more areas on both properties. Leucaena has boosted cattle weight gains and increased the carrying capacity of our operation. Wagyu cattle assessment and price rely on a high marbling score and weight; our Wagyu cattle grown on leucaena are sought after for these characteristics. All categories of cattle graze leucaena pastures on our properties but sale cattle have priority to enable earlier turnoff. We graze our steers on leucaena pastures to reach target weights quickly and reduce age of turnoff (Figure 4). Similarly, young heifers graze leucaena pastures to reach 300 kg (the desired mating weight) so they reach puberty and breed early, preventing them being carried over to the following breeding season. Cull females, bulls, cows and calves all benefit from time spent grazing leucaena.

Figure 4. Wagyu cattle at Sunland Cattle Co.

The results achieved have been impressive and leucaena is now an integral part of our production system. Initially, some cattle on leucaena did display symptoms of mimosine toxicity but after dosing animals with the 'rumen bug' (*Synergistes jonesii*) the problem was resolved and cattle grew well. Since then we have dosed only a small number of cattle with rumen inoculum. Subsequent tests have shown that cattle do carry mimosine-degrading organisms in their rumens naturally but we continue to sample animals periodically to confirm that this situation continues.

Limitations

There is potential on our property to more than double the area of leucaena planted. However, we are limited by our capacity to manage it in accordance with The Leucaena Network Code of Practice. While we possess the mulching equipment required to prevent the plant from flowering and setting seed, it is preferable to control it through grazing pressure rather than mulching. We have experienced 2 psyllid (*Heteropsylla cubana*) infestations since we began growing leucaena. Aerial spraying was considered to control the infestations but after a period of cold weather the insects disappeared. Climatic conditions on our properties are normally sufficiently dry to prevent psyllid infestations being a significant problem.

Future leucaena development options

We are satisfied with the economics of planting and grazing leucaena as it is profitable and greatly increases our carrying capacity and rate of turnoff. While it has been planted on our property for only a limited time, we intend to plant more at Old Bombandy Station. With increased cattle numbers and appropriate machines we can control the plants effectively and intend to plant more areas to leucaena. Almost all of our leucaena is cultivar Tarramba as this was the latest and best variety at the time of planting. However, Tarramba has a tendency to grow tall, which presents management issues, so future plantings will involve a different cultivar. We have the soils, climate, equipment, staff and the know-how to establish much more leucaena but will not proceed until we are confident we can contain the plant. Leucaena is essential for our operation and we are interested only in new properties that have suitable soils for leucaena production.

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ILC2018 Poster and Producer paper*

Leucaena in southern Queensland, Australia
Leucaena en el sur de Queensland, Australia

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Keywords: Animal performance, establishment, fattening, management, tree legumes.

Background

Our 4 properties are located 250 km west of Brisbane and 100 km north of the Queensland-New South Wales border. Soil types range from undulating fertile Brigalow clay soils to infertile sandy forest loams of ironbark, pine and box country. Average annual rainfall is 625 mm, spread between winter and summer with the heavier falls in summer.

Three of the properties are used for breeding Angus cattle, while steer and cull heifer progeny are carried on the remaining property until they reach their respective target weights. Our target markets include feeder steers for feedlots (400–500 kg live weight), cull heifers for slaughter (500 kg live weight) and milk and two tooth cattle (260–280 kg dressed) aimed at either Meat Standards Australia (MSA) Grassfed or Angus grids (depending on price), if the season allows.

Cropping history

Historically this region was composed of small farms for dairying and over time, most landholders diversified into dryland (grain) cropping and small-scale beef production enterprises. As with all farming areas in Australia, with limited and unreliable rainfall plus marginal soil fertility for cropping, continuous cropping has resulted in rundown of soil nutrients. Subsequently, there has been a progressive shift from cropping to beef production on sown pastures with this nutritional rundown. Sown pasture establishment primarily involved tropical grasses as attempts to establish legumes were generally unsuccessful due to poor soils, variable rainfall and unsuitable legume varieties. Sown grass pastures would remain productive for 2–3 years then slowly decline leaving the land devoid of ground cover and susceptible to erosion and weeds.

Trialing leucaena

Our leucaena journey began in 2003. Although many pasture advisors deemed leucaena unsuitable in southern Queensland, due to the impact of cold temperatures and frost on growth and overall profitability, we made the decision to trial the plant. Owing to the favorable elevation (higher) and north-facing slopes on some of our country, we were confident of being able to establish and grow leucaena for 6–7 months of the year. As land prices increased, we decided that improving what we already had was preferable to purchasing more land. The first planting in March 2003 (twin rows at 30 cm apart; 4 m inter-row spacing) was with a broad-acre planter with a narrow point and press wheel following directly behind. Establishment was only partially successful with approximately 2 plants/m of row growing to around 50 cm high by late May, when the first frosts for the year were experienced. Good rainfall (100–150 mm; 95th percentile for that time of year) and mild temperatures (25–35 °C) in late August and early September (late-winter and early spring) provided good growing conditions. The leucaena plants competed successfully with weeds and poor soil fertility and we were surprised how they recovered and finally flourished.

Refining leucaena establishment practice

With the promising performance of leucaena in this initial trial, we decided to continue with further sowings, but sought additional information for refining our establishment techniques. After attending a University of Queensland leucaena course I proceeded to build a planter, which proved to be a bad decision. After a couple of unsuccessful attempted plantings with that planter, we eventually purchased a twin-disc vacuum planter for $12,000. Acquiring this purpose-built planter

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coupled with meticulous seedbed preparation and serious post-planting weed control regimes were all key factors in achieving successful leucaena establishment on our properties. Problems with weed control are common and from experience we found that higher application rates of Spinnaker® (Imazethapyr 700 g/kg) are required on lighter soils (160 g/ha) in comparison with clay soils (120 g/ha). Spinnaker® is applied in a single pass pre-planting. Depending on the weeds in a given season, we spray across the leucaena strip (approx. 3 m) and cultivate the remainder (sometimes across the whole paddock; Figure 1). We use Verdict™ (520 g/L haloxyfop) to control grass in leucaena, and, if weed problems persist, we use conventional inter-row tillage. On our property, land that was used previously to grow grain does not require seedbed preparation but intensive cultivation is required on land developed from tree regrowth.

Figure 1. Leucaena rows at Borambil.

Our best recipe for success is September planting (twin rows 1 m apart; at 8 m inter-row centers spacing) with effective weed control and fertilizer application. Seeding rate is a seed every 3 cm, which is the equivalent of 1.4 kg/ha. If soil moisture is adequate and well distributed down the profile and adequate summer rainfall is received, we can graze leucaena in the following March (6 months after sowing). By sowing grass or forage oats for winter feed (Figure 2) in the inter-row space, the leucaena-grass pasture can be in full production by October-November with adequate spring rain (Figure 3).

Good soil fertility is paramount for leucaena establishment and productivity. Fertilizer must be added to our soils as soil phosphorus levels range from 8 to 20 mg/kg (Colwell). Our fertilizer regime focuses on phosphorus, sulphur and zinc. MAP Starter (22% P, 10% N) is applied pre-planting at 25 kg/ha across the total area, or closer to 100 kg/ha if applied directly under the twin rows of leucaena. We plant a mixture of leucaena varieties, i.e. Cunningham, Wondergraze and Tarramba, with no specific preference, although adjacent to creeks where frosts are more prevalent, Tarramba is well suited. Infestations of psyllids have been a problem on only rare occasions and we do not spray to control psyllids.

Figure 2. Cattle grazing winter oats.

Figure 3. Leucaena with fully established inter-row pasture.

Paddock and business benefits

As our land use changed we noticed how our country improved. Since soil nutrient rundown had occurred prior to planting leucaena, cattle preferentially grazed the leucaena, leaving grass on areas after the available leucaena had been eaten. We were able to subdivide paddocks into 40–60 ha blocks and to implement rotational grazing, which maintained good ground cover in each paddock after the edible leucaena had been eaten. This reduced runoff and rates of soil loss, while improving soil organic matter and nutrient status.

Our establishment costs are lower than those for most growers as we own the necessary machinery and our paddocks are already cleared. We have cleared regrowth in some paddocks to plant leucaena, which increased costs. Regrowth control must be thorough prior to planting, as controlling suckers is problematic in established leucaena stands. Depending on variety, leucaena seed can cost $10–50/kg and, taking into account costs of using our own machinery, we estimate that establishment costs are $200–250/ha on country previously farmed and greater than $300/ha on country where regrowth must be cleared first.

Leucaena-grass pastures will increase annual live-weight gains and carrying capacities over those on grass pastures but are profitable only if correct establishment procedures are followed. With occasional planting failures taken into account, establishment lags of 2–3 years are common, which results in significant ‘opportunity costs’ or income foregone.

Our best daily gain results from this leucaena program were 1.6 kg/hd/d (2 month period) averaging out over the summer (7 months) at 1.3 and 1.4 kg/hd/d (heifers and steers, respectively). Gains at this level could have been maintained for longer if the stocking rate was decreased. We focus on kg live weight produced per ha and have achieved up to 250 kg/ha in the best years. Our stocking rates have almost doubled in the leucaena paddocks (to 1 beast/ha). In conventional grass paddocks, the long-term carrying capacity deteriorates over time and there is more longevity in leucaena as it is a perennial legume and reduces grazing pressure in the inter-row pastures. It enables us to look after the grass better due to decreased time spent grazing in the rotations. The nature of the leucaena taproot has provided a much-needed improvement in our ability to manage drought and target appropriate markets, as well as predict daily weight gains even over long dry spells.

Summary

To date we have established approximately 400 ha of leucaena. Unfortunately efforts to expand leucaena plantings across our fattening block have been hampered by a series of below-average summer rainfall years. Future development plans include expansion of leucaena plantings across both our fattening block (500–600 ha) and breeder country (approx. 1,000 ha). Planting leucaena on the breeder country will increase protein supply and assist with drought mitigation. We propose to use wider row spacings (12 m) on this area. In the future we intend to trial inter-row winter forage cropping (Figure 2) to improve paddock productivity over the winter-spring period and extend production to 12 months of the year.

While there are many challenges with leucaena establishment and productivity in the southern regions of Queensland, the positive outcomes for our business far outweigh the negatives. Once the ‘upfront’ costs are covered, leucaena pasture systems are relatively cost-free (with the exception of fertilizer applications in some circumstances). When we look at the methane emissions reduction potential, carbon sequestration attributes and drought mitigation qualities (which in the future may provide additional income opportunities), as well as increased carrying capacity and profitability, the decision to plant leucaena on our property is not one that I regret and I cannot envisage any change to that situation in the future.

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*ILC2018 Poster and Producer paper**

Irrigated leucaena in the Burdekin catchment produces high quality cattle for premium markets

Leucaena bajo riego en la cuenca del río Burdekin, norte de Queensland, produce carne para mercados premium

DON HEATLEY

Byrne Valley, Home Hill, QLD, Australia

Keywords: Grazing, irrigation, north Queensland, tree legumes.

Background

We are fifth-generation, north Queensland cattle producers. Between our 2 stations, Byrne Valley and Rangemore, we run around 8,000 head of cattle. The business focuses on producing beef for highly specialized markets in Korea, Japan and the USA.

Byrne Valley (12,000 ha) is 90 km south of Townsville on the lower Burdekin River and is operated as a back-grounding and leucaena finishing property. Rangemore (15,000 ha) is operated primarily as a breeding property with a 2,000 head *Bos indicus*-based breeding herd. In recent years, we have been infusing Angus genetics and aim to stabilize the herd at approximately 40% Angus content.

Leucaena in our program

Initially we were hesitant about planting leucaena, due to a fear of farming, as we were cattle producers not farmers.

We planted our first leucaena at Byrne Valley in 1998, after several visits to Kununurra on the Ord River in Western Australia. We currently have 500 ha of leucaena under irrigation in an industrial-type farming operation (Figure 1). Paddocks have been laser-levelled (2,000 m long × 400 m wide with a 2 m fall). We plant leucaena on double raised-bed rows with 4 m inter-row spacing and deep inter-rows to speed water flow. Two centrifugal pumps deliver 150 L/sec to flood irrigate the pastures, with every second inter-row being watered on an alternating basis with a fast flush of water (Figure 2). Water and power usage have been halved using this method down a V-shaped inter-row compared with slow watering that soaks into a level inter-row. Leucaena is fertilized every 4–5 years with 500 kg/ha of superphosphate (8% P, 11% S).

Figure 1. Peter Heatley (left) and Bruce Mayne (right) inspecting the leucaena.

Figure 2. Alternately irrigated inter-rows in the leucaena at Byrne Valley.

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*Poster presented at the International Leucaena Conference, 1–3 November 2018, Brisbane, Queensland, Australia.

Key learnings with an irrigated system:

- Never plant prior to a wet season hoping for a free rainfall advantage as failed seed strike due to heavy rain events is a major loss.
- Initially lack of understanding about the importance of depth of planting (planting too deep) led to establishment failures after heavy rainfall events. These issues with seed strike are significantly reduced if planting occurs after the wet season.
- It is impossible to mechanically control weeds in a wet paddock.
- Control of grass and weeds is limited to a maximum of 2 applications of herbicide.
- Leucaena in an irrigated paddock is more important than roughage in the same paddock.
- Maintain a consistent watering pattern. It is false economy to start late, hoping to save water.

Psyllid infestations can be significant in this region but the new psyllid-resistant variety Redlands should help minimize this problem. Height management of leucaena is also a major issue in an irrigated system. We plan to address this in the future by decreasing our inter-row width from 4 m to 2 m, which will enable us to increase the stocking rate and allow cattle to have access to grazing height leucaena no matter where they are standing at all times.

Animal production

We operate a rotational grazing system and move cattle to a new paddock every 14 days, removing all cattle from the leucaena during the wet season. Average daily gain (ADG) ranges between 0.9 and 1.4 kg/hd/d and by continued emphasis on genetic improvement we aim to increase these figures over time. Molasses is fed at 2 kg/hd/d to supply additional energy and we cut and bale (600 kg square bales) Callide Rhodes grass hay on the property as a source of roughage (Figure 3). The hay is provided on an ad lib basis and consumed by cattle at approximately 5 kg/hd/d. We bale approximately 700 tonnes hay per year and recoup about 30% of the production costs by selling surplus hay. By using this system, we have halved age of turnoff compared with cattle grazing a grass pasture-only diet and have the flexibility of marketing cattle at a time of year when prices are favorable, as opposed to having to sell as seasonal conditions decline when the majority of producers are also selling. Irrigated leucaena has eliminated many risks and variables in our steer production system, largely removing the influence of seasonal conditions, and we can calculate guaranteed kilos of beef which equals greater income and profit security. We sell direct to meat processors who supply markets in Japan, Korea and USA and our steers reach live weights of 630–670 kg at 24–26 months of age with carcass weights of 340–360 kg (54% dressing percentage). In association with Prof. Luciano Gonzalez at the University of Sydney, we have introduced automatic walk-over weighing units and automated drafting of finished cattle. With our electronic identification system for animals, this has allowed us to monitor performance of all animals (identifying both high and low performers) and has enabled us to monitor the economics of the overall production system.

Figure 3. Crossbred steers (24 months) eating Rhodes grass hay and molasses in association with the leucaena.

Future operations

We are currently developing an additional 700 ha for planting with leucaena and the planned decrease in inter-row spacing from 4 m to 2 m, to increase stocking rate and reduce maintenance trimming costs, as well as to change from fluming (Figure 4) to multiple fixed outlets in the underground pipelines.

Figure 4. The current fluming irrigation system in operation at Byrne Valley.

Our goal is to have every male weaner grazing leucaena as soon as possible after weaning. We are considering the cost-benefits of both selling slightly lighter younger steers (to capitalize on superior feed conversion efficiency) and the economics of cubing or pelleting leucaena to supplement breeders.

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ILC2018 Poster and Producer paper*

Leucaena production in central Queensland, Australia
Producción de leucaena en Queensland central, Australia

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Keywords: Animal performance, buffel grass, cultivars, establishment, Wondergraze, tree legumes.

Overview

We operate a 100% Wagyu business across 3 central Queensland cattle properties: Falcon Downs, Yaraandoo and Overflow, with an additional block at Glen Innes, New South Wales to grow out cattle prior to entering feedlots. The operation includes breeding, growing and feedlot finishing. Finished cattle are contract-slaughtered and marketed both domestically and overseas. The central Queensland properties are made up of largely cracking-clay Brigalow soils with box flats, which are highly suitable for leucaena. Dryland leucaena was established on Falcon Downs and Yaraandoo beginning in 2009. It took 5 years to plant 3,700 ha and we aim to plant 400–800 ha/year on all suitable land. There is some irrigated leucaena on Overflow (Table 1) which we also aim to expand.

Table 1. Areas of Falcon Downs, Yaraandoo and Overflow properties and areas planted with leucaena.

Property	Total area (ha)	Leucaena (ha)	
		Dryland	Irrigated
Falcon Downs	3,645	3,645	
Yaraandoo	3,645	243	
Overflow	8,100	1,112	182

Establishment

The entire paddock is cross-cultivated before planting. Initially, we used a single-row planter, before moving to a twin-row planter. Now we use a much larger unit to plant 6 rows at a time, 3 sets of twin rows (1 m apart) with 6 m spacing between centers (Figure 1). In the 6 m inter-row space, we leave the center 2 m untreated to allow pasture to re-establish. Spinnaker™ (700 g/L imazethapyr) and Round Up™ (glyphosate) are applied on a 2 m wide strip straddling the leucaena twin rows at planting as per manufacturer's instructions to control weeds, and Spinnaker™ and Verdict™ (520 g/L haloxyfop) are applied post planting (timing dependent on weed growth).

Figure 1. Six-row leucaena planter used across our operation.

The first grazing occurs about 12 months after planting. The main variety used in our operation has been Wondergraze, with some areas of Cunningham, Tarramba and Redlands. Wondergraze appears to be the most palatable. We harvest about 1–2 tonnes per year of Wondergraze seed for home use, clean the seed and scarify it before planting. Usually, 2-year-old stands of Wondergraze are the best for seed production but sometimes first-year crop is also used. Inter-row pasture is buffel grass (*Cenchrus ciliaris*; Figure 2). No fertilizer has been used to date on our leucaena-buffel pasture. While 182 ha of irrigated leucaena is currently established at Overflow, we aim to expand this area to 2,000 ha. Trickle tape irrigation is used, with irrigation lines being fed by an electric bore and a solar bore. We aim to plant

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*Poster presented at the International Leucaena Conference, 1–3 November 2018, Brisbane, Queensland, Australia.

all of the newly purchased property Yaraandoo to leucaena eventually.

Figure 2. Typical leucaena-buffel grass pasture.

Animal performance

Leucaena has doubled the carrying capacity across our operation to about 1 adult beast to 2–3 ha. The leucaena rumen bug (*Synergistes jonesii*) was introduced to our herd by purchasing cattle from an existing leucaena producer. We run approximately 4,500 cows and progeny under a rotational grazing system. The system we have adopted in Queensland is to grow out weaners to over 300 kg LW, and transport them to Glen Innes, where they gain another 100 kg LW on improved temperate pastures, before entering feedlots at over 400 kg LW for a 400-day finishing period. We aim for a final carcass weight of 420–450 kg with high marbling. In addition we sell 100–200 (depending on demand) Wagyu bulls each year. Leucaena has made a significant contribution to our successful business model and we expect this impact to increase as we expand the area under the legume.

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*ILC2018 Poster and Producer paper**

Ingelara Grazing: Leucaena in speargrass country, Queensland, Australia

Ingelara Grazing: Leucaena en pasturas nativas de Heteropogon contortus *en Queensland central, Australia*

STUART & SHEREE OGG

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Keywords: Animal performance, establishment, fattening, management, oats, tree legumes.

Background

Ingelara is a 7,280 ha property located 20 km from the Carnarvon National Park in central Queensland. It was originally operated as a breeding block, selling store cattle, as there was no capacity to fatten. The establishment of leucaena on Ingelara has allowed us to change to a breeding and fattening operation. Ingelara receives an average annual rainfall of 750 mm and consists of loamy creek flats, leading into narrow-leaf ironbark ridges. Cunningham and Peru cultivars of leucaena have been established across 445 ha, and the oldest plantings are 30 years old. Forage oats is also grown on 240 ha. Our crossbred steers (combinations of Simmental, Brahman and Angus; Figure 1) are sold to Teys Abattoir, Biloela and we target premium EU and PCAS markets. By grazing leucaena, these steers reach market weights at under 24 months of age, averaging 300 kg dressed weight and are graded into Meat Standards Australia (MSA) boning groups 1 to 8 (Figure 1).

Leucaena in speargrass country

In the early 1990s we started clearing creek flats to grow forage crops including oats, lablab and Sugargraze forage sorghum. When we observed the benefits achieved on the neighboring property 'Nyanda' from planting leucaena, we realized that black speargrass (*Heteropogon contortus*) flats could be transformed into sustainable, prime fattening country. We started planting leucaena at 6–8 m inter-row spacing on our farming country. Aside from some weed pressure, leucaena established easily on our soil types, particularly the deep (>6 m) well drained loamy creek flats. Paddock production losses (opportunity cost losses) were kept to a minimum during the establishment stage as forage oats was grown between rows in the establishment year. We adapted our existing machinery for use in planting leucaena and performing cultivation to control these costs. Leucaena was planted straight into the oat stubble from a previous crop using a seeding rate of 2.5 kg/ha at a depth of 2–3 cm. We consider the optimal sowing time is October–December but have planted as late as the end of February. For weed control at the planting stage, we used Fusilade® (250 g/kg fluazifop-p-butyl; for grasses) and Basagran® (broad-leaf) on the strip rows and, once leucaena was established, have not needed to control weeds. We estimate establishment costs of approximately $200–250/ha, on land that was already cultivated for oats.

Figure 1. Crossbred steer on Ingelara in 2018.

Leucaena management

Leucaena is managed in a 3-stage cycle at Ingelara.

Stage 1

We manage leucaena under a rotational grazing system using a 4-paddock system and a 200-day cattle rotation.

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*Poster presented at the International Leucaena Conference, 1–3 November 2018, Brisbane, Queensland, Australia.

In the wet season, when leucaena is green (Figure 2), our steers run in one mob and are moved when the paddock has been optimally grazed and needs a rest. Approximately 450 steers, with a start weight of 300–350 kg, enter the system in November (depending on rainfall) and achieve average daily liveweight gains (ADG) of 1–1.2 kg/head or 200–220 kg/head over the 200-day grazing period. Forage oats are also planted in other paddocks for grazing during the winter.

Figure 2. Leucaena has regrown and is ready for the first grazing rotation.

Stage 2

With the onset of frosts (Figure 3) around June, our cattle are moved from the leucaena pasture to the oats paddocks (Figure 4) at weights ranging from 500 to 550 kg. Steers graze on the oats until they reach target slaughter live weights of 560–600 kg. Ninety percent of leucaena plants are frosted to ground level in winter (July) which controls leucaena height. For leucaena which is not frosted, height is controlled by cutting or pushing with a bulldozer. Weaner steers are moved on a rotation through frosted leucaena paddocks and graze on inter-row Callide Rhodes grass until spring.

Figure 3. Frosted leucaena (Stage 2).

Figure 4. Oats paddock to which steers are moved after frosting of leucaena (Stage 2).

Stage 3

The leucaena is spelled in spring for 6–8 weeks to allow adequate regrowth (Figure 5). Rumen inoculum (*Synergistes jonesii*) was introduced on one occasion approximately 10 years ago. We could not detect any noticeable benefit from the drenching and consider that these organisms must be widespread across our environment.

Figure 5. Leucaena re-shooting in spring following frosting and a 6–8 week spell (Stage 3).

Limitations and challenges

One of the biggest challenges is controlling the spread of leucaena from designated paddocks into creeks and waterways. We have a poisoning program in place to control leucaena spread into riparian areas and manage our grazing of leucaena stands to minimize seed-set.

The most significant leucaena production losses are associated with leaf loss from psyllid attack in wet and humid years. The last psyllid outbreak was in the mid-2000s and we estimate that weight gains were halved. Aerial spraying of psyllids with Rogor (dimethoate) is the only effective control method and suppresses psyllids for only 2–3 weeks. We consider it is undesirable to spray our paddocks regularly, although there is no withholding period before slaughter on this chemical.

Establishment failures have been experienced only in wet areas or on clay soils (box or sandalwood country) and where soil types were appropriate, establishment has always been successful.

Summary

We intend to expand areas sown to leucaena at Ingelara when seed of the Redlands variety becomes readily available. New plantings will be into cultivated strips and we will not be ploughing whole paddocks. The aim is to use leucaena on areas that are inundated during the wet season, and on some hilly country to reduce the risk of erosion. The use of leucaena has transformed our business from one of breeding and selling store cattle, into breeding and selling top quality prime finished cattle. The value of our land has increased from $3,700 to $12,000/ha. Growing leucaena is the single most important element in our system. In the future, we intend to trial slashing leucaena to ground level in an endeavor to improve leaf volume in our non-frosted areas.

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*ILC2018 Keynote Paper**

Leucaena intensive silvopastoral system: The CIPAV experience in Colombia

Sistema silvopastoril intensivo con leucaena: La experiencia de CIPAV en Colombia

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Abstract

The Center for Research in Sustainable Systems of Agricultural Production (CIPAV) has worked since 1991 on the establishment and management of intensive silvopastoral systems (ISPS) involving leucaena (*Leucaena leucocephala*). The initial work was carried out in the Valle del Cauca department, and afterwards in other regions of Colombia and abroad. This document presents the main characteristics of the work carried out on various farms in the tropical lowlands of Colombia, located between 0 and 1,300 masl, with 22–28 °C average annual temperature. The leucaena ISPS integrate this species with grasses, mainly *Cynodon plectostachyus*, *C. nlemfuensis* and *Megathyrsus maximus*, although other species have been used, such as *Dichanthium annulatum*, *Urochloa humidicola* (including cv. Llanero, formerly classified as *Brachiaria dictyoneura*) and *Urochloa* hybrids. Leucaena is planted at densities in excess of 10,000 plants per ha, in rows 1 to 1.5 m apart with 0.3–0.6 m between plants within rows. These ISPS are grazed by *Bos indicus* and *B. taurus* cattle and their crosses, in beef, dairy (tropical lowlands) and dual-purpose systems. The proper management of an ISPS requires a rotational grazing strategy with each paddock grazed for 1–3 days (ideally 1 day) followed by a 42–46 day rest period. Stocking rates are 2.5–4.5 head/ha. Average daily gains by beef cattle are 650–800 g/head (2–3 kg/ha/d). Production in dairy systems (tropical lowlands) fluctuates between 5 and 14 L milk/cow/d, depending on genetic makeup, season (dry or rainy) and supplementation, with up to 17,000 L milk/ha/yr. Information from various farms that use ISPS is presented including main ecological characteristics and animal performance.

Keywords: Beef production, dairy production, dual-purpose production, establishment, management, stocking rate, tree legumes.

Resumen

El Centro para la Investigación en Sistemas Sostenibles de Producción Agropecuaria (CIPAV) ha trabajado desde 1991 en el establecimiento y manejo del sistema silvopastoril intensivo (SSPi) con leucaena (*Leucaena leucocephala*). El trabajo inicial se llevó a cabo en el Departamento del Valle del Cauca y posteriormente en otras regiones de Colombia y en el exterior. Este documento presenta las principales características del trabajo realizado en varias fincas del trópico bajo en Colombia, situadas entre 0 y 1,300 msnm, con temperatura promedio anual de 22–28 °C. El SSPi con leucaena integra esta especie con gramíneas, principalmente *Cynodon plectostachyus*, *C. nlemfuensis* y *Megathyrsus maximus*, aunque otras especies han sido utilizadas, tales como *Dichanthium annulatum*, *Urochloa humidicola* (incluyendo el cv. Llanero, anteriormente clasificado como *Brachiaria dictyoneura*) e híbridos de *Urochloa*. La leucaena se establece en densidades superiores a 10.000 plantas por ha,

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en surcos separados entre 1 y 1.5 m, con distancias entre plantas de 0.3–0.6 m. Estos SSPi son pastoreados por ganado *Bos indicus* y *B. taurus* y sus cruces, en sistemas de producción de carne, leche (en trópico bajo) y doble propósito. El manejo adecuado de los SSPi requiere una estrategia de pastoreo rotacional con un período de pastoreo de cada potrero de 1–3 días (idealmente 1) seguido de un período de descanso de 42–46 días. Las cargas animal son 2.5–4.5 animales/ha. Aumentos de peso diario de ganado de carne son 650–800 g/animal (2–3 kg/ha/día). La producción en sistemas lecheras (trópico bajo) varía entre 5 y 14 L de leche/vaca/día, según raza y genética, época del año (seca o lluvias) y suplementación, obteniéndose hasta 17,000 L de leche/ha/año. Se presenta información de varias fincas que usan SSPi, incluyendo sus principales características ecológicas y datos de producción animal.

Palabras clave: Carga animal, establecimiento, ganado de doble propósito, manejo, producción de carne, producción de leche.

Introduction

Since 1991 the CIPAV Foundation has worked on the establishment of Intensive Silvopastoral Systems (ISPS) incorporating leucaena (*Leucaena leucocephala*) and grasses, following preliminary research carried out by CIAT and CENICAFE (Echeverri et al. 1987; Suárez et al. 1987). The initial work by CIPAV was carried out in the Valle del Cauca department. Subsequently, work was performed on the Hacienda El Chaco (Tolima department), then beginning of 2002 in the Quindío department and since 2005 in other regions of Colombia (Ramírez 1997; Molina et al. 2001; Espinel et al. 2004; Zapata Cadavid and Silva 2010, 2016; Murgueitio et al. 2016) and abroad (Zapata Cadavid et al. 2010; Solorio-Sánchez and Flores-Estrada 2011; Alves-Cangussu et al. 2012; Mahecha et al. 2012a). The system and the particular characteristics of the work carried out on various farms in different regions are described below.

The CIPAV work with leucaena in Colombia and other countries has focused mainly on very high leucaena densities (above 10,000 shrubs per ha) in association with various tropical grasses under cattle grazing with rotational grazing systems. These systems are called Intensive Silvopastoral Systems, different from other silvopastoral arrays in which grasses are associated with lower tree densities or leucaena is used as a fodder bank.

ISPS in Colombia where leucaena has been planted

In Colombia leucaena ISPS have been planted in several geographical regions, between 3°30' N and 10°58' N, at elevations up to 1,300 masl, with average temperatures ranging from 22 to 26 °C, and an average annual rainfall range between 700 and 2,500 mm, in areas which originally were tropical forest (ranging from dry to humid tropical forest).

The farms, where leucaena has been planted in Colombia, are located in the Caribe region (0–200 masl), including areas of low (Dry Caribe) and higher (Wet Caribe) precipitation, and in the Andean region in the main 2 valleys (Cauca and Magdalena Rivers) located amid the 3 Andean mountain ranges at elevations of 200–1,300 masl, in ecosystems originally supporting dry or wet tropical forest.

Systems of plantation

Colombian leucaena ISPS have been planted in different ways, briefly explained below according to availability of labor and machinery, cost and topographical conditions. The main features of the systems in Colombia are:

- Leucaena is planted at high density (>10,000 shrubs/ha) in a single-row configuration with 1–1.7 m between rows, and 0.3–1.0 m between plants within rows, to give leucaena densities of 10,000–20,000 shrubs/ha.
- Leucaena is planted in combination with improved grasses, mainly *Cynodon plectostachyus*, *C. nlemfuensis* and *Megathyrsus maximus* (cvv. Tanzania, Mombasa, Colonial and Massai), although other species have been used, e.g. *Dichanthium annulatum*, *Urochloa humidicola* (including cv. Llanero, formerly classified as *Brachiaria dictyoneura*) and *Urochloa* (formerly *Brachiaria*) hybrids.
- Before planting, leucaena seeds are scarified and inoculated with specific rhizobium at 50 g peat powder/kg seed.
- Improved grasses are established just after leucaena planting or up to 45 days later.
- After planting, weed control is carried out using chemicals, mechanical control, manual weeding or a combination of these operations (Uribe et al. 2011).
- Leucaena toxicity has not been a limitation and animal inoculation with rumen bacteria (*Synergistes jonesii*) is not practiced.

Manual planting of nursery seedlings

This system has been used mainly in the central coffee production area of the country, in the Andean foothills (Espinel et al. 2004; Zapata Cadavid and Silva 2010, 2016).

In this case, seedlings are produced in a nursery for subsequent transplanting into the field. Plastic bags, such as those normally used for coffee seedlings (13 cm × 23 cm), are utilized. Good soil, preferably mixed with some chicken or cattle manure, is used and 3 or 4 seeds are deposited in each bag. The nursery phase lasts 6–8 weeks, during which the plants reach a height of 25–40 cm.

An advantage of this system is that it reduces establishment risks because seedlings have reached an acceptable height and stage of development before transplanting. This ensures seedlings have a greater capacity to withstand unfavorable weather conditions and it facilitates the control of weeds, while the establishment time for a field can be reduced by as much as 2 months compared with direct seeding. Disadvantages are the nursery cost, which can be very high (10,000 or more seedlings are required per hectare) for farmers with little experience in this type of activity, plus high labor costs for transplanting the seedlings to the field.

Direct planting with mechanical soil preparation

Planting following mechanical land preparation is carried out in situations where the topography (flat or of moderate slope) allows this method to be implemented and where machinery is available (areas with a tradition of mechanized agriculture like the Caribe region).

After land preparation, leucaena seed is planted either with machinery or manually, in single rows 1.5–1.7 m apart and with about 20 seeds/m of row. All seeds that germinate and establish are allowed to remain, so plant densities in excess of 20,000 shrubs per ha can be obtained (Zapata Cadavid and Silva 2010, 2016; Murgueitio et al. 2016).

Direct planting with manual soil preparation

In some cases leucaena has been seeded into plots by hand without mechanical preparation but using herbicides to eliminate the plant cover. A common layout has been single rows at 1–1.5 m spacing with 50–70 cm between planting sites within rows and 4 or 5 leucaena seeds per site.

Grass establishment

Grasses have been planted either immediately after leucaena or about 45 days later (in order to allow leucaena to reach 30–45 cm height). In the former case, rapid growth of the grass can outstrip the growth of leucaena and compete for light, nutrients and water, thereby affecting development of leucaena. Planting grasses about 45 days after leucaena seeds are sown is the most commonly used system now.

Management and utilization

Leucaena is first grazed about 5–7 months after planting, when the plants are about 1.8 m tall.

Recommended management of the leucaena ISPS requires that the plots be divided into several paddocks, thus allowing a rotational grazing system to be implemented with:

- Grazing not exceeding 5 days — preferably 1 day only; and
- Rest periods of 45–50 days.

Applying these 2 strategies means that each cycle requires a minimum of 9 paddocks and preferably more than 15. To reduce establishment costs, plots are divided with electric fencing, although permanent fencing or a combination of permanent fencing and mobile electric wires is often used.

In Colombia leucaena trees are normally pruned every 6–12 months. The higher frequency is employed in the Caribe region where solar radiation is high and leucaena grows very quickly during the rainy season. Trees are pruned at 1–1.2 m from ground level with a machete.

Mimosine toxicity has not been observed to be a problem for cattle in Colombia so inoculation with rumen bacteria is not carried out.

Animal performance

In Colombia, leucaena is grazed by both dairy and beef cattle, although dual-purpose cattle are most common. Both *Bos taurus* and *B. indicus* cattle are used, as well as their crosses, but usually not 100% *B. taurus*, as in Colombia 100% *Bos taurus* dairy or beef cattle are raised at elevations above 2,000 masl, which are unsuitable for leucaena ISPS.

Stocking rates in Colombia range from 2.5 to 4.5 adult equivalents (AE; 450 kg dry animal)/ha. In the Caribe region, where the dry season lasts for 4–5 months, stocking rates must be adjusted seasonally, i.e. 4–6 AE/ha during the rainy season and 2–3 AE/ha during the dry season.

Animal performance and general characteristics of some farms, on which CIPAV has worked for several years, are presented in Table 1.

Beef production

Hacienda El Chaco is devoted to dairy production but in 2010 an experiment was carried out to investigate fattening of young steers in the leucaena systems (Mahecha et al. 2011; 2012a, 2012b). The results of this experiment are presented in Table 2.

Table 1. Location, system characteristics and animal performance of some farms on which CIPAV has worked over a number of years.

Farm, location	Geographical conditions, leucaena ISPS characteristics	Livestock breed composition and productive parameters
Hacienda Lucerna[1], Bugalagrande, Valle del Cauca	1,000 masl; 1,400 mm rainfall/year (AAR); 24 °C. Tropical dry forest; leucaena first established in 1991, currently 49 ha, with *C. plectostachyus* and *M. maximus* (cvv. Mombasa and Tanzania).	Dual-purpose Lucerna breed[2] (national breed); 142 milking cows producing 10.7 L milk/cow/d and 17,000 L/ha/yr; stocking rate 4.3 cows/ha; calving interval 390 days.
El Hatico[1], El Cerrito, Valle del Cauca	1,000 masl; 750 mm AAR; 24 °C. Tropical dry forest; leucaena first established in 1992, currently 64 ha, with *C. plectostachyus* and *M. maximus* (cvv. Mombasa and Tanzania).	Dual-purpose Lucerna breed; 220 milking cows producing 10 L/cow/d and 15,000 L/ha/yr; stocking rate 4.3 cows/ha; milking cows fed 3.5 kg/d of an energy supplement (rice and wheat byproducts); calving interval 395 days.
Hacienda El Chaco, Piedras, Tolima	605 masl; 1,200 mm AAR. Tropical dry forest; leucaena first established in 1992, currently 42 ha, with *C. plectostachyus.*	Tropical lowland specialized dairy. Around 75% *Bos taurus* × 25% *B. indicus* cows; 70 milking cows producing 13 L/cow/d; lactation length 296 days; stocking rate 3.5 cows/ha; calving interval 380 days.
Hacienda Asturias, La Tebaida, Quindío	1,300 masl; 1,800 mm AAR. Leucaena first planted in 2002 using seedlings, 1 m between rows and 1 m between plants within rows with *C. plectostachyus* and *M. maximus.*	50–75% *B. taurus* × 25–50% *B. indicus* cows*;* 183 milking cows producing 13 L/cow/d; stocking rate 4 cows/ha; milking cows fed 2.7 kg concentrate/d.
Hacienda El Porvenir, San Diego, Cesar	724 mm AAR. Caribe region; dry tropical forest; leucaena first established in 2006, currently 110 ha (60 ha associated with rows of *Eucalyptus tereticornis* and 50 ha with native trees).	Steers 180–250 kg achieving liveweight gains of 524 g/d; stocking rate 2.33 AE/ha.

[1]Lucerna and El Hatico farms have international organic certification and include livestock and sugar cane production.
[2]The Lucerna breed is a Colombian 100% *B. taurus* breed developed in Hacienda Lucerna as a product of a crossbreeding program started in 1937 with Holstein, Red Milking Shorthorn and Hartón del Valle (a red Criollo breed in the region, descended from cattle brought by Spanish conquerors about 500 years ago).

Table 2. Fattening of steers in the leucaena ISPS of Hacienda El Chaco[1] (Mahecha et al. 2012a; 2012b).

	LWG (g/animal/d)	Stocking rate (AE/ha)	LWG (kg/ha/yr)
Leucaena Group 1	896	3.5	1,145
Leucaena Group 2	811	3.5	1,036

[1]Performance of steers was evaluated over a period of 8.8 months. Final weight was 451 kg (average).
LWG = liveweight gain; AE = adult equivalent.

Leucaena and cow reproductive performance

Data from more than 20 years, hundreds of cows and different farms show calving intervals for cows grazing leucaena that are considerably lower than those recorded in Colombia for outstanding dual-purpose and specialized dairy farms (456 and 458 days, respectively, the national averages being 664–700 days; Gómez 2013). For example, calving rates recorded in the farms Lucerna, El Hatico and El Chaco are 390, 395 and 380 days, respectively (Table 1).

Problems and constraints

Cost of establishment

High cost of establishment has been a major constraint for scaling-up the area under the leucaena intensive silvopastoral system in Colombia and several factors contribute to these high costs. Difficult topography or lack of available machinery means some farmers use manual labor and this increases the costs of land preparation, planting and all subsequent activities required. Even where machinery is used, the machinery plus operating costs are usually high. Cost of establishment is about US $1,000 per ha, and to this must be added the infrastructure for intensive rotational grazing (paddock divisions, electric fences and a system for permanent supply of water), if these have to be constructed.

Proper management of grazing and rest periods

In rotational grazing systems, ranchers traditionally allow a rest period of about 30 days for their grass-only pastures and many find it difficult to understand or accept that a system which requires a 42–50 day rest period can be more productive than a set-stocked area, and must be managed accordingly. It has been observed that a rest period shorter than 42 days does not allow leucaena to recover properly and plants begin to progressively weaken, which can lead to the death of plants and the collapse of the whole system.

Overgrazing

Although stocking rates achieved on ISPS are significantly higher than those under traditional grass-only grazing (≥3 vs. ≤1 AE/ha), farmers often tend to increase the stocking rate beyond the capacity of the leucaena silvopastoral system they have established, and a progressive and steady process of leucaena weakening and death begins. Fine-tuning of the management has proved difficult to achieve on many farms, and long-term and good-quality technical assistance is required.

Leucaena is not invasive

CIPAV has worked with leucaena for more than 25 years, not only in Colombia but also in other countries like Brazil, Nicaragua (Zapata Cadavid et al. 2010) and Mexico (Mahecha et al. 2012a). No cases of leucaena weediness have been observed (Calle et al. 2011). While leucaena is invasive in disturbed areas like degraded lands or roadsides, it has not been observed to invade undisturbed ecosystems. This observation is in accordance with findings of Costa and Durigan (2010) in Brazil.

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(Note of the editors: All hyperlinks were verified 11 August 2019.)

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The inclusion of *Leucaena diversifolia* in a Colombian beef cattle production system: An economic perspective

Leucaena diversifolia *en un sistema de producción ganadera en Colombia: Una perspectiva económica*

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Abstract

Despite the great potential of legumes in cattle production, their adoption and use throughout the tropical world remain limited. While this is largely attributed to factors such as limited knowledge or access to credit, lack of information on the viability and profitability of the technology can influence the adoption decision. The objective of this study is to evaluate the profitability of including *Leucaena diversifolia*, accession ILRI 15551 in a Colombian beef cattle production system. For this purpose, we use data from a grazing experiment comparing a grass-legume association (*Brachiaria* hybrid cv. Cayman and *L. diversifolia*) with a grass monoculture (cv. Cayman) in the Valle del Cauca department, both with the purpose of beef production. We use a discounted cash flow model, developed with the simulation software @Risk, which considers inherent risk and uncertainty factors in these types of rural investment projects, under three different pasture degradation scenarios. The results indicate that the inclusion of *L. diversifolia* is financially profitable and substantially improves the associated risk and performance indicators. Profitability indicators increased in a range of 15–110%, and the probability of suffering economic losses decreased from 72% to 0%. The results were directly related to the increases in animal productivity (49%) and efficiency resulting from including the legume. This work shows that *L. diversifolia* has significant potential to increase both animal production and profitability, which is conducive to the sustainable intensification of beef production in grazing systems.

Keywords: Grass-legume systems, Monte Carlo simulation, risk analysis, shrub legumes, sustainable intensification.

Resumen

A pesar del gran potencial de las leguminosas para la producción ganadera, su adopción y uso siguen siendo limitados. Mientras que esto se atribuye en gran medida a factores como el conocimiento limitado o falta de acceso a crédito, también la información faltante sobre la viabilidad y rentabilidad de la tecnología puede influir en la decisión de adopción. Este estudio tiene como objeto evaluar la rentabilidad de la inclusión de *Leucaena diversifolia* accesión ILRI 15551, en un sistema de producción de ganado de carne, basado en el pasto *Brachiaria* híbrido cv. Cayman (Cayman), en el Departamento del Valle del Cauca, Colombia. Se usaron datos de un experimento de pastoreo para comparar la asociación Cayman-*L. diversifolia* con el monocultivo de Cayman. Se aplicó la metodología de flujo de caja libre descontado y un análisis de simulación Monte Carlo con el software de simulación @Risk, con el fin de incluir los factores de riesgo e incertidumbre en las variables identificadas como críticas, bajo tres escenarios de persistencia de las pasturas. Los resultados indican que la inclusión de *L. diversifolia* es financieramente rentable y permite mejorar sustancialmente todos los indicadores de riesgo y desempeño. Los indicadores de rentabilidad incrementaron en un rango del 15 al 110%, y la probabilidad de obtener pérdidas económicas pasó del 72.1 al 0%. Los resultados estuvieron directamente relacionados con el incremento en la productividad animal (49%) y eficiencia resultantes de la inclusión

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de la leguminosa. Este trabajo muestra que *L. diversifolia* tiene un potencial significativo para aumentar tanto la producción animal como la rentabilidad, lo cual es propicio para la intensificación sostenible de la producción de carne en sistemas bajo pastoreo.

Palabras clave: Análisis de riesgo, intensificación sostenible, simulación Monte Carlo, sistemas gramínea-leguminosa.

Introduction

The forage-based cattle sector plays a key role in tropical food production, food security and poverty alleviation (Peters et al. 2013; Capstaff and Miller 2018). However, along with the benefits, negative consequences on the environment can occur. Globally, it has been estimated that the sector contributes 14.5% of all anthropogenic greenhouse gas (GHG) emissions, mainly as methane (CH_4) from the enteric fermentation process (Gerber et al. 2013). In addition, the sector is being associated with problems of land degradation, deforestation, water pollution and depletion, and loss of biodiversity (Steinfeld et al. 2009). Under this perspective, and in the context of: scarce resources; increased global demand for food; and climate change (FAO 2017), governments, NGOs and other organizations have developed strategies to mitigate the sector's environmental impacts, increase its efficiency and improve its productivity. In this regard, improvements in animal feeding and sustainable intensification are considered to be among the most promising strategies to date (Gerber et al. 2013; FAO 2017).

Given this panorama, the inclusion of forage legumes in cattle production systems has the potential to achieve the aforementioned objectives. Firstly, legumes can increase both yield and nutritional value of the forage, and improve the efficiency in converting forage to animal protein (meat/milk) (Lüscher et al. 2014). Secondly, legumes can reduce enteric CH4 emissions from ruminants (Harrison et al. 2015) and increase the levels of nitrogen (N) in the soil through biological N fixation (Dubeux et al. 2017). For example, studies show that, when *Leucaena leucocephala* is sown into grass pasture, CH_4 emissions per kg of consumed dry matter can be reduced by 15% (Molina et al. 2016) and more than 75 kg N/ha/yr can be fixed (Shelton and Dalzell 2007). Other environmental benefits include: the improvement of soil fertility and carbon accumulation (Rao et al. 2015); the potential for mitigation of and adaptation to climate change (Schultze-Kraft et al. 2018); and a contribution to rehabilitating degraded pastures (Plazas and Lascano 2006).

Despite the great potential of tropical legumes in cattle production, their adoption and use by producers remain limited (Shelton et al. 2005). Among the limiting factors for widespread use are: economic factors that determine access to capital (e.g. size of the productive unit, access to credit); lack of knowledge and limited perceived benefits by the producer (Thomas and Sumberg 1995; Wortman and Kirungu 2000; Lapar and Ehui 2004); and aspects associated with risk aversion and uncertainty (Feder 1980; Marra et al. 2003). A key aspect for successful adoption of an innovation is personal sustainability, i.e. adoption will not occur unless the economic benefits of adopting exceed the costs for technological investment (Carey and Zilberman 2002; Pannell et al. 2006). Although adoption levels of forage legumes are still low in the tropics, some successful examples from different continents were reported by Shelton et al. (2005), highlighting their profitability and multipurpose benefits to farmers. However, this type of information is often scarce, making the decision making process difficult for the producer. Therefore, it is important to perform economic evaluations to generate information about the viability and profitability of the desired technology.

The objective of this study was to evaluate the profitability of including *Leucaena diversifolia* in a Colombian cattle production system. For this purpose, we compared a grass-legume association (*L. diversifolia* in a *Brachiaria* hybrid cv. Cayman pasture) with a grass monoculture (Cayman) in the Valle del Cauca department, Colombia, both with the purpose of beef production. The methodology is based on a discounted cash flow model, developed with the simulation software @Risk, and considers the inherent risk and uncertainty factors in these types of rural investment projects. The results provide a mechanism for improving the quality of the decision making process regarding adoption of legumes for cattle production systems.

Materials and Methods

Data source and study area

The data used in this study were obtained from field evaluations of: a) Cayman as a monoculture; and b) a Cayman-*L. diversifolia* association, carried out by the Tropical Forages Program at the facilities of the International Center for Tropical Agriculture (CIAT) in Palmira, Valle del Cauca, Colombia. The ecological classification of the study area, according to Holdridge (1967), corresponds to a pre-montane wet forest (bh-P), located at 1,001 masl, with average temperature, relative humidity and annual precipitation of 23.8 °C, 75% and 1,045 mm, respectively and a bimodal rainfall regime (March–April and October–November). The experiment was established on a fertile Mollisol with clayey texture (clay content between 40 and 60%; Howeler 1986), good drainage, pH (H_2O) 7.54, organic matter 4.85%, CEC 16.4 cmol/kg, P concentration 25 ppm and Ca, Mg and K concentrations 7.87, 6.17 and 0.82 cmol/kg, respectively. The pastures were established in August 2013 and until grazing commencement were maintained by cutting at 6 week intervals. Grazing was between August 2014 and August 2015, using 10 Colombian half-blood steers (zebu × Holstein, zebu × Normande, zebu × Jersey); liveweight gains were measured monthly. The steers were 12 months old and weighed 210±25 kg (±SD) at the start and 416 ±28 kg at the end of the evaluation. The data related to the costs were compiled using economic information collected during the establishment of the trial, and adjusted with the help of Colombian forage and livestock experts to avoid overestimation for research reasons. The prices were later updated to 2018 levels, according to the price bulletins of the Colombian Price Information System for the Agricultural Sector (SIPSA) and the Colombian Cattle Federation's (FEDEGAN) databases.

Description of the treatments

The treatments were: T1) Cayman monoculture (100%); and T2) Cayman-*L. diversifolia* association (in a proportion of 70:30 of DM at the beginning of the trial). Each treatment had an area of 9,900 m^2, divided into 3 plots of 3,300 m^2, under an experimental design of a randomized complete block. Each plot was divided with electric fences into 3 sub-plots of 1,100 m^2. The animals grazed under a rotational system with 6 days of occupation and 48 days of rest for each sub-plot. For T2, 2,000 *L. diversifolia* plants/ha had been established and distributed in twin rows separated by a distance of 8 m. The twin rows were separated by a distance of 1.5 m, and distance between plants within rows was 1 m. The initial stocking rate (SR) for both treatments was 2.3 animal units (AU = 450 kg) per hectare and by the end of the evaluation year SRs were 3.36 AU for T1 and 4.04 AU for T2. It is important to point out that during the time of the evaluation, observations on the selective behavior of the animals showed a high acceptance in the consumption of the legume. This explains, partly, the high liveweight gains and animal production in T2 (Table 1). Other factors contributing to the generally high forage and livestock production values are high soil fertility and the fact that the measurements refer to the initial 1–2 years of this production systems comparison trial.

Table 1. Forage dry matter production, nutritional quality and animal response data over 1 year for a *Brachiaria* hybrid cv. Cayman monoculture (T1) and a Cayman-*L. diversifolia* association (T2).

Parameter	Variable	T1		T2	
		(Mean ± SD)	CV (%)	(Mean ± SD)	CV (%)
DM production	Tonnes DM/ha/yr	22.5		32.2	
Nutritional quality	Protein (%)	6.7		8.25 (Cayman) 26.7 (*L. diversifolia*)	
	IVDMD (%)	65.5		64.9 (Cayman) 58.6 (*L. diversifolia*)	
Animal response	Mean stocking rate (AU/ha)	3.36		4.04	
	Weight gain (g/hd/d)	440 ± 41	9.3	657 ± 73	11.2
	Liveweight production (kg/ha/yr)	723 ± 68	9.3	1,078 ± 120[1]	11.2
	Time to reach sale weight (months)[2]	18		12	

DM = Dry matter; IVDMD = In vitro dry matter digestibility; AU = 450 kg animal.
[1]Statistically different at P<0.01.
[2]Period of time required to bring a calf with an average weight of 200 kg to a sale weight of 450 kg.

Economic risk and sensitivity analyses

The economic evaluation is based on a discounted cash flow model for the estimation of financial profitability indicators capable of measuring the viability of the 2 treatments. The evaluated indicators include the internal rate of return (IRR), net present value (NPV), cost:benefit ratio (C:B) and payback period. The evaluation was made based on the principles established by Park (2007) for each indicator. In addition, the minimum profitable area required to generate 2 integral Colombian Basic Salaries (CBS) on a monthly basis during the 10 year evaluation horizon (1 integral CBS = US$ 469/month in 2018) was estimated as an indicator for smallholder producers, who normally experience strong resource limitations.

The model includes a systematic categorization of the variable costs and the benefits associated with the 2 evaluated treatments. Specifically, the following categories of costs per hectare were considered: total cost of establishment; costs of renewal and maintenance of each treatment; capital opportunity costs during the establishment period for both treatments (T1: 3 months, T2: 8 months); and operational costs (e.g. purchase of animals, animal health, mineral supplementation, labor costs for permanent and occasional staff). The benefits derived from beef production in a cattle raising and fattening system, according to the animal response indicators, are presented in Table 1. The evaluation horizon for both treatments was 10 years, according to the lifespan of the grass (Holmann and Estrada 1997). Although it has been shown that *L. leucocephala* can remain productive for periods longer than 30 years in other regions of the tropics and subtropics (Jones and Bunch 1995; 2000), we decided to maintain a conservative scenario for T2, given the lack of data and information on the persistence of *L. diversifolia* in the specific study area. Additionally, a discount rate of 12%, and constant prices and flows for each treatment according to the respective release and fattening periods (T1: 18 months; T2: 12 months) were assumed for constructing the cash flow.

In order to include risk and uncertainty levels in the variables identified as critical for the model and to consider different scenarios, a quantitative risk analysis was carried out by running a Monte Carlo simulation in the software @Risk (Paladise Corporation). In such a simulation, random input variables are identified and represented by means of probability distributions, to later calculate the profitability indicators (outputs of the model). This process is repeated numerous times to obtain the probability distributions of these outputs (Park 2007). For this analysis 5,000 simulations were carried out for 3 pasture persistence scenarios and the following variables were randomly combined: liveweight gain/animal/year; investment costs; maintenance costs; sale price per kg live weight; and purchase price per kg live weight. For the 2 price variables, a correlation coefficient of 0.89 was determined. The simulation used a confidence level of 95%. Table 2 shows the probability distributions for the input variables.

Table 2. Probability distributions for input variables, parameters and risk factors.

Variable	Treatment	Distribution	Parameters			Distribution adjustment	Randomness
			p1	p2	p3		
Liveweight (LW) gain (kg/hd/yr)	T1	Pert (a,b,c)	139	161	174	Judgment of the researcher according to the availability of data and behavior of the variable according to literature (Gutiérrez et al. 2009).	Interaction between decision variables (e.g. type of feeding) and non-controlled ones (e.g. climatic conditions).
	T2	Pert (a,b,c)	205	239	268		
Sale price (US$/kg LW)[1]	T1 & T2	Lognormal (μ,σ)	1.64	0.33		Based on the best historical data adjustment, using the Akaike information criterion (AIC; Akaike 1974).	Varies as a result of factors associated with the supply and demand of the market.
Purchase price (US$/kg LW)[2]	T1 & T2	Lognormal (μ,σ)	1.36	0.22			
Investment costs (US$/ha)	T1	Triangular (a,b,c)	586	689	794	This distribution is recommended to specify situations that involve costs and investments.	Vary depending on the specific place where the establishment is made (e.g. the amount of tillage and level of fertilizer applied are determined by soil characteristics and rainfall regime) (Rincón and Caicedo 2010).
	T2	Triangular (a,b,c)	941	1,106	1,272		
Maintenance costs (US$/ha)	T1	Triangular (a,b,c)	134	148	163		
	T2	Triangular (a,b,c)	102	114	123		

a,b,c: minimum, most probable and maximum value, parameters of the Triangular and Pert distributions. [1]Exchange rate used: 1 US$ = 2,800 Colombian Pesos (COP). [2]Historical data taken from FEDEGAN (2018).

In both treatments, application of maintenance fertilizer and pasture renewal were assumed for Year 5 in T1 and Year 7 in T2, in order to maintain the level of production during the defined evaluation horizon. However, animals can cause physical damage to the legume or grass which can affect production. To include this factor in the model, 3 treatment persistence scenarios were built. These were determined by considering 3 annual degradation rates that decrease the total forage supply and therefore the carrying capacity. The rates were estimated according to criteria provided by several forage experts, under the assumption of adequate management in terms of fertilizer application, rotation and rest of the pasture, as follows: for T1 at 1% (S1), 3% (S2) and 8% (S3); and for T2 at 1% (S4), 3% (S5) and 5% (S6). In T2, the maximum rate of degradation is assumed to be lower than for T1, given the constant supply of N to the pasture contributed by the legume through the process of atmospheric N fixation. It should be noted that both the simulations and risk indicators do not capture effects of extreme (climatic) events or losses due to an extraordinary incidence of pests and diseases.

As decision criteria, the mean value and the variations of the obtained profitability indicators were used, as well as the probability of success (NPV<0). The use of the mean value criterion is based on the law of large numbers, which states that, if many repetitions of an experiment are made, the average result will tend toward the expected value (Park 2007). On the other hand, sensitivity and scenario analyses were carried out in order to identify those variables with the strongest effects on the profitability indicators within the total set of variables defined as critical. The variables identified in the previous analyses were studied individually by means of a stress analysis, where the values of the distribution are restricted to the 10th percentile, and through which the changes in the NPV indicator were identified.

Results

The two treatments were compared in terms of their economic performance, considering the uncertainty of random variables identified for the estimation of profitability indicators. Table 3 shows the main results associated with the costs and income for each treatment. The costs of establishing T2 are 60% higher than those for T1. However, the evidenced animal production indicators for T2 allowed average annual increases per hectare of 66% in gross income and 119% in net profit, when compared with T1.

Table 3. Costs and income for fattening steers on *Brachiaria* hybrid cv. Cayman pasture (T1) and a Cayman-*L. diversifolia* association (T2).

Parameter	T1	T2
Investment costs		
Establishment of pasture (US$/ha)[1]	689	1,107
Pasture renewal (US$/ha)[2]	211 (Year 5)	153 (Year 7)
Electric fence (US$/ha/yr)[3]	750	752
Purchase of animals (US$/ha/cycle)	1,071	1,253
Operational costs		
Pasture maintenance costs (US$/ha)[4]	148	209
Permanent labor (US$/ha/yr)[5]	623	622
Animal health (US$/ha/yr)	20	22
Supplementation (US$/ha/yr)[6]	87	86
Gross income (US$/ha/yr)	2,190	3,199
Unit cost of production (US$/kg)[7]	1.2	1.21
Net income (US$/ha/yr)[8]	356	695

[1]For establishment, herbicide application and mechanical soil tillage were carried out. The sowing rate of Cayman was 8 kg/ha with a level of fertilizer of N, P, K, Mg and S of 100, 22, 41.5, 20 and 20 kg/ha, respectively. Two thousand *L. diversifolia* plants were established per ha. [2]Includes maintenance fertilizer, soil 2x plowing and replanting of Cayman at a sowing rate of 2 kg/ha. [3]Electric fence for a rotational grazing system. [4]Maintenance is carried out every 2 years and includes weed control, fertilizing with half the dose used for establishment (no N fertilizer in T2), and pruning of *L. diversifolia*. [5]Estimated: 2.5 permanent jobs required for every 100 animals in a cattle raising and fattening system (FEDEGAN 2018), and a legal minimum wage in force plus benefits in 2018 of US$ 469/month. [6]Supplementation with mineralized salt at a rate of 100 g/hd/d. [7]Unit cost of production: dividing total cost of the product by total production. [8]Net income: total income (sale price x yield) minus total costs.

The summary of the main financial results of the simulation for both treatments is presented in Table 4. The results suggest that the inclusion of *L. diversifolia* is financially profitable and would improve all risk and performance indicators when compared with Cayman as monoculture. The model shows a positive mean NPV for T2 that, according to the pasture degradation scenario, varies between US$ 1,716 and US$ 2,055, and an internal rate of return (IRR) to own resources of around 21%. In addition, the superior productive indicators for T2 allow reduction in the minimum profitable area required to generate 2 Colombian basic salaries from 6.54 ha to 3.76 ha, as well as reducing the payback period from 6 to 4 years. T1 shows a higher NPV variability than T2.

With regard to the probability of finding that the evaluated treatments were not financially feasible, Figure 1 shows the distributions for the NPV indicator, which reflects the amplitude of the variation for the NPV indicator. For T1, the indicator ranges from negative values close to US$ 1,506, to positive values close to US$ 948, with 72% probability of obtaining negative values. For T2, the inclusion of *L. diversifolia* shifts the distribution curve to the right, reducing the probability of losses to 0%, with values ranging from -US$ 61 to US$ 4,145.

Table 4. Summary of profitability indicators of the simulation model for fattening steers on *Brachiaria* hybrid cv. Cayman pasture (T1) and a Cayman-*L. diversifolia* association (T2).

Decision criterion	Indicator	T1			T2		
		Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
NPV (US$)	Mean[1]	(288)	(342)	(473)	2,055	1,881	1,716
	SD[2]	447	434	404	697	673	651
	CV	1.55	1.26	0.85	0.34	0.36	0.38
	CI (95%)[3]	(1,135)–558	(1,165)–481	(1,239)–292	743–3,389	610–3,172	484–2,965
IRR (%)	Mean	11	11	10	22	21	21
	CI (95%)	4–15	4–15	4–14	16–28	15–28	15–27
Benefit:Cost[4]	Mean	0.98	0.97	0.96	1.13	1.12	1.12
	CI (95%)	0.9–1.05	0.9–1.04	0.89–1.03	1.05–1.22	1.04–1.21	1.03–1.20
Payback period (years)	Mean	6	6	6	4	4	4
	CI (95%)	3–8	3–8	3–8	3–5	3–5	3–5
Minimum area (ha)[5]	Mean	6.54			3.76		

[1]Mean value of the NPV obtained in the simulation (5,000 iterations). [2]SD: Standard deviation of the NPV with respect to the mean value. [3]CI: Minimum and maximum values with a 95% confidence interval. [4]Quotient between benefits and discounted costs. [5]Minimum area (in ha) required for generating 2 basic Colombian salaries.

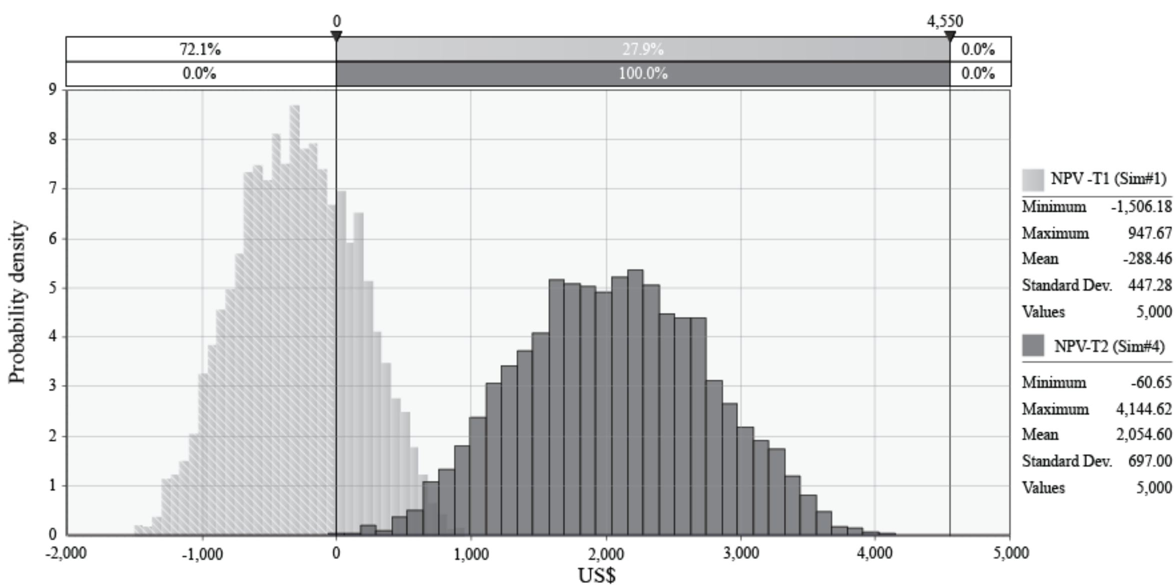

Figure 1. Probability and cumulative density distributions for NPV for fattening steers on *Brachiaria* hybrid cv. Cayman pasture (T1) and a Cayman-*L. diversifolia* association (T2).

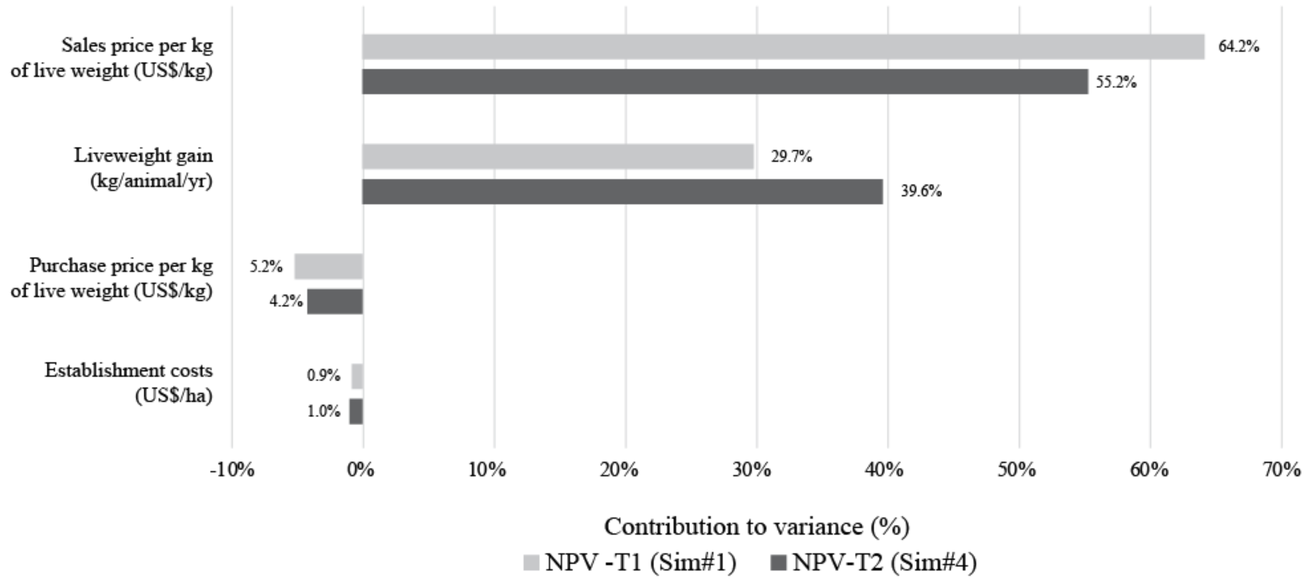

Figure 2. Contributions of random input variables to the variance of the NPV for fattening steers on *Brachiaria* hybrid cv. Cayman pasture (T1) and a Cayman-*L. diversifolia* association (T2).

The contribution of the input variables to the variance of the NPV is shown in Figure 2. The calculated correlation coefficients show that profitability is affected primarily by 2 variables: sale price per kg of live weight; and animal production. Increases in these variables have an effect on the variability in the forecast of the indicator as follows: Changes in sale price per kg of live weight lead to changes in the variance of 64.2% for T1 and 55.2% for T2. Similarly, changes in animal production modify the variance of the indicator by 29.7% for T1 and 39.6% for T2. When conducting a stress analysis in the 10th percentile for the 2 variables at the same time, negative changes with respect to the mean value of the NPV indicator can be observed for T1 (335%) and T2 (57%).

Discussion and Conclusions

The inclusion of *L. diversifolia* in a grazing system for beef production improved the productive and economic performance indicators under different scenarios of animal production and market conditions. In productive terms, the association of Cayman and *L. diversifolia* increased animal production by 49%, compared with a Cayman monoculture. The results are consistent with various experimental studies in a wide range of environments, which demonstrate the ability of *Leucaena* spp. to improve production and profitability in the tropics (Kennedy and Charmley 2012; Peck et al. 2012; Harrison et al. 2015). For example, in northern Colombia, associations of *L. leucocephala* with grass have been shown to increase animal production per hectare by 110%, a result of increased liveweight gain per animal (56.6%) and carrying capacity (43.4%), when compared with improved grass monoculture (Gaviria et al. 2012). In Queensland, Australia, liveweight gains on buffel grass (*Cenchrus ciliaris*)-*L. leucocephala* pastures were 38% higher than on buffel grass alone (Walton 2003).

However, these studies have been carried out mainly with different accessions of the species *L. leucocephala*, which has been widely acknowledged as having excellent yield and high forage quality leading to high liveweight gains in cattle, compared with other species of *Leucaena* (Lefroy 2002). For example, evaluations at Lansdown, north Queensland, Australia found differences in daily animal liveweight gains between *L. diversifolia* (532 g) and *L. leucocephala* (694 g), which were associated with greater in vitro dry matter digestibility and lower levels of condensed tannins in *L. leucocephala* (Jones et al. 1998). However, *L. diversifolia* has shown a greater range of adaptation to different edaphoclimatic conditions than *L. leucocephala*, in particular to higher soil acidity and cooler temperatures (Peters et al. 2011), allowing a wider use in tropical and subtropical regions.

In terms of animal response indicators, T2 showed superior performance to T1, which translates into better financial performance in all 3 evaluated degradation scenarios. The profitability of the system is improved when

L. diversifolia is associated with Cayman. These results are comparable with values reported in other studies, which have identified the potential of legumes to improve cattle profitability, livelihoods and resource use efficiency (Muir et al. 2017). In Queensland, *L. leucocephala* has been identified as the most productive and profitable legume, increasing liveweight production (both per hectare and per animal) by 2.5 times and doubling the gross margin/ha, when compared with perennial grasses (Bowen et al. 2016). At the regional level in Queensland, economic benefits from the adoption of *L. leucocephala* have been estimated to be more than US$ 69 million/yr for 2006 in a planted area of 150,000 ha (Shelton and Dalzell 2007). Profitability evaluations in Costa Rica, Michoacán (Mexico) and the Colombian Caribbean region report an IRR that oscillates around 33% for a *L. leucocephala*-grass association (Jimenez-Trujillo et al. 2011; González 2013; Murgueitio et al. 2015). The productive and economic indicators of sowing *L. diversifolia* presented in this study are a fundamental input to the discussion on how to reduce the need for expansion of land area required for agricultural production (FAO 2017), and show that *L. diversifolia* can become a potential option for sustainable intensification and for reducing the pressure on natural resources.

Improvements in the profitability indicators when including *L. diversifolia* in the system demonstrate a reduction in the risk of economic loss and less variance in changes in critical variables. In particular, the results of the sensitivity analysis showed that changes in the sale price of meat have stronger impacts on the profitability indicators for the Cayman monoculture, which suggests increased risk with respect to market conditions that cause price decreases. Although the price risk is also present after including *L. diversifolia*, it is much lower and this might be a key factor in encouraging adoption, since farmers, being naturally rather risk-averse (Marra et al. 2003), will most likely favor technologies with a relatively lower variance. In addition, its higher stability over the years in terms of forage production and the higher protein concentration, especially in dry seasons, compared with a grass monoculture (Tedonkeng Pamo et al. 2007), allow for stronger persistence and result in less variability when it comes to indicators of production.

In addition to the increased production and profitability highlighted in this research, several other studies have shown improvements in meat quality when *Leucaena* is being used. For example, Montoya et al. (2015) found that animals from systems incorporating *L. leucocephala* produced meat with superior tenderness, better pH and color, as well as higher carcass weights, when compared with animals from traditional grazing systems. Such quality attributes could contribute to product differentiation strategies and price premiums and therefore promote the adoption of legumes. We recommend that these additional benefits be included in the evaluation of legume-based cattle fattening systems. As mentioned in this paper, the inclusion of legumes also leads to important environmental benefits in the cattle system, such as the reduction of enteric methane emissions (Campbell et al. 2014) and overall greenhouse gas emissions (Kennedy and Charmley 2012; Harrison et al. 2015). These, among others, represent significant environmental benefits with economic and welfare impact at society level. We recommend that environmental benefits be included in future economic evaluation studies.

The authors of this research are aware that the data reported were obtained in an experiment under controlled conditions both in terms of animal and pasture management, following expert recommendations and constant monitoring schemes. This has to be taken into account when replicating the trial. Alterations to the reported values might occur under different settings and more so under real farming conditions, depending on the region, climate or soil conditions, animal breeds, or animal and pasture management, among others.

In conclusion, this study indicates that investing in the establishment of legumes in grass-legume associations, such as *L. diversifolia*, turns out to be a valuable option for improving both efficiency and profitability of the production system, and thus can contribute in a positive way to producer welfare. Providing livestock producers with such information is a first step towards overcoming barriers to technology adoption, i.e. towards decreasing the misconception by producers that there are limited benefits from planting pasture legumes (Shelton et al. 2005). However, for broader adoption to occur, providing this type of information on its own is not sufficient; improvements in the framework conditions are also needed. The establishment of such systems should be accompanied by specific training and extension programs, which in many cases would need to be developed (e.g. in the Colombian context), to overcome the lack of knowledge and experience in the use of tropical forage legumes. This should reduce uncertainties associated with technology adoption and increase adoption rates. At the same time, the access to and structure of necessary financial resources (e.g. credits), as well as the availability and access to seed or vegetative material, need to be improved in order to provide the necessary resources for technology adoption. This holds true especially for Colombia, where credit schemes do not respond to the producer reality (i.e. no credits available for pasture improvement, too short grace periods in livestock credits) and where a well-functioning legume seed system is non-existent.

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ILC2018 Keynote Paper*

Feeding leucaena to dairy cows in intensive silvopastoral systems in Colombia and Mexico

Leucaena como alimento para vacas lecheras en sistemas silvopastoriles intensivos en Colombia y México

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Abstract

The demand for milk and dairy products globally is expected to grow in future decades, leading to an increase in the global dairy cattle population. Therefore it is important to identify production options that both improve efficiency and help reduce negative effects on the environment. Intensive silvopastoral systems have been proposed as a sustainable strategy in the tropics to increase the availability and quality of forage throughout the year for milk production from cattle. This paper reports the effects of silvopastoral systems that include leucaena at the farm level on milk production and on the environment in both Colombia and Mexico. Evaluation of different milk production systems has shown that the leucaena-based systems increased milk production both per cow and per hectare, increased the production of milk solids, improved the fatty acid profile in the milk and resulted in environmental benefits when compared with conventional systems.

Keywords: Cattle, environmental benefits, grazing, milk solids, profit, tree legumes.

Resumen

Se espera que la demanda de leche y productos lácteos a nivel mundial crezca en las próximas décadas, lo que llevará a un aumento de la población de ganado lechero en todo el mundo. Debido a esto, es importante identificar opciones de producción ganadera que mejoren la eficiencia y ayuden a reducir los efectos negativos sobre el medio ambiente. En las últimas décadas, se han propuesto los sistemas silvopastoriles intensivos como una estrategia sostenible en el trópico para aumentar la disponibilidad y la calidad del forraje durante todo el año para la producción de leche bovina. Este documento informa sobre los efectos de los sistemas silvopastoriles con leucaena a nivel de finca sobre la producción de leche y cómo estos pueden ser más amigables con el medio ambiente en Colombia y México. La evaluación de diferentes sistemas de producción de leche ha demostrado que los sistemas basados en leucaena aumentan la productividad tanto por unidad animal como por unidad de área, aumentando de igual forma la producción de sólidos lácteos, mejoran el perfil de ácidos grasos en la leche y aportan beneficios ambientales en comparación con los sistemas convencionales.

Palabras clave: Beneficios ambientales, ganado bovino, leguminosas arbóreas, pastoreo, rentabilidad, sólidos en leche.

Introduction

It is projected that the world's demand for animal protein will continue to grow during future decades as a result of increases in global population, income per capita and the percentage of people living in urban areas (Alexandratos and Bruinsma 2012). In particular the demand for milk and dairy products is expected to grow by 58% between 2010 and 2030, and world milk production is projected to increase by 177 Mt (23%) by 2025 compared with the

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base years (2013–15), corresponding to an average growth rate of 1.8% per annum (OECD/FAO 2017).

To achieve these production levels an increase in world milk production of 35% or 300 Mt will be required. Therefore, it is important to identify livestock production systems that improve efficiency and reduce negative effects on the environment while fulfilling the demand for good quality food in an economically efficient manner (Thornton and Herrero 2010).

Intensive silvopastoral systems (ISPS) have been advanced as sustainable strategies in the tropics to increase the availability and quality of forage throughout the year for milk production from cattle (Chará et al. 2017). In addition, these systems are claimed to reduce or reverse the negative environmental impacts of cattle ranching, while increasing animal production and economic performance. With these systems it is also possible to certify milk and cheese as organic products (Nahed-Toral et al. 2013), thereby justifying improved prices (Solís-Méndez et al. 2013). For example, some leucaena-based systems in Colombia have been certified organic for more than 20 years, with milk products such as long-life milk without additives in either the milk or the animal diet.

This paper reports the effects of ISPS with leucaena (*Leucaena leucocephala*) on milk production and environmental outcomes at the farm level. For more than 20 years in Colombia, different systems of milk production have been evaluated. The leucaena-based systems have increased milk production per cow and per hectare, increased the production of milk solids and improved the fatty acid profile of milk, when compared with conventional systems (Rivera et al. 2009; Prieto-Manrique et al. 2018).

ISPS are a type of silvopastoral system that combines high-density cultivation of fodder shrubs (4,000–40,000 plants/ha) with: (i) improved tropical grasses; and (ii) tree or palm species at densities of 100–600 trees/ha. These systems are rotationally grazed for periods of 12–24 hours followed by 40–50 day resting periods (Chará et al. 2017) (Figures 1 and 2). On the other hand, typical traditional systems in Colombia are characterized by: low stocking rates (fewer than 0.6 AU/ha; AU = 450 kg dry animal), the use of grass monocultures, low biomass and animal production, low fodder quality and low animal reproductive performance (González et al. 2015).

Intensive silvopastoral systems with *Leucaena leucocephala* for milk production

In the Valle del Cauca department in Colombia for example (El Hatico farm), ISPS with *L. leucocephala* interspersed with highly productive improved pastures (*Megathyrsus maximus* and *Cynodon plectostachyus*), native multipurpose trees and palms (25–100 trees/ha) have been evaluated for many years (Figure 3).

Figure 1. ISPS with leucaena, *Cynodon plectostachyus* and *Megathyrsus maximus* grazed by Brahman breed animals in a dual-purpose system. El Porvenir, Cesar, Colombia. (Photo: Claudia Córdoba)

Figure 2. ISPS with leucaena with more than 20 years of continuous production. El Chaco, Tolima, Colombia. (Photo: Julián Rivera)

Figure 3. ISPS with leucaena and *Megathyrsus maximus* grazed by Lucerna breed animals in a tropical dairy system. El Hatico, Valle del Cauca, Colombia. (Photo: M. Kohut)

After establishing the silvopastoral system, there was an increase in both quantity and quality of forage. Forage dry matter (DM) production increased by an average of 17% compared with the initial situation (a grass monoculture with fertilizer application and irrigation, concentrate feed use and high production costs). Although leucaena shrubs planted at high density directly produced only 20% of the total DM/yr, through their N contribution, total DM production in the ISPS increased from 24 to 36 t/ha/yr. Thus, this system can produce up to 47% more biomass than treeless pastures (Calle et al. 2013; Gaviria et al. 2015). By incorporating leucaena and scattered trees on El Hatico farm, the use of chemical fertilizers was eliminated from the grazing system, which once relied on the application of 400 kg urea/ha/year (equivalent to 184 kg N). Average milk production was maintained at 12,000 L/ha/yr for more than 20 years without relying on the use of concentrate feeds (Calle et al. 2013).

Another example is Lucerna farm, where in the 1990s African star grass (*Cynodon plectostachyus*) monocultures supported a stocking rate of 3.5 cows/ha and produced 9,000 L milk/ha/yr, but required N fertilizer application (450–500 kg urea/ha/yr). Since converting to ISPS with 10,000 *L. leucocephala* shrubs/ha, the same farm now supports up to 4.5 cows per hectare, produces 15,000 L milk/ha/yr and requires no fertilizer or concentrate feeds on areas that have had 28 years of continuous production (Chará et al. 2017; Rivera-Herrera et al. 2017).

In the Colombian dry Caribe region, Rivera et al. (2009) reported production of 5,551 L milk/ha/yr in ISPS with leucaena (10,000 shrubs/ha), *C. plectostachyus* and *M. maximus* (Figure 1) but only 1,150 L milk/ha/yr in a conventional grass pasture without trees. In Brazil, Paciullo et al. (2014) reported that incorporating leucaena in *Urochloa decumbens* pasture increased milk production from 9.5 to 10.4 L/cow/d ($P<0.05$).

The concentrations of protein, fat and total solids in the milk from ISPS were significantly higher ($P<0.05$) than from pure grass pastures with yields of 0.15 vs. 0.13 kg/cow/day, 0.22 vs. 0.17 kg/cow/day and 0.59 vs. 0.51 kg/cow/day for the ISPS and conventional system, respectively (Rivera et al. 2009). Another benefit leucaena offers is the modification of the fatty acid profile of the milk. Prieto-Manrique et al. (2018) observed that cows in ISPS produced higher amounts of polyunsaturated fatty acids than cows in conventional systems fed grass plus concentrates. Unsaturated fatty acids such as c9t11 conjugated linoleic acid, t11 transvaccenic acid and some long-chain n-3 fatty acids in bovine milk are associated with human health benefits, e.g. reduced incidence of heart disease (Livingstone et al. 2012).

With the higher milk solids from ISPS, the characteristics of the milk produced allow for increased yields of dairy products and improved efficiency in the transformation of milk to cheese, when compared with milk produced by animals fed grass plus sorghum grain (Mohammed et al. 2016). In spite of using lower supplementation, the ISPS did not differ from the conventional system regarding production, according to Mohammed et al. (2016), who also indicated higher profitability in the system with leucaena. González (2013) estimated internal rates of return (IRR) of 13% in systems involving leucaena and only 0.7% in conventional systems in Mexico and Colombia. In World Animal Protection et al. (2014), it is reported that once the system is established, maintenance costs are lowered due to the reduction in external inputs such as fertilizers, mineralized salts and concentrate feeds. After the initial investment and a stabilization period, the higher productivity per hectare generates returns that ensure the economic viability of ISPS. Analyzing financial data identified that, after the 4th year, income exceeds costs resulting in a positive balance in cash flow, achieving situations of economic surplus. For this study, farm income and profitability were 56 and 72% higher, respectively, than those of the traditional system (grass monoculture with high concentrate feed use) (Reyes et al. 2016).

Finally, with respect to environmental issues, Rivera et al. (2016) found lower emissions of greenhouse gases (GHG) from ISPS involving leucaena and *C. plectostachyus* rotationally grazed (1 day grazing and 28 days rest) than from a conventional system. To produce one kg of fat-and-protein-corrected milk (FPCM), the ISPS emitted 12.3% less GHG (2.05 vs. 2.34 kg CO_2-eq). Regarding the use of non-renewable energy, the ISPS required only 63% of the energy used in the conventional system to produce one kg FPCM (3.64 vs. 5.81 MJ/kg). In the context of climate change, systems with leucaena can produce milk more consistently in times of severe drought, e.g. during periods of El Niño. The shade provided by the trees reduces soil moisture losses and soil biological activity is increased, especially dung beetle activity, allowing the resilience of the system through periods of drought (Chará et al. 2017).

The mechanisms that explain the productive responses from the ISPS include an increase in forage supply, greater intake of dry matter and improved nutritive value of the pastures. Animals grazing in ISPS including leucaena have DM intakes up to 30% higher than those grazing in conventional systems (Cuartas et al. 2015). This could be a function of higher forage on offer in the ISPS, which can be up to 330% higher than that of conventional systems based only on tropical grass monocultures, allowing higher selectivity for the animals (Broom et al. 2013; Gaviria et al. 2015).

According to Gaviria et al. (2015) and Cuartas et al. (2015), including leucaena at 25% of the diet with *M. maximus* and *C. plectostachyus* could lower neutral detergent fiber (NDF) concentration in the total ration by 15%, while the acid detergent fiber (ADF) concentration could be reduced by 20%. The low fiber concentration in the diet improves intake by allowing higher passage rates (Boval and Dixon 2012). In addition, legume particles are cubic, while grass particles are long and thin, which implies higher passage rates in such species as *L. leucocephala* (Barahona and Sánchez 2005). An added benefit is that ISPS with *L. leucocephala* provide higher thermal comfort for the animals, so they can dedicate more time to browsing and grazing, because they have possibilities of ingesting a higher biomass quantity (Broom et al. 2013). Molina et al. (2016) reported that including *L. leucocephala* at 24% of the diet of growing heifers increased DM intake from 2.02 to 2.47% of the animal live weight (P=0.01).

From a nutritional point of view, an aspect to be considered is the digestibility of the legume, which describes the quantity of truly available nutrients for the animal. Although leucaena has a lower digestibility than some forage species due to the presence of secondary metabolites such as condensed tannins, its combination with lower quality grasses increases the degradability of the total forage, which increases the availability of nutrients to be used by rumen microflora and by the animal itself. Other desirable attributes are the high protein concentration, low fiber percentages and acceptable non-structural carbohydrate values (rapidly soluble carbohydrates).

Final considerations

Intensive silvopastoral systems incorporating leucaena constitute a sustainable strategy to increase the availability and quality of forage throughout the year for milk production from cattle in the tropics. Relative to grass monocultures ISPS can: produce more edible dry matter and nutrients per hectare (more crude protein and less fiber); increase milk production due to higher diet quality while reducing the need for chemical fertilizers and concentrate feeds; improve farm profitability; increase carbon sequestration and reduce methane emissions from enteric fermentation; and contribute to improved animal welfare and biodiversity.

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(Note of the editors: All hyperlinks were verified 11 August 2019.)

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*ILC2018 Keynote Paper**

Leucaena leucocephala feeding systems for cattle production in Mexico

Sistemas de alimentación con Leucaena leucocephala *para la producción bovina en México*

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Abstract

The impacts of leucaena (*Leucaena leucocephala*) feeding systems on cattle production, environmental services and animal welfare in Mexico are discussed. A total of about 12,000 ha of leucaena have been established in the tropical regions of México, where most of the information for the current review was obtained. Incorporating leucaena in a grass pasture increases dry matter intake of grazing cattle and reduces the level of methane produced. This results in improved liveweight gains and milk yields as well as a reduction in the level of greenhouse gas released. Additional benefits are increases in soil carbon and nitrogen levels and less stress on animals as the leucaena plants provide shade and reduce environmental temperatures. While these benefits are substantial, the area developed to leucaena represents less than 0.1% of the area which could potentially be developed. Strategies to increase adoption of these grass-legume systems by farmers need to be developed to make effective use of the systems for increasing beef and milk production while reducing the undesirable environmental outcomes normally associated with ruminant production.

Keywords: Environmental services, liveweight gain, mitigation of methane emissions, tree legumes.

Resumen

Se discuten los impactos de los sistemas de alimentación con leucaena (*Leucaena leucocephala*) sobre la producción bovina, los servicios ambientales y el bienestar animal en México. En las regiones tropicales de México se han establecido cerca de 12,000 ha de leucaena, de donde se obtuvo la mayor parte de la información para la presente revisión. La incorporación de leucaena en las pasturas de gramíneas incrementa el consumo de materia seca de bovinos en pastoreo y reduce el nivel de metano producido. Esto resulta en incrementos en la ganancia de peso y rendimientos de leche, así como reducción del nivel de gas de efecto invernadero emitido. Beneficios adicionales de este sistema son los incrementos en los niveles de carbono y nitrógeno almacenados en el suelo y la reducción del estrés animal asociada con la sombra y la mitigación de las temperaturas ambientales aportada por la leucaena. A pesar de estos beneficios substanciales, el área establecida con leucaena representa únicamente el 0.1% del área potencial total que podría desarrollarse. Se requiere diseñar estrategias para incrementar la adopción de estos sistemas de gramíneas-leguminosas por los ganaderos para hacer un uso efectivo de los sistemas para incrementar la producción de carne y leche al mismo tiempo que se reducen los efectos indeseables en el ambiente usualmente asociados con la producción de rumiantes.

Palabras clave: Ganancia de peso vivo, leguminosas arbóreas, mitigación de emisiones de metano, servicios ambientales.

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Introduction

In Mexico, animal production systems which utilize leucaena (*Leucaena leucocephala*) can increase productivity, improve animal welfare and mitigate environmental impacts relative to grass-only systems (Figure 1), but adoption of these systems by commercial farmers is limited. In this review, we discuss the Mexican experience in terms of animal productivity, energy supplementation and environmental services. This analysis provides an understanding of the achievements that have been made and challenges facing the system.

Figure 1. Gyroland cattle in a leucaena-grass system for milk production.

Leucaena-grass systems can provide a wide range of ecosystem services. These include: reduction of greenhouse gas emissions through both mitigation of methane (CH_4) emissions and increased carbon (C) storage; improved nutrient cycling; increased soil organic matter; and improved atmospheric nitrogen (N) fixation.

Considerable effort has been made in various countries to improve our understanding of mechanisms of enteric CH_4 mitigation in cattle fed rations containing foliage of leucaena, notably in Australia (Harrison et al. 2015) and Colombia (Molina-Botero et al. 2016). In Mexico, respiration chamber methodology (Canul-Solis et al. 2017) has been used to measure enteric CH_4 emissions in cattle fed leucaena.

In the tropical regions of Mexico, environmental temperatures and relative humidity are high, and at certain times of the day (during summer), above the physiological capacity of livestock to dissipate body heat. This condition leads to low animal productivity due to elevated body temperature and respiratory rate, leading to reduced voluntary feed intake. A strategy to improve animal comfort is the inclusion of woody species in monocrop-grass systems (Figure 2).

Figure 2. Leucaena-grass-trees systems have the potential to improve animal comfort.

Materials and Methods

Information analyzed in the current review was generated from several regions of the Mexican tropics, particularly the states of Michoacán and Yucatán. In those regions, leucaena has been established by 615 livestock owners (mainly cattle producers) located in 10 different states (Campeche, Chiapas, Guerrero, Jalisco, Michoacán, Quintana Roo, San Luis Potosí, Tamaulipas, Veracruz and Yucatán), with a total livestock production area of 27,307,096 ha (Sagarpa 2014) of which about 14,906,331 ha are appropriate for leucaena establishment. This indicates the enormous potential to expand the planting of this legume, since only about 0.08% (12,000 ha) has been successfully established to date.

Animal performance and energy supplementation trials have been carried out using crossbred (*Bos taurus* × *B. indicus*) cattle. Levels of C storage, N fixation and nutrient cycling were quantified in commercial grass-only pastures and leucaena-grass associations under grazing.

Environmental services of leucaena feeding systems

Methane mitigation in crossbred cattle fed rations containing leucaena

Trials carried out in open-circuit respiration chambers revealed that, as the level of chopped fresh foliage of leucaena was increased in a basal ration of a low-quality grass (*Cenchrus purpureus* syn. *Pennisetum purpureum*), enteric CH_4 emissions of cattle decreased linearly (Piñeiro-Vázquez et al. 2018) (Table 1). This confirmed previous results by Harrison et al. (2015) in Australia. It is possible that condensed tannins contained in leucaena foliage induced changes in the microbial population of the rumen, thus affecting methanogenic *Archaea* and decreasing CH_4 emissions. Energy loss through CH_4

Table 1. Effects of increasing levels of incorporation of leucaena forage in a basal ration of low-quality *Cenchrus purpureus* (syn. *Pennisetum purpureum*) grass for cattle on emissions of enteric methane and dry matter digestibility (Piñeiro-Vázquez et al. 2018).

Parameter	Leucaena level in the ration (% DM)					s.e.	Linear
	0	20	40	60	80		
Cattle LW (kg)	293	298	289	298	295	6.8	
Intake (kg DM/hd/d)	7.0	7.2	7.1	7.0	7.0	0.6	NS
Methane (L/hd/d)	137.3	101.2	87.4	74.9	53.5	14.8	**
Methane (L/kg DMI)	20.1	14.7	12.1	10.5	7.7	2.1	**
Digestibility (% DM)	54.2	50.5	47.8	46.9	46.6	4.0	NS

LW = live weight; DMI = Dry matter intake.

production, as percentage of gross energy intake (Y_m), fell from 5.2% for the grass-only ration, to 3.6%, when leucaena was fed at 20% of ration dry matter (DM), and it continued to fall as legume levels were increased. DM digestibility also decreased as leucaena percentage in the ration increased, but differences were not significant. These findings suggest that incorporating leucaena at 20% of ration DM would reduce CH_4 emissions by around 25%, relative to a grass-only diet. This represents an important outcome from both an environmental point of view (reduction of CH_4 production and emission) and animal performance (improvement through reduced energy loss).

Carbon storage and N cycling increased

Carbon storage and N cycling increased by 38 and 47%, respectively, in leucaena-grass systems compared with pure grass pastures. The legume fixed more than 200 kg N/ha/yr and soil organic matter increased by about 200% in the legume association compared with the grass-only system. Environmental temperature was reduced by almost 13% in the legume tree-grass system (Table 2).

Table 2. Environmental factors in leucaena-grass and grass-only systems recorded in Michoacán, Mexico (Solorio Sánchez et al. 2009; Sarabia 2013; López-Santiago et al. 2019).

Environmental factor	Grass only	Leucaena-grass
Total C storage (t/ha/yr)[1]	78	120
Temperature (ºC)[2]	34–38	30–34
Nutrient recycling (kg/ha/yr)	1–15 (N), 6 (P), 17 (K)	22–30 (N), 4 (P), 2 (K)
Soil organic matter (kg/ha)[3]	320	1,005
Atmospheric N fixation (kg/ha/yr)	0	200–300

[1]Above- and below-ground (0–0.30 m soil depth) carbon.
[2]Measured at 0.80 m above ground in the grass-monocrop and in the tree shade in the leucaena-grass system. Range recorded during April-May (dry season) and June (early rainy season) at 12:00 h.
[3]Measured from 0 to 0.60 m soil depth.

Animal performance

Intake and productivity of animals grazing leucaena

Farmers are interested in knowing the amount of leucaena forage consumed under practical grazing conditions in a leucaena-grass system to achieve maximum benefit. In south-east Mexico, Bottini-Luzardo et al. (2016) measured the intakes of both grass and leucaena under grazing conditions (n-alkane technique) and observed that dual-purpose lactating cows were able to browse 34% of their diet as leucaena. That level of leucaena DM intake will probably correspond with a reduction in CH_4 emissions of around 30%, which is a substantial decrease on environmental grounds. Piñeiro-Vázquez et al. (2018) demonstrated in a respiration chamber experiment with heifers that feeding 20% (of ration DM) leucaena (in a basal ration of tropical grass) induced a reduction of 26% in CH_4 emission while 40% leucaena gave a reduction of 36%. It is reasonable to assume that 34% of ration DM (Bottini-Luzardo et al. 2016) would probably lead to a reduction of around 30% in CH_4 emissions. This guesstimate agrees, in general, with results obtained at other laboratories. Intakes of leucaena reported by Bottini-Luzardo et al. (2016) agreed with results reported by Sierra-Montoya et al. (2017), who found a leucaena intake (DM) of around 28% of the diet in dual-purpose lactating cows grazing in a silvopastoral system in Colombia. Steers in silvopastoral systems with leucaena (without supplementation) gained 770 g/hd/d (Mayo-Eusebio et al. 2013), with associated benefits of improvement in carcass yield and lean meat production, made possible through desired fatty acid composition and high concentration of unsaturated fatty acids (Rodríguez-Echevarria et al. 2013).

Energy supplementation to increase efficiency of nitrogen (N) utilization

Intake of crude protein (CP) by cattle grazing in paddocks with high leucaena plant densities (about 35,000 plants/ha), as currently used in Mexico, could be high, resulting in excessive losses of N in the urine (Bottini-Luzardo et al. 2015). This may increase energy requirements for maintenance of cattle (Jennings et al. 2018) and increase N_2O emissions from the urine (Bao et al. 2018). There may also be an imbalance in the protein:energy ratio in the rumen leading to inefficient microbial protein synthesis (Calsamiglia et al. 2010; Barros-Rodríguez et al. 2013). Blood urea nitrogen (BUN) is a good indicator of nutritional balance in ruminants and the protein:energy ratio in total dietary intake is the most important factor related to fluctuations in BUN (Hess et al. 1999). In south-east Mexico, Ruiz-González (2013) found that both BUN and urinary N excretion in cows increased linearly with increasing levels of leucaena in the diet, suggesting inefficient use of N in the rumen. In addition, Arjona (2015) compared cane molasses, sorghum grain, citrus peel and rice polishing as energy supplements for lactating Holstein × Zebu cows fed a diet containing 45% leucaena foliage, relative to a control treatment without energy supplementation. Both BUN and urinary excretion of N were higher for the control group than for the supplemented treatments, suggesting that energy supplementation improved the utilization of N in the rumen. Total feed intake was 25% higher and milk yield was increased by 30% with energy supplementation, with no differences due to the particular energy sources. It was concluded that energy supplementation, regardless of the source used, will improve the efficiency of microbial protein synthesis in the rumen, as well as increase consumption of DM and animal performance, in cattle fed rations incorporating leucaena (Castillo et al. 2000).

Animal welfare

In the central part of Mexico, growing bullocks grazing leucaena associated with *Megathyrsus maximus* had lower body temperature (measured with an infrared thermometer) and respiratory rates in the morning (36 vs. 38 °C and 42 vs. 65 breaths per minute) and in the afternoon (38 vs. 39.5 °C and 59 vs. 80 breaths per minute) than in a feedlot (Utrilla-García 2013). This suggests that the feedlot system, which is becoming a common practice in Mexico, can have negative impacts on animal welfare and productivity, if shade is not provided, since it could reduce feed intake and liveweight gain and therefore general productivity. In another study, undertaken in southeast Mexico, to evaluate animal welfare of dairy cattle grazing leucaena-grass systems with trees, improved microclimate conditions allowed animals to cope better with heat stress. In addition to increased biodiversity there were advantages for animal welfare in terms of social and affiliative behavior, such as social licking, head leaning and social rubbing (Améndola et al. 2015).

Leucaena-grass system adoption

From 2012 to 2017, leucaena-grass systems have been established over almost 12,000 ha (615 farms), which represents about 0.08% of the total livestock area suitable for leucaena establishment (14,906,331 ha) in 10 states of the tropical region in Mexico. Although this area is significant, the rate of adoption has been slow and limited, as there are more than 350,000 cattle farms in the tropical region (PGN 2018). Possible contributing factors are: a) uncertainty in livestock markets; b) lack of state laws that give long-term support to this initiative; c) lack of long-term extension services for cattle producers; d) high labor demand for leucaena-based systems, which means farmer leaders must have confidence in the system; e) lack of availability of good quality farm inputs and services and the need for an appropriate market-chain for distribution; f) inefficient support from state policies; and g) high costs and limited access to credit.

Conclusions

Leucaena feeding systems could be an important strategy in the tropical regions of Mexico to improve animal productivity and welfare, and to reduce greenhouse gas emissions to the environment.

Silvopastoral systems with leucaena have proved highly productive in Mexico. However, these systems have not been adopted widely by farmers, mainly due to lack of readily available technical support, several socio-economic and political constraints and appropriate strategies to make effective use of the systems for cattle production with minimal impact on the environment.

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ILC2018 Keynote Paper*

Leucaena feeding systems in Argentina. I. Five decades of research and limitations for adoption

Sistemas de alimentación con leucaena en Argentina: I. Cinco décadas de investigación y limitantes para su adopción

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Abstract

This review describes the history of research in *Leucaena leucocephala* (leucaena) feeding systems carried out by the National Institute of Agricultural Technology (INTA) over the last 5 decades and discusses the main limitations resulting in poor adoption in Argentina. Leucaena was introduced in the subtropical region of the north of the country in the late 1960s and early 1970s. Since then, INTA has conducted research to evaluate forage and animal productivity, leucaena accessions, rhizobial strains, contribution to soil carbon and total nitrogen and density effects on competition and other ecosystem interactions in silvopastoral systems. In spite of the convincing research results showing the excellent potential of leucaena to increase forage quality and animal production in suitable areas, there has been poor adoption of this forage tree legume on a broad scale.

Keywords: Beef cattle, Chaco region, forage tree legumes, protein banks, silvopastoral systems.

Resumen

Esta revisión describe la historia de investigación conducida por el Instituto Nacional de Tecnología Agropecuaria (INTA) en la utilización de *Leucaena leucocephala* (leucaena) en sistemas ganaderos en las últimas 5 décadas, y analiza las principales limitantes que resultaron en su escasa adopción en Argentina. Leucaena fue introducida en la región subtropical del norte de Argentina a finales de la década de 1960 y comienzos de los 70s. Desde entonces, INTA ha conducido investigaciones para evaluar la productividad forrajera y ganadera, accesiones de leucaena, cepas de rizobio, contribución de carbono y nitrógeno al suelo, y efectos de la densidad de leucaena sobre competencia y otras interacciones ecosistémicas en sistemas silvopastoriles. A pesar de los alentadores resultados de dichas investigaciones, que mostraron el excelente potencial de leucaena para incrementar la producción forrajera y ganadera en áreas aptas para su crecimiento, se observa escasa adopción de esta leguminosa forrajera arbórea en gran escala.

Palabras clave: Bancos de proteína, Chaco, ganado de carne, leguminosas arbóreas, sistemas silvopastoriles.

Introduction

In the subtropical region of the north of Argentina, livestock feed mainly on pastures and grasslands dominated by grasses, which are deficient in protein for most of the year. *Leucaena leucocephala* (leucaena) has excellent potential to increase forage quality and animal production in suitable areas for its growth (Goldfarb et al. 2005; Radrizzani and Nasca 2014). In the late 1960s and early 1970s the National Institute of Agricultural Technology (INTA) investigated

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the role of leucaena in feeding systems for this region by evaluating its persistence in different environments and farming systems. This paper reviews the history of research carried out by INTA on leucaena feeding systems over the last 5 decades and discusses the main limitations affecting adoption of leucaena by farmers.

History of research

Although several tropical forage legumes have been tested as possible solutions to the protein deficiencies of grasslands and pastures, only leucaena has stood out against other perennial legumes in terms of forage production and persistence (Royo Pallarés and Fernández 1978; Goldfarb et al. 1986; Goldfarb and Casco 1994). During the last 5 decades, leucaena has been evaluated in terms of forage and animal productivity, performance of various accessions, nodulation, contribution to soil carbon (C) and total nitrogen (N) and density effects on competition and synergistic effects.

Forage and animal productivity

Since the early 1980s, experiments have been conducted to test forage and animal production of pastures incorporating leucaena. Cattle liveweight gains (LWGs) with and without leucaena in the diet were compared in the following 7 experiments, that are summarized in Table 1.

Leucaena protein bank, INTA Mercedes Research Station. On the Experimental Farm located in the center of Corrientes province (29º22'18.88" S, 57º40'36.48" W; 95 masl) with a mean annual rainfall (MAR) of 1,380 mm, more than 1,000 accessions of forage legumes were introduced in 1965 and their adaptation and forage characteristics were evaluated. Leucaena stood out for its yield, quality and persistence (Royo Pallarés and Fernández 1978). Two decades later leucaena was still vigorous and productive, so Pizzio et al. (1989) evaluated forage and animal productivity of native grasslands with and without access to leucaena protein banks comparing the effect of 0, 10 and 20% of the grassland area sown to leucaena cv. Peru. Grazing periods were 288 days/year (June–March) over 3 years. Mean annual LWGs with 20% leucaena protein banks were 38% higher than on pure grassland (Table 1a). Annual LWGs with 20% leucaena were 143 kg/head and 190 kg/ha compared with 103 kg/head and 137 kg/ha for grassland only. Since large steers lost little weight (-8%) during winter and small steers gained weight (+4%) with 20% leucaena, an increased proportion (30%) of leucaena was recommended. Steers 32 months old with access to 20% leucaena could be finished at heavier weights (476 kg) than steers grazing pure native grassland (410 kg). Animals grazing leucaena showed no symptoms of mimosine toxicity under these conditions.

Table 1. Cattle liveweight gains (LWGs) on treatments with and without leucaena in 7 experimental trials in Argentina.

Experiment and treatments	LWG (kg/hd/d)	Increment due to leucaena	Toxicity	Reference
a. Protein bank, INTA Mercedes				Pizzio et al. 1989
- Leucaena, 20% of available area	0.497a[1]	38%	No	
- Native grassland	0.358b			
b. Protein bank, INTA Corrientes				Gándara et al. 1986
- Leucaena, 18% of available area	0.385a	75%	No	
- Native grassland (winter)	0.220b			
c. Silvop. syst., INTA Corrientes				Gándara and Casco 1993
- Leucaena	0.436a	35% (70%)[2]	No	
- Native grassland	0.322b			
d. Protein bank, INTA Cerro Azul				Lacorte et al. 1987
- Leucaena, 20% of available area	0.408a	57%	No	
- *Cynodon plectostachyus* pasture	0.259b			
e. Supplement, INTA Cerro Azul				Lacorte 2001
- Leucaena supplementation	0.657a	No difference	No	
- Comercial protein supplement	0.586a			
f. Protein bank INTA El Colorado				Roig 1992
- Leucaena, 10% of available area	0.454a	22%	No	
- Pangola pasture	0.373b			
g. Silvop. system, INTA Leales				Radrizzani and Nasca 2014
- Leucaena, 40% of available area	1.070a	65% (195%)	Yes	
- Brachiaria pasture	0.650b			

[1]Values within experiments followed by different letters differ at P<0.05.
[2]Values within parentheses indicate the increase in production per hectare.

Leucaena protein bank, INTA Corrientes. During 3 consecutive winters (May–September 1981, 1982 and 1983) on a cattle farm located in 'Empedrado', Corrientes province (27º54'41.25" S, 58º44'47.81" W; 71 masl; MAR 1,350 mm), Gándara et al. (1986) compared LWGs of heifers and cows grazing native grasslands with access to protein banks of leucaena cv. Peru for 4 h/d with those of heifers and cows grazing only native grassland. LWGs/head of animals with daily access to leucaena were 44, 130 and 110% greater in 1981, 1982 and 1983, respectively, than on native pasture alone (mean increase 75%, 0.39 vs. 0.22 kg/hd/d; Table 1b). The improved gains were directly related to the additional quantity and quality of forage provided by leucaena. In this trial, animals grazing leucaena also showed no symptoms of mimosine toxicity

Leucaena silvopastoral system, INTA Corrientes. In the same area as the previous experiment, Gándara and Casco (1993) conducted an exploratory trial to assess the LWGs of steers in a silvopastoral system with leucaena in hedgerows in comparison with steers on straight grassland over 2 years (August 1989–August 1990 and November 1990–November 1991). Leucaena (cv. Cunningham) had been established in spring 1987 in hedgerows 5 m apart with *Digitaria eriantha* (syn. *D. decumbens*, Pangola grass) as a companion grass in the inter-rows. LWGs of steers grazing the leucaena silvopastoral system were 34 and 36% greater in 1989–90 and 1990–91, respectively, than those on grass only (Table 1c). Animal production per hectare from leucaena-Pangola grass was 170% greater than on grass only as a result of a doubling of stocking rate (2 vs. 1 head/ha). Between 1992 and 1996, Goldfarb et al. (2005) explored different cutting regimes to maintain a dense leafy canopy within the browse height (<2 m) and improve forage quality. This work, also conducted at the Corrientes Research Station, showed that cutting regime did not affect forage quality (protein and phosphorus concentrations).

Leucaena protein bank, INTA Cerro Azul Research Station. In the 'Cuartel Río Victoria' Experimental Farm, located in the center of Misiones province (MAR 1,650 mm), Lacorte et al. (1987) evaluated LWGs of steers grazing protein bank systems in comparison with a pure grass control pasture during 1984–85 and 1985–86. Leucaena protein banks had been planted in September 1981 in 20% of the area of a *Cynodon dactylon* pasture, which was sown in summer 1980/81. The pure grass pasture was dominated by *Cynodon plectostachyus* ('pasto estrella'). Steer LWGs were 57% higher in the leucaena protein bank systems than in pure grass pastures (Table 1d). Recommendations from this study were to reduce the proportional area of the protein banks since there was an oversupply of leucaena forage, and to use protein banks in winter when the difference in LWG was greatest, viz. 0.7 kg LWG/d for protein banks vs. a loss of 0.4 kg/d for pure grass pastures. However, to maintain leucaena green leaf in winter, protein banks must be established in elevated areas protected by tree windbreaks to reduce damage from frosts and cold winds.

Leucaena supplementation, INTA Cerro Azul. Lacorte (2001) used fresh leucaena to replace commercial protein supplements for heifers and showed that weight gains in the leucaena and protein supplement treatments were similar (Table 1e). The author recommended leucaena cut-and-carry for reducing feeding costs in small farming systems. Furthermore, Pachas et al. (2011; 2012) carried out collaborative experiments with dairy producers using 'intensive silvopastoral system' configurations with leucaena planted at high densities (10,000–20,000 plants/ha) in single rows spaced 1.6 m apart with companion grass between rows and high-quality timbers planted in alleys 10–20 m apart. These collaborative trials helped to involve smallholders in leucaena utilization to improve the quantity and quality of forage produced and increase dairy cattle productivity.

Leucaena protein bank, INTA El Colorado Research Station. On the Experimental Farm located in the southeast of Formosa province (MAR 1,150 mm) in the years 1980, 1981, 1983, 1987, 1988 and 1989, Roig (1992) studied LWGs of weaner and yearling steers grazing Pangola grass pastures or Pangola grass with 10% of area as a leucaena protein bank. Pangola grass pastures were continuously grazed, while pastures with leucaena were rotationally grazed with access to protein banks for 2–3 h/d. Mean daily LWGs were higher in steers with access to leucaena during the first, second and fourth years (Table 1f), but not in the other years. Both age groups responded, but the effect was stronger in younger animals that require forage with higher nutritive value. The absence of responses in LWG in the other years was attributed to the abundance of native and naturalized legumes, e.g. *Desmodium incanum*, annual *Vicia* spp. and *Melilotus* sp., in the Pangola grass pastures.

Leucaena silvopastoral system, INTA Animal Research Institute of the Semi-arid Chaco region. On the Experimental Farm located in Leales, Tucumán, with a subtropical subhumid climate and MAR of 880 mm, Radrizzani and Nasca (2014) conducted a trial in the 2009/10 summer to evaluate the effects on beef productivity and its toxicity of planting leucaena in a *Urochloa brizantha* (syn. *Brachiaria brizantha*) cv. Marandú (brachiaria) pasture established in 1995. Leucaena cv. K636 was zero till-planted into the pasture in hedgerows (single or twin rows) with 5 m inter-row spacings in December 2009 to form 3 treatments with different proportions of the total area planted to leucaena (0, 20 and 40%). For the first 45 days, mean LWGs were 0.65, 1.00 and 1.07 kg/hd/d for straight brachiaria, brachiaria with 20% leucaena and brachiaria with 40% leucaena, respectively, with corresponding gains per unit area of 1.33, 3.08 and 4.32 kg/ha/d (Table 1g). At this point animal LWGs on pastures containing leucaena began to decline significantly, maintaining this trend until the end of the trial. This coincided with signs of mimosine toxicity, despite high yields of available leucaena. This study suggested that, before putting animals on a pasture containing a high proportion of leucaena (e.g. 40%) in the Chaco region, the value of ruminal inoculation with mimosine- and DHP-degrading bacteria (as used in other tropical and subtropical areas) must be assessed.

Leucaena accessions

Temperatures in the subtropical region of Argentina are favorable for leucaena growth during most of the year (7–9 months) but frost can significantly slow or stop its growth in winter when leucaena forage is needed most to supplement ruminant diets. To identify tolerance to low temperature while maintaining adequate forage yield and quality, Goldfarb and Casco (1998) selected 56 accessions of *Leucaena* species and hybrids. The study was conducted in 2 phases: in Phase 1, 3-month-old seedlings were subjected to temperature treatments of either -8 or -3 °C for 14 h. After the -8 °C treatment, only 1 plant of a single accession (*L. leucocephala* × *L. diversifolia* SF 9043) survived. After -3 °C treatment, 17 plants retained 50% of their leaves. In Phase 2, these 17 plants were planted out in the field to measure agronomic features. Eight plants, representing 4 cultivars and accessions of *L. leucocephala* and 4 plants of different *L. leucocephala* × *L. diversifolia* hybrids, showed good agronomic adaptation and chilling tolerance but only a single plant of *L. leucocephala* K72 (SF8073) maintained green stem and meristematic tissue after a frost event of -8.8 °C.

In 2000, other field trials evaluated the sensitivity of *Leucaena* species to low temperatures in winter and leucaena production in hedgerow silvopastoral systems (Goldfarb and Altuve 2002; Goldfarb 2005; Goldfarb et al. 2005; Rolhaiser 2013). All *Leucaena* spp. survived the frost, reshooting vigorously from the stem base as temperatures rose. Accessions of *L. leucocephala* that persisted until 2018 and have continued under evaluation are: 368 (Lot 2 Zwai 1985), Cunningham P13, Cunningham P14, CIAT 17481, CIAT 17479, Hawaiian Giant and ecotypes 'Piquete' and 'Colorado'. Other *Leucaena* spp. that persisted and are still under evaluation are: *L. collinsii*, *L. glabrata*, *L. esculenta*, *L. pulverulenta*, *L. stenocarpa* (CIAT 17268), *L. diversifolia* (CIAT 17461, CIAT 17264, 11677 Lot 5 Zwai 1989 and 11676 Lot 7 Zwai 1989), *L. pallida* (CPI 84581), *L. retusa* (CIAT 17267), *L. macrophylla* (CIAT 17481, CIAT 17245 and 55/58 ILCA Kenya), *L. gregii* (CPI 91198), *L. lanceolata* var. *lanceolata* (CPI 95571). The hybrids that persisted until 2018 and are still under evaluation are: *L. leucocephala* × *L. diversifolia* (Line 7, Line 18, Batch 283-050-10).

In another study Acosta (2008) selected 19 accessions (*L. leucocephala*, *L. diversifolia* and their hybrids) from the INTA Corrientes collection to evaluate forage yield in acid soils; results showed good yields for most of these accessions, with the top 5 producing between 4,238 and 5,685 kg DM/ha/year.

In 2011, 57 accessions of *Leucaena* species and hybrids from the INTA Corrientes collection were established at the Animal Research Institute of the Semi-arid Chaco region, INTA, Leales, Tucumán, to preserve and allow evaluation of these genetic resources in another environment.

Rhizobial strains and nodulation

Effective nodulation is essential for vigorous leucaena growth and it is known that the presence of inadequate or ineffective rhizobial strains may limit both biological N fixation and forage yield in many subtropical soils. In the year 2000, farmers from northeast Argentina sought inoculum to establish leucaena, given the absence of effective nodulation due to a lack of specific rhizobia in these soils (A. Perticari unpublished data). Facing this demand, Bryant (2007) evaluated nodulation capacity and leucaena biomass production under controlled conditions of 40 strains stored in the collection of the Institute of Microbiology and Agricultural Zoology (IMYZA-INTA) in comparison with a control strain (CB81, *Bradyrhizobium* sp. introduced from CSIRO, Australia and recommended since the first introductions of leucaena in the 1960s). The 40 strains were collected either from leucaena nodules from other countries or from *Phaseolus vulgaris* nodules. Four strains were preselected for their symbiotic effectiveness (100% of plants nodulated with more than 3 nodules per plant and plants had a dark green color): CB81, C215 (*Bradyrhizobium* sp. from soils cropped with *P. vulgaris* in Salta province, northwest Argentina) plus C191 (*Bradyrhizobium* sp. from the Central University of Venezuela) and CIAT899 (*Rhizobium tropici*, from CIAT, Colombia that had been recommended for inoculation of *P. vulgaris*). The effectiveness study was carried out with cvv. Cunningham and K636 in a growth chamber over 50 days, using 2 control treatments: uninoculated and N-fertilized leucaena plants. Strains CIAT899 and C215 were the most effective in terms of total shoot biomass accumulated and nodule size, while nodule number was highest with strains CB81 and C191. *Rhizobium tropici* (strain CIAT899) showed the fastest growth rate compared with *Bradyrhizobium* spp., known as having slow to moderate growth. The shorter generation time of CIAT899 facilitates the production of inoculum by reducing fermentation time, costs and contamination risks. From this study, 2 new strains, CIAT899 and C215, were recommended for inoculating leucaena in northeast Argentina in preference to the CB81 strain (these 3 strains are currently available in IMYZA-INTA). Strains CIAT899 and C215 continue to be evaluated in field trials showing excellent nodulation and plant growth (A. Perticari unpublished data).

In another study to evaluate the effectiveness of naturalized rhizobia, Eöry et al. (2010) collected soil samples from 28 sites in northeast Argentina (Corrientes, Chaco and Formosa provinces), where leucaena had been growing for up to 50 years since establishment. They found little or no presence of nodulating rhizobia in these soils, though some of the naturalized rhizobia were more effective than the control strain CB81 (Eöry et al. 2010). This collection was added to the IMYZA-INTA collection for future studies. In these regions a high and persistent response to inoculation of leucaena is expected.

By contrast, in northwest Argentina (Salta, Jujuy, Tucumán and Santiago del Estero provinces), rhizobia strains that nodulate leucaena have been detected and the nodules are assumed to be formed by native *Rhizobium etli* or other species of rhizobia associated with cultivated *P. vulgaris* and other native wild beans. According to Martínez-Romero (2009) these species of rhizobia have the ability to nodulate several legumes, particularly *P. vulgaris* and *L. leucocephala*. Nevertheless, even in northwest Argentina, field trials are warranted to ensure that apparently effective strains are competitive in leucaena feeding systems.

Contribution to soil organic carbon and total nitrogen levels

Banegas et al. (2019) determined concentrations and vertical distribution of organic C (OC) and total N (TN) and their fractions (particulate and associate forms) in the profiles (0–100 cm) of a 4-year-old leucaena-grass pasture and an adjacent grass-only pasture at the Animal Research Institute of the Semi-arid Chaco region, INTA, Leales, Tucumán (27º11' S, 65º14' W; 335 masl), in the west of the Chaco region, northwest Argentina. Leucaena introduction increased OC concentration in the subsoil (20–100 cm) by 45%, particularly the stable form (associate OC) in the deepest horizon (50–100 cm). This was attributed to a greater abundance of leucaena roots than of grass roots deeper in the profile. Leucaena also enhanced N concentration by 7.6% (0.13 vs. 0.14%) in the topsoil (0–20 cm) associated with an increment in the labile form (particulate organic N), due to leaf deposition, recycling of animal feces and nodule-N turnover from N fixation. Introduction of leucaena into tropical grass pastures has the potential to improve soil fertility and hence N availability for companion grass growth.

Density effects on competition and facilitation

The effect of leucaena density on forage biomass was studied by Gándara et al. (2019) in a silvopastoral system at INTA Corrientes Research Station. Leucaena hedgerows consisting of twin rows 1 m apart with inter-row spacings of 8, 4 and 2 m (22,222, 40,444 and 66,666 trees/ha, respectively) were planted in October 2016. The companion grass, *Urochloa brizantha* (syn. *Brachiaria brizantha*) cv. Marandú, was sown in October 2017. Tree density was positively and linearly related to total leucaena biomass and inversely related to grass yield ($R^2 = 0.99$). Maximum total biomass was obtained in hedgerows with inter-row spacing of 2 m (leucaena 11 t DM/ha and grass 2.5 t DM/ha) but maximum grass yield was obtained with 8 m inter-row spacing (6.7 t DM/ha). Apart from leucaena density, the decline in grass yield was directly related to the increase in degree of shading with higher leucaena density. Level of shade was estimated from the luminous intensity measured by a ceptometer. Edible leucaena biomass was linearly and directly related to leucaena density ($R^2 = 0.99$) and it was highest with 2 m inter-row spacing (6.2 t DM/ha), but the percentage of edible biomass was not significantly different at the 3 leucaena densities. Substantial changes in forage production arise from diverse leucaena densities, i.e. combinations of single or twin rows and different inter-row spacings, in silvopastoral systems. The low radiation available under high density (2 m inter-row spacing) limits grass growth but moderate density (4 m inter-row spacing, 40,444 plants/ha) allows an efficient combination with grasses that produces an adequate fiber:protein balance in available forage.

Limitations to adoption

In spite of the convincing research results showing that leucaena introduction in tropical pastures or grasslands improves forage and animal production, there has been poor adoption of this forage tree legume on a wide and intensive scale in Argentina. Based on our experience, we identify 8 main reasons for the slow adoption over the last 5 decades:

The contradiction of planting trees on cleared land

Most cropping land in north Argentina, a region dominated by forest vegetation, was developed by clearing trees. Therefore, it is contradictory for farmers to plant trees in a paddock where trees and shrubs have been systematically controlled and removed. Moreover, some farmers have concerns accepting that a pasture formed with trees can be as productive as a cleared pasture, as with a silvopastoral system. Traditionally for a cattle farmer, a pasture is formed by pure grass only and all shrubs and trees have to be cleared.

Rigidity of land uses

Some farmers have issues about the loss of flexibility associated with conversion of land suitable for dryland cropping into long-term leucaena silvopastoral systems (soils suitable for leucaena are generally also suitable for cropping). The expected life of leucaena hedgerows (>30 years) makes it difficult to conduct a rotational management program in which crops and pastures are alternated over time in the same paddock. Moreover, in mixed farming systems, leucaena establishment reduces the possibility of allocating more or less land for crops or animal production, according to the expected net returns of cropping and livestock (a relationship that has been changing frequently in recent years).

Slow establishment of leucaena

The slow early growth of leucaena seedlings makes them vulnerable to ant attacks, weed and grass competition and predatory wildlife, e.g. rabbits. Consequently, leucaena must be planted as a crop using current cropping techniques, e.g. zero-till for sowing leucaena into grass pastures, selective herbicides for weed control and appropriate insecticides for ant control. Further, some cattle farmers have insufficient experience and machinery, e.g. sowing and spraying machines. Moreover, erratic leucaena establishment owing to the unreliable summer rain of the semi-arid Chaco region demands a careful approach to successful establishment.

Leucaena-grass pastures are more expensive to establish than pure grass pastures

The establishment costs of leucaena hedgerows and the companion grass, plus costs of seed scarification, and control of ants, weeds and rabbits is higher (about double that for a pure-grass pasture). Therefore, the higher initial investment in establishing leucaena means the payback period is extended unless returns from leucaena are much higher than from grass only. Alternatively, the lifespan of a leucaena stand must be long to ensure sufficient time for cost recovery to be complete.

Inexperience in managing silvopastoral systems

Livestock farmers are unfamiliar with managing shrubs/trees as forage plants, an uncommon practice among cattle farmers in Argentina. Even farmers from the Pampa region (dominated by grasslands) with experience in establishing and grazing herbaceous legumes in mixed pastures, e.g. clover-grass pastures, have to gain new knowledge to manage hedgerow trees with companion grasses in silvopastoral systems. Although it is known that leucaena plants need time to recover carbohydrate reserves during the regrowth phase before they are grazed again (Stür et al. 1994), some farmers are unaware that successive severe grazings combined with frost damage can seriously affect leucaena survival.

Excessive leucaena height

To ensure stock can access leucaena forage in direct grazing systems, animal pressure should be managed to maintain leucaena hedgerows at up to 2–3 m tall with a dense leafy canopy within the browse height (Dalzell et al. 2006). However, tall-growing leucaena cultivars, e.g. K636 or Tarramba, can easily grow beyond the browse height, making forage inaccessible to stock, even in frost-prone areas where frost can help to control plant height. Consequently, farmers must develop skills to control leucaena height through heavy grazing pressure and/or cutting back plants by trimming machines, e.g. slashers/mulchers, tree pruners or roller-choppers.

Misinformation regarding mimosine toxicity

Farmers in Argentina have a poor understanding and awareness of the occurrence and significance of leucaena toxicity. They are uncertain if their animals are suffering from chronic toxicity since animals may still be performing better in systems with leucaena than in those without it, but rarely use urine tests to diagnose if a problem exists. Research and extension programs to inform farmers of upgraded inoculation protocols and improved management practices are needed urgently (Halliday et al. 2018).

Scarce funding for research and development programs

There have been no well-supported research and extension programs to promote the utilization of tropical legumes in Argentina in recent decades. Nowadays, there is a lack of technical information on leucaena feeding systems in a form accessible to both technicians and farmers. Effective research programs and extension services are urgently needed to improve establishment methods, management practices and grazing systems. Utilizing successful leucaena farmers as 'champions' to promote the practice and demonstrate it on commercial farms seems a promising approach. Greater involvement of experienced and successful leucaena growers in the technology transfer process is essential to improve the future uptake and success of leucaena feeding systems.

Conclusion

Experiments involving forage and animal productivity have shown that leucaena has excellent potential to increase animal production in areas suitable for leucaena in the subtropical region of northern Argentina. However, when leucaena was introduced to fill the winter forage gap, this expectation was not always fulfilled and will be difficult (if not impossible) to achieve in frost-prone areas without new cold-tolerant leucaena varieties. Moreover, to avoid toxicity associated with a high proportion of leucaena in the diet, e.g. 40%, appropriate management practices are needed. Studies to assess the effectiveness of rhizobial strains and soil C and N contributions have revealed the potential of leucaena to fix N and to improve soil fertility and C storage. However, there is still a gap in knowledge about how much N leucaena can fix associated with different rhizobial strains under different environmental conditions and management practices. With regard to competition studies and the effective integration of leucaena and grass, there is still limited information on how to optimize planting layout and management of leucaena, grass and animals in grazing systems. In spite of the convincing research results showing that leucaena introduction in tropical pastures and grasslands can improve forage and animal production, the limited adoption of this technology is a major concern. It has been attributed to a mix of social, economic and agronomic constraints and education and extension programs are needed to address this issue.

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(Note of the editors: All hyperlinks were verified 11 August 2019.)

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*ILC2018 Keynote Paper**

Leucaena feeding systems in Argentina. II. Current uses and future research priorities

Sistemas de alimentación con leucaena en Argentina: II. Situación actual y prioridades de investigación futura

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Abstract

This paper presents the current status of *Leucaena leucocephala* (leucaena) feeding systems and proposes research priorities for leucaena development in Argentina. Although research on leucaena as forage for cattle production began in the late 1960s, it was not widely adopted until 2010 (5 decades later). The recent adoption is related to the incorporation of the 'Australian technology package', previously adapted for use by farmers in the neighboring region of the Paraguayan Chaco. In June 2018, we surveyed 8 properties with about 2,400 ha of leucaena in silvopastoral systems for beef cattle production in the Argentinean Chaco region, as well as 10 smallholder farms with about 10 ha of leucaena protein banks for dairy cattle in the northeast of Argentina. In the silvopastoral systems, leucaena condition was excellent on most properties in the 750–1,350 mm/year rainfall zone and low/poor on only 1 farm due to low rainfall (600 mm/year). In protein banks, leucaena condition was excellent or good on 6 of the properties and low/poor on the remaining 4, attributed to ingress of weeds and/or overgrazing. Grass condition was good in most of the systems but was low/poor in 2 silvopastoral systems due to very high stocking rates imposed to restrict leucaena height. Although there is high potential for leucaena development in Argentina, expansion should take place carefully with leucaena planted only on areas suitable for successful establishment, and using appropriate management practices to reduce establishment failures and costs, restrict leucaena height, enhance grass persistence, improve grazing strategies and manage mimosine toxicity problems.

Keywords: Beef cattle, Chaco region, forage tree legumes, protein banks, silvopastoral systems.

Resumen

Este trabajo presenta la situación actual de sistemas de producción ganadera que utilizan *Leucaena leucocephala* (leucaena) en Argentina. Aunque la investigación en leucaena como forrajera para la producción ganadera comenzó a fines de los 60s, la especie fue adoptada en mayor escala recién a partir del 2010 (5 décadas después). Esta reciente adopción se relaciona con la incorporación del 'paquete tecnológico australiano', también adoptado y adaptado por productores de la región vecina del Chaco paraguayo. En junio de 2018 identificamos y avaluamos unas 2,400 ha (8 propiedades) de leucaena en sistemas silvopastoriles de bovinos de carne en la región del Chaco argentino. Al mismo tiempo, evaluamos unas 10 ha (10 pequeños productores) con leucaena como bancos de proteína para vacas lecheras en el noreste argentino. En los sistemas silvopastoriles, la condición de leucaena fue calificada como excelente en la mayoría de los campos ubicados en áreas con precipitación anual de 750 a 1,350 mm/año, a excepción de una propiedad con mala condición de leucaena asociada a la baja precipitación (600 mm/año). En los bancos de proteína, la condición de leucaena fue valorada como excelente y buena en el 60% de los campos

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y fue mala en el 40% restante, atribuida a la falta de control de malezas y/o sobrepastoreo. La condición de las gramíneas fue buena en la mayoría de los sistemas, pero fue mala en 2 de los sistemas silvopastoriles donde se aplicó alta presión de pastoreo para evitar el crecimiento excesivo de leucaena. Si bien existe un gran potencial para el desarrollo de leucaena en Argentina, la expansión debe hacerse cuidadosamente, seleccionando solo aquellos sitios apropiados para su crecimiento, y aplicando prácticas de manejo adecuadas para reducir riesgos y costos de implantación, restringir la altura excesiva, aumentar la persistencia de las gramíneas, mejorar las estrategias de pastoreo y manejar los problemas de toxicidad por mimosina.

Palabras clave: Bancos de proteína, ganado de carne, leguminosas forrajeras arbóreas, región del Chaco, sistemas silvopastoriles.

Introduction

Leucaena (*Leucaena leucocephala)* is grown as forage for grazing cattle in the subtropical region of the north of Argentina, where livestock graze mainly on pastures and grasslands that are deficient in protein for much of the year. Both research and extension staff recognize that the introduction of leucaena into grass pastures as hedgerows (silvopastoral systems) and as blocks of high leucaena density (protein banks) has excellent potential to increase both forage quality and animal production in areas suitable for its growth. This paper presents the current status of use of leucaena in livestock feeding systems in Argentina and proposes research priorities for future development.

Usage of leucaena feeding systems

In May-June 2018, we surveyed leucaena growers in Argentina to gather information regarding property location, area of established leucaena, its intended use, planting methods employed, grazing management, condition of grass and leucaena and any concerns about leucaena introduction into their feeding systems. We might not have included all growers, as adoption of leucaena feeding systems in the region has not previously been documented.

Hedgerow silvopastoral systems

Eight properties with leucaena established in hedgerow silvopastoral systems were surveyed and were located in the 600–1,350 mm average annual rainfall (AAR) zone of the Chaco region (Salta, Chaco and Formosa provinces) (Figure 1; Table 1). These silvopastoral systems were established between December 2011 and January 2018 and covered a total area of 2,379 ha (average 297 ha/property, range 4–950 ha). Physical and chemical properties of prevailing soils on the farms did not present any major obstacles to the growth of leucaena. The main purpose for introducing leucaena into the grazing systems was to improve forage and beef production and to enhance soil nitrogen (N) concentration and hence sustainability of the system. On all properties, leucaena was planted in twin rows with 5–10 m inter-row spacing using scarified seed of cv. Tarramba (improved K636) imported from Paraguay (previously imported to Paraguay from Australia). On one property (ID 4 in Table 1) leucaena cv. Cunningham was sown on part of the farm and cv. Tarramba on the other part. On 5 properties (63%) seed was inoculated with specific rhizobium provided by INTA's Institute of Microbiology and Agricultural Zoology (IMYZA-INTA), while seed was sown without rhizobia on the other 3 properties. The most common grass species sown in the inter-row spaces were *Megathyrsus maximus* (4 pastures with cv. Gatton panic and 1 with cv. Tanzania) and *Urochloa brizantha* (syn. *Brachiaria brizantha*) cv. Marandu, while other species were *Dichanthium aristatum* and native grasses. All leucaena silvopastoral systems were rotationally grazed, 6 at high grazing pressure and the remaining 2 at very high grazing pressure based on 4 possible ratings (low, moderate, high and very high). Cattle were inoculated with the mimosine-degrading rumen bacterium *Synergistes jonesii* imported from Paraguay (previously imported from Australia to Paraguay) on 5 properties, while no inoculum was applied on the other 3 properties.

Current leucaena condition, based on 4 possible levels (low/poor, moderate, good and excellent), was excellent on 7 farms, while the other property, where growth was rated as low/poor, was located in a dry zone (600 mm AAR) and 2 years after planting (February 2013) only 50% of the plants had survived. The farmer attributed leucaena mortality to low rainfall on this property (ID 2 in Table 1), since the surviving plants have persisted in depressions where soil water content was highest. The same farmer is successfully grazing 588 ha of leucaena in the northeast of Salta province (ID 1 in Table 1), where AAR is 750 mm. Current grass condition (same condition scale) was good on 6 of the properties and low/poor on 2 farms, where very high stocking rates were employed. These 2 farmers reported that leucaena had been heavily grazed to restrict the height growth of leucaena plants, causing overgrazing of the inter-row grass. The main concerns about leucaena silvopastoral systems were poor grass persistence and excessive leucaena height.

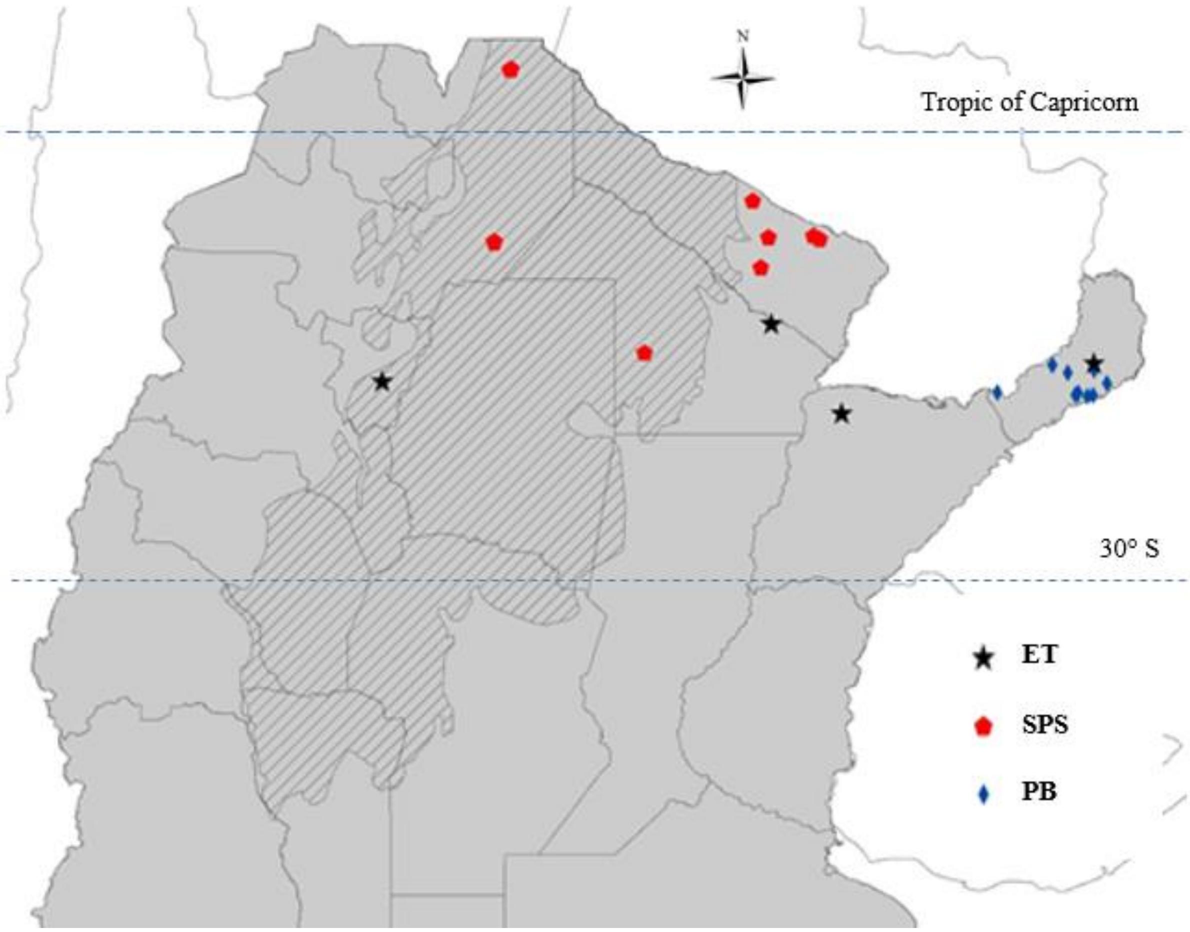

Figure 1. Leucaena feeding systems recognized and surveyed in Argentina in 2018: 8 hedgerow silvopastoral systems (SPS), 10 protein banks (PB) and 4 experimental trials (ET). The hatched area represents the Dry Chaco region.

Table 1. Characteristics of the leucaena hedgerow silvopastoral systems surveyed.

ID	AAR (mm/yr)	Leucaena area (ha)	Establishment (month and year)	Inter-row spacing (m)	Seed inoculation	Companion grass[1]	Cattle inoculation	Grazing pressure	Current leucaena condition	Current grass condition
1	750	588	Dec. 11–Mar. 14	5.5 (twin)	Yes	Mm	Yes	Very high	Excellent	Low/poor
2	600	104	Feb. 13	6 (twin)	Yes	Mm	Yes	High	Low/poor	Good
3	950	50	Oct. 17	6 (twin)	No	Ub	No	High	Excellent	Good
4	1,100	28	Mar. 14	5 (twin)	Yes	Nat - Mm	Yes	Very high	Excellent	Low/poor
5	1,350	650	Jan. 17–18	8–10 (twin)	Yes	Mm - Ub	Yes	High	Excellent	Good
6	1,150	950	Jan. 15–16	10 (twin)	Yes	Mm	Yes	High	Excellent	Good
7	1,000	4	Dec. 11	5 (twin)	No	Ub - Da	No	High	Excellent	Good
8	900	5	Dec. 17	6 (twin)	No	Ub	No	High	Excellent	Good

[1]Mm: *Megathyrsus maximus*; Ub: *Urochloa brizantha*; Nat: Native grass; Da: *Dichanthium aristatum*.

The survey indicated that recent adoption of leucaena in Argentina was based on technology developed over the last 2 decades in northern Australia, including mechanical seed scarification, improved agronomic practices, especially weed control during establishment, appropriate animal management and solving of the mimosine toxicity problem (Dalzell et al. 2006; Radrizzani et al. 2010). This 'Australian technology package' was adopted initially by cattle farmers in the neighboring central Chaco region of Paraguay, where the area sown increased from 20 ha in 2001 to about 10,000 ha in 2018 (Glatzle et al. 2019). A contributing factor in this expansion was the introduction of cv. Tarramba and the rumen bacterium from Australia, with the support of the Central Chaco Research Station (EECC) and the Initiative for Sustainable Agricultural Technology Research and Transfer (INTTAS) (Klassen 2005).

Protein banks

Ten properties with leucaena protein banks for dairy cattle production were surveyed in the 1,650 mm AAR zone of the Misiones province, in the humid Mesopotamia region of northeast Argentina (Figure 1; Table 2). These protein banks occupied a total area of 10 ha (average 1 ha/property, range 0.25–3 ha). Physical and chemical properties of prevailing soils on the farms did not present any major obstacles to the growth of leucaena. The main purpose of introducing leucaena to these grazing systems was to improve forage quantity and quality for increased milk production, and to enhance soil fertility from atmospheric nitrogen fixed by leucaena. Most of the farmers established leucaena between December 2010 and October 2011, while one planted it in October 2006. In contrast with hedgerow silvopastoral systems, all protein banks were planted in single rows 1.5–2.5 m apart using cvv. Cunningham and Peru. Seed was inoculated with rhizobia on 9 properties with specific rhizobium provided by IMYZA-INTA. The most common grass species sown between leucaena hedgerows was *Axonopus catarinensis* ('Jesuita gigante'), while other species were *U. brizantha* and *Cynodon nlemfluensis* ('pasto estrella'). All protein banks were rotationally grazed, 8 at high grazing pressure and the remaining 2 at very high grazing pressure. Cattle were not inoculated with the mimosine-degrading rumen bacterium on any property.

Current leucaena condition was excellent on 2 farms, good on 4 farms and poor on the remaining 4, owing to an ingress of weeds and/or overgrazing. Grass condition was good on 9 properties with only a single farm classed as moderate, associated with a very high stocking rate. The main concerns about leucaena protein banks were how to manage leucaena in relation to intensity and frequency of grazing and height control. Poor establishment and overgrazing were observed on farms that received less technical support. Farmers were not familiar with managing leguminous trees in their feeding systems and need ongoing technical support to optimize the establishment and persistence of their protein banks. While dairy farmers are still interested in growing leucaena in the Misiones and Corrientes provinces, based on the assessment of research and extension personnel, adoption remains low, probably due to a lack of promotion and information about how to utilize leucaena for feeding dairy and beef cattle.

Experimental trials

Four experiments were identified and surveyed. Their main purposes were: to evaluate leucaena persistence under different environmental conditions, agronomic practices and grazing systems; to determine the potential of leucaena introduction to improve forage and animal production; and to enrich soil fertility and C sequestration in the soil. The 4 experiments occupied a total area of 5.2 ha (average 1.3 ha/experiment, range 0.2–4 ha) and were located on Experimental Farms operated by INTA (Figure 1; Table 3).

'Cerro Azul' Agricultural Research Station, 'Cuartel Río Victoria' farm. This farm (ID 1 in Table 3) is located in the center of Misiones province where AAR is 1,650 mm. The soils in the experimental area are Ultisols and Oxisols (Rhodic Kandiult and Rhodic Hapludox, respectively, in the US Soil Taxonomy System), deep, well-drained, strongly acidic and of low fertility (including high aluminum concentration). Leucaena cvv. Cunningham and Peru were planted in October 1985 as a protein bank for dairy cattle production, in single rows 2 m apart. *Cynodon nlemfuensis* was planted between the rows.

Table 2. Characteristics of the leucaena protein bank systems surveyed.

ID	AAR (mm/year)	Leucaena area (ha)	Establishment (month and year)	Inter-row spacing (m)	Seed inoculation	Companion grass[1]	Cattle inoculation	Grazing pressure	Current leucaena condition	Current grass condition
1	1,650	0.9	Dec. 10	1.5 (single)	Yes	Ac	No	High	Good	Good
2	1,650	0.8	Jun. 11	1.5 (single)	Yes	Ac	No	Very High	Good	Moderate
3	1,650	3.0	Sep. 11	1.5 (single)	Yes	Ub	No	Very High	Poor	Good
4	1,650	1.0	Oct. 11	1.5 (single)	Yes	Ac	No	High	Poor	Good
5	1,650	0.5	Sep. 11	1.5 (single)	Yes	Ac	No	High	Good	Good
6	1,650	0.5	Sep. 11	1.5 (single)	Yes	Ac	No	High	Poor	Good
7	1,650	1.0	Sep. 11	1.5 (single)	Yes	Ac	No	High	Good	Good
8	1,650	0.3	Oct. 11	1.5 (single)	Yes	Ac	No	High	Excellent	Good
9	1,650	0.8	Sep. 11	2.5 (single)	Yes	Ac	No	High	Poor	Good
10	1,650	1.0	Oct. 06	1.0 (single)	No	Cn	No	High	Excellent	Good

[1]Ac: *Axonopus catarinensis*; Ub: *Urochloa brizantha*; Cn: *Cynodon nlemfuensis*.

Table 3. Characteristics of the experimental trials surveyed (1. INTA Cerro Azul; 2. INTA El Colorado; 3. INTA Leales; and 4. INTA Corrientes).

ID	AAR (mm/year)	Leucaena area (ha)	Establishment (month and year)	Inter-row spacing (m)	Seed inoculation	Companion grass[1]	Cattle inoculation	Grazing pressure	Current leucaena condition	Current grass condition
1	1,650	2.0	Oct. 85	2 (single)	No	Cn	No	High	Good	Good
2	1,150	0.8	Oct. 01	8 (single)	No	Cp - Ub	No	Very high	Excellent	Low/poor
3	880	4.0	Dec. 09	5 (double)	Yes	Ub - Cg	No	Very high	Excellent	Low/poor
4	1,350	0.2	Oct. 16	2–8 (double)	No	Ub	No	High	Excellent	Good

[1]Cn: *Cynodon nlemfuensis*; Cp: *Cenchrus purpureus;* Ub: *Urochloa brizantha*; Cg: *Chloris gayana.*

'El Colorado' Agricultural Research Station. This site (ID 2 in Table 3) is located in the southeast of Formosa province with AAR of 1150 mm. The soil in the experimental area is a Mollisol (Oxic Haplustoll in the US Soil Taxonomy System), clayey but well-drained, acidic. Leucaena cv. Cunningham was sown in a hedgerow pastoral system (single rows 8 m apart) in October 2001 with *Urochloa brizantha* and *Cenchrus purpureus* (syn. *Pennisetum purpureum*, 'pasto elefante') in the inter-row spaces. The pasture was rotationally grazed at very high stocking rates.

Animal Research Institute of the semi-arid Chaco region in Leales. Located in the southeast of Tucumán province, this site (ID 3 in Table 3) has AAR of 880 mm. The soils in the experimental area are Mollisols (Fluventic Haplustoll and Typic Haplustoll in the US Soil Taxonomy System), both well-drained with slow to good permeability, slightly basic reaction. Leucaena cv. K636 was sown as a hedgerow silvopastoral system in double rows 5 m apart after inoculation with specific rhizobium provided by IMYZA-INTA in December 2009. *Urochloa brizantha* was sown in the inter-row spaces in association with *Chloris gayana* ('grama Rhodes'). The pasture was rotationally grazed at very high stocking rates.

Corrientes Agricultural Research Station. The research station (ID 4 in Table 3) is located in the northwest of Corrientes province with AAR of 1,350 mm. The soil in the experimental area is a Mollisol (Aquic Argiudoll in the US Soil Taxonomy System), clayey, with low phosphorus, slightly acidic. Cultivar Cunningham was sown as a hedgerow silvopastoral system in October 2016 in double rows at different row spacings (2–8 m apart) with *U. brizantha* in the inter-rows.

Cattle were not inoculated with the mimosine-degrading rumen bacteria in any experimental trial. Leucaena condition was good to excellent at all sites, while grass condition was low/poor at El Colorado and Leales, associated with very high grazing pressure and overgrazing.

Apart from the 4 experiments, germplasm is preserved in 2 leucaena collections in Argentina. The first was established at INTA Corrientes in September 1994 and the second, a replica of the first, at the Animal Research Institute of the semi-arid Chaco region in Leales, Tucumán in September 2011. The 57 accessions of *Leucaena* spp. and hybrids in each collection were selected by Goldfarb and Casco (1998) for low-temperature tolerance and for forage yield and quality.

Future research and development priorities

The potential for further adoption of leucaena in subtropical Argentina, particularly in the Chaco region, is huge. Areas suitable for leucaena are mostly in the subhumid part of the Chaco region (AAR 700–1,200 mm), where large and medium size farms for breeding and finishing beef cattle predominate. Both domestic and export markets require tender beef that usually is produced in farming systems where cattle gain weight throughout the whole year, which is difficult for farmers to achieve on native pastures in the north of Argentina without significant protein and energy supplementation. Leucaena is an excellent protein source with potential to increase daily liveweight gains in the Chaco region (Radrizzani and Nasca 2014) and can contribute to reducing reliance on expensive protein supplements for growing and finishing cattle.

Other benefits from leucaena demonstrated in the Chaco region are its contribution to deep C storage/sequestration in the subsoil and to increased availability of soil N in the topsoil (Banegas et al. 2019). Moreover, there is substantial potential for dairy cattle farmers in the humid Mesopotamia region of northeast Argentina to establish leucaena to supply protein-rich forage and improve digestibility of native grasslands and improved grass pastures (Pachas et al. 2011; 2012). Nitrogen is the key element for sustaining grazing systems and there is a great opportunity for increasing usage of tropical forage legumes as cattle farming systems are intensified.

However, many issues still need to be clarified if maximum benefit is to be obtained from this 'new' technology, namely:

- *High establishment risks and costs*. Since leucaena seedlings are susceptible to ant attacks, weed and grass competition and predatory wildlife (rabbits), leucaena has to be planted as a crop using current cropping techniques (e.g. zero till for sowing leucaena into grass pastures, selective herbicides for weed control and appropriate insecticides for ant control). Furthermore, the erratic leucaena establishment associated with the unreliable summer rain of the semiarid Chaco region demands careful approach to establishment. The establishment cost of leucaena hedgerows, plus the establishment cost of the grass, plus seed scarification, plus ant, weeds and rabbit control, is higher (about double) than that of a pure-grass pasture. Consequently, a long productive life of leucaena is essential to achieve high returns and allow repayment of the initial investment in establishment.
- *Inoculation with an effective rhizobial strain.* This is required to promote vigorous leucaena growth. Native rhizobia in the soil in northeast Argentina are unlikely to form effective nodules with leucaena and will fix little, if any, N (Radrizzani et al. 2019). However, no commercial leucaena inoculant is readily available and only IMYZA-INTA supplies specific rhizobial strains to leucaena growers. To maintain the availability of inoculant, it is vital to preserve the IMYZA-INTA strain collection. This collection could also provide strains to assess rhizobial effectiveness and competitiveness in both the northeast and northwest regions. Moreover, since farmers expect to enhance soil N concentration using leucaena in their pastures, further research is needed to determine soil organic carbon and total N stocks, and to quantify actual biological N fixation by leucaena in association with different rhizobial strains under a range of environmental conditions, management practices and grazing systems.
- *Excessive leucaena height.* Large animals (big steers, bulls and cows) control leucaena height better than small animals, since they can break down tall stems (4–5 m) to reach leaf at the tips. However, most cattle in Argentinean herds are small animals, such as calves, heifers and even fattening steers (mean live weight at slaughter is 280–300 kg for the domestic market), and only a few animals in the herds are large (cows, bulls and steers finished for export). When leucaena plants grow to beyond browse height, material above the desirable height must be removed by trimming machines (e.g. slashers/mulchers, tree pruners and roller-choppers). This operation incurs unnecessary costs. Development of appropriate machinery and management practices to control leucaena height is necessary.
- *Low grass persistence*. This problem is closely linked to excessive leucaena height since, when grazing pressure is increased to control the height of leucaena hedgerows, overgrazing of the inter-row grass can result. Grass persistence and productivity over time need to be evaluated under different management practices and grazing regimes. Grass management in relation to leucaena density (inter-row spacing, double or twin rows, plant numbers/ha) and plant height also must be evaluated to properly understand the interaction between leucaena and grass (competition and ecosystem benefits).
- *Interactions between leucaena and grasses.* A better understanding of above- and below-ground interactions between leucaena and grasses is required to optimize the design and management of leucaena silvopastoral systems given the highly variable rainfall and severe dry seasons in the Chaco region. Studies on root distribution of both leucaena and grass, together with better knowledge of soil water usage and the resulting water use efficiencies under diverse leucaena densities (e.g. combinations of single or twin rows with varying inter-row spacings) and different environmental conditions, management practices and grazing systems, would provide information to promote efficient use and long-term stability of leucaena feeding systems.
- *Improved winter growth of leucaena*. This is needed as in many areas of northern Argentina growth is constrained by cold temperatures and frost (Radrizzani unpublished data), which occur at a time when leucaena is most needed to supply protein to ruminant diets. There are promising cold-tolerant accessions in the INTA collection which could increase forage availability in winter (Radrizzani et al. 2019). Research to evaluate these accessions under different environmental conditions, agronomic management and grazing systems needs to be continued. Furthermore, development of new leucaena varieties, cultivars and even interspecific hybrids, e.g. combining the frost resistance of *L. retusa* and *L. greggii* with the vigor and cool-season growth of *L. pallida*, *L. diversifolia* and *L. trichandra* and the superior forage quality of *L. leucocephala,* could help fill the winter forage gap and extend the environmental adaptation of *Leucaena* spp. in Argentina.
- *Mimosine toxicity*. Concern about mimosine toxicity and its management has contributed to restrict

adoption of leucaena as a forage for ruminants in Argentina (Radrizzani et al. 2019). Farmers are uncertain if their animals are suffering from toxicity since animals may still be performing better in systems with leucaena than in those without it. Research is needed to clarify the effects of feeding high leucaena diets on cattle performance (Shelton et al. 2019) and to improve management practices (Halliday et al. 2018), along with extension activities for future success of leucaena feeding systems.

- ***Scarce research and development programs*.** For successful leucaena adoption, farmers must increase their skills and become involved in the process of testing and validating the technology and even in establishing priorities for research. Research and extension specialists must develop and provide to farmers all necessary information for effective leucaena adoption, if the species suits their farming system. Participatory research and extension activities, including training courses, on-farm demonstrations and field days, are valuable techniques to ensure that accurate and practical information about the technology is readily available and is transmitted to farmers using appropriate tools. A flexible approach is necessary to allow farmer innovations to be included in the information base to improve recommendations and for these to be passed on to other farmers in their locality (neighbors) and in other regions.

Conclusion

Leucaena as forage for cattle production was not widely adopted in Argentina until 2010 and there is still a considerable potential for a broader adoption in the north of the country. However, expansion should take place wisely, selecting only suitable areas for its establishment, and using appropriate management practices to: reduce establishment costs and risk of failure; restrict leucaena height; enhance grass persistence; improve grazing strategies; and manage mimosine toxicity problems. Although some adoption can be achieved with relatively little intervention, for complex and new farming systems, such as leucaena silvopastoral systems, sustained support from the State and private sector is required in order to reach maximum adoption with real impact for the economic, environmental and social well-being of farmers and rural communities.

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ILC2018 Keynote Paper*

Leucaena feeding systems in Paraguay
Sistemas de alimentación con leucaena en Paraguay

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Abstract

Leucaena leucocephala became naturalized in Paraguay long ago. However, due to cases of toxicity in horses and cattle, now identified as mimosine toxicity, leucaena was considered a weed until the beginning of this millennium. At this time the mimosine toxicity problem was overcome by the introduction of ruminal fluid from Australia containing the mimosine-degrading and -detoxifying bacterium *Synergistes jonesii*. As long as an internationally funded technical assistance project was operating (offering technical advice, provision of seed, seed scarification service and transmission of ruminal fluid containing *Synergistes*), the area sown to leucaena (either in twin rows into grass pastures or as fodder banks) increased rapidly in Paraguay, particularly in the Chaco area. However, the powdery fluvisols of the drier parts of the Chaco were not well suited to growth of leucaena, as persistence was restricted due to the impact of rodents, termites and also leaf-cutting ants, which prosper particularly well in this part of the Chaco. In more humid areas with usually heavier soils, currently leucaena represents an integral part of the feeding systems in hundreds of Paraguayan farms (large-scale as well as smallholders), mainly for steer fattening and dairy cow supplementation. After taking into account the above-mentioned setbacks, the total area of leucaena is currently estimated at about 10,000 ha.

Keywords: Chaco, fodder bank, mimosine toxicity, row seeding, shrub legumes, steer fattening.

Resumen

Leucaena leucocephala ha sido naturalizada en Paraguay desde hace mucho tiempo. Sin embargo, debido a casos de intoxicación en caballos y bovinos, ahora identificada como toxicidad por mimosina, la leucaena fue considerada una maleza hasta principios de este milenio. El problema de la intoxicación se ha podido solucionar mediante la introducción, en 2003 desde Australia, de fluido ruminal con la bacteria *Synergistes jonesii* que degrada y desintoxica la mimosina, Mientras estuvo en funcionamiento un proyecto de asistencia técnica financiado con fondos internacionales, el cual ofrecía asesoría técnica, suministro de semilla, servicio de escarificación de semilla y provisión de fluido ruminal con *Synergistes*, el área sembrada con leucaena (ya sea en forma de doble-hileras en pasturas o como bancos de forraje) aumentó rápidamente en Paraguay, particularmente en la región del Chaco. Sin embargo, los fluvisoles de las partes más secas del Chaco resultaron no ser aptos para el cultivo de la leucaena, ya que su persistencia estuvo afectada por roedores, termitas y también hormigas cortadoras de hojas. Estas plagas prosperan particularmente bien en esta parte del Chaco. En áreas más húmedas, con suelos generalmente más pesados, la leucaena representa actualmente una parte integral de los sistemas de alimentación animal en centenares de granjas paraguayas (tanto propiedades grandes como pequeñas fincas), principalmente para novillos de engorde y suplementación de vacas lecheras, abarcando una superficie de aproximadamente 10,000 ha.

Palabras clave: Bancos de forraje, ceba de novillos, Chaco, hileras dobles, leguminosas arbustivas, toxicidad por mimosina.

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Introduction

The leguminous forage shrub *Leucaena leucocephala* is not native to Paraguay; having been introduced a long time ago it has been partly naturalized. Anecdotally, there was a major effort during the 1970s to grow leucaena on a broad scale for grazing and feeding purposes and to integrate this excellent forage, also named ´tropical alfalfa´, into local feeding systems. Clearly, these efforts failed and farmers had a generally poor image of leucaena. Although it was used occasionally by small-holders as a source of forage, it was considered primarily a weed, as cases of hair loss, particularly among horses, were observed.

In the 1990s, a German-financed agricultural R&D project commenced in the Paraguayan Chaco. Initial small-scale, short-term grazing trials demonstrated leucaena´s high potential to increase growth of steers, even when both grass and leucaena leaves were dry but abundant after being frosted in winter (Glatzle 1999; Cabrera et al. 1999). In studies over longer grazing periods, however, monthly bodyweight gains in steers decreased progressively, with weight losses being experienced after animals grazed leucaena for approximately 6 months (Klassen 2005) (Figure 1). The cause of this phenomenon was identified as mimosine toxicity. It became obvious that a solution to this problem was crucial if wider acceptance of leucaena as a forage crop at farm level was to be achieved.

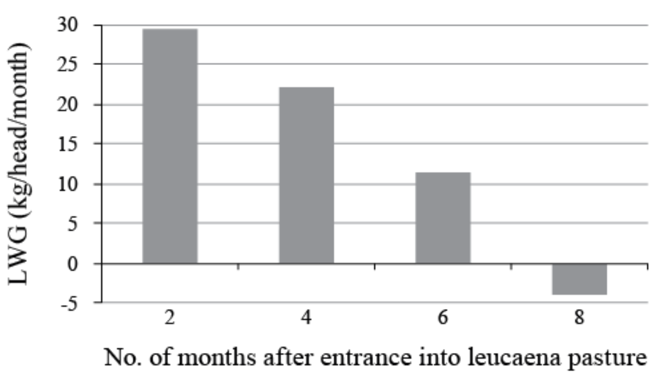

Figure 1. Monthly liveweight gains (LWG) of steers (without mimosine-degrading bacteria) as a function of the time spent grazing on leucaena.

Dealing with the mimosine toxicity problem

In early 2003, INTTAS (Iniciativa para la Investigación y Transferencia de Tecnología Agraria Sostenible) contacted Dr Raymond Jones, the discoverer of the mimosine-degrading rumen bacterium *Synergistes jonesii* (Jones 1986), a retired senior scientist from the CSIRO Davies Laboratory in Townsville, Australia and invited him to Paraguay. After extended zoo-sanitary clearing procedures in Australia and Paraguay, Dr Jones managed to bring a thermos of ruminal fluid from Australian steers grazing leucaena, which contained the appropriate bacteria. Immediately on arrival at the Central Chaco Research Station (it was after midnight) we inoculated 2 rumen-fistulated steers with this fluid, about 72 hours after it had been extracted from steers in Queensland. The recipient animals had been prepared by feeding abundant leucaena for several days. By 5 days after inoculation a urine coloration test demonstrated that these steers were effectively degrading mimosine in their rumens (Jones and Megarrity 1986).

After some animal-to-animal transmission tests of the mimosine-degrading capability of the rumen fluid we offered a service for ruminal fluid transmission to farm animals grazing on leucaena. This service was soon taken over by a local agricultural extension program that maintained fistulated steers on leucaena as rumen fluid donors. Between 2003 and 2017 an estimated 800 farmers were provided with the mimosine-degrading microflora in order to prevent mimosine toxicity from developing in stock grazing leucaena. Even leucaena growers from neighboring Argentina came to collect a thermos of rumen fluid for dosing their animals.

Initially the ruminal fluid (10 mL/animal) was injected with a rumen injection gun to about 20% of the animals in the target herds grazing leucaena. The ruminal fluid was transported in a flexible rubber bottle (Figure 2) to avoid suction of air into the container as the fluid volume was reduced with each injection. Oxygen is lethal for the obligate anaerobic *Synergistes* bacterium. When injection into the rumen was not properly executed, isolated cases of infections happened (resulting in subsequent animal mortality in one case). Therefore we changed to an oral application system (Figure 3), and doubled the dose to 20 mL/animal. This method has proven quite effective.

When considering some basic rules, it is necessary to inoculate only a single group of animals per farm, as the ruminal bugs are readily transmitted from one animal to another within the same herd. Jones (1986) suggested that, as *Synergistes* needs mimosine (or its metabolite 2,3-DHP) as its major carbon and energy source, these organisms are lost from the rumen within 6–9 months, after the delivery of substrate ceases when animals are no longer fed on leucaena. However, we observed mimosine toxicity symptoms in a group of dairy cows when they re-entered a leucaena fodder bank after a break of only 4 months without access to leucaena. We assumed that the diet of the dairy cows, which was primarily silage and concentrate feed, reduced the survival time of *Synergistes* in the rumen in the absence of mimosine. On commercial beef ranches some steers are usually kept as donor animals on leucaena pasture for most of the year. These animals are mixed with groups of 'naïve' steers to provide a source of inoculum when these groups enter leucaena for fattening. When fattened animals are sold, the lightest ones are usually held back and mixed with the next group for fattening.

Figure 2. Transmission of ruminal fluid with a rumen injection gun supplied from a flexible rubber bottle to avoid suction of air.

Figure 3. Oral application of ruminal fluid is less risky for the recipient animal but requires more restraint.

Large-scale adoption of leucaena feeding systems on farms

The solution to the mimosine problem in 2003 was the 'launching pad' for a rapid expansion of the area sown with leucaena in the semi-arid and subhumid Chaco region (600–1,200 mm of annual, summer-dominant rainfall) with geologically young, mostly neutral to alkaline soils, as well as the more humid ecosystems in Eastern Paraguay (1,200–1,700 mm annual rainfall) with ferralitic and slightly more acidic soils. This expansion was supported and driven by the active promotion of a technology package for leucaena establishment and management made public through numerous field days, active participation in agricultural expositions with exhibition stands, pamphlets, extension videos (which were even broadcast on television) and a well-attended leucaena congress with international (including Australian) participation organized in the Chaco in 2005.

The disseminated technology package covered all relevant aspects of leucaena establishment, including seedbed preparation, sowing methods, initial weed and pest (leaf-cutter ants) control and leucaena management under grazing. Acceptance of the technology was supported by the offer of a number of services provided by the R&D project INTTAS: general technical assistance to leucaena growers; provision of ruminal fluid containing *Synergistes* bacteria; and supply of leucaena seed, both the common Peru type and the new cultivar Tarramba (tree type, fast-growing and more frost-tolerant). By signing a contract with the Australian license holder, Leucseeds, INTTAS acquired the right to multiply and commercialize Tarramba seed in Paraguay (Figure 4) and was equipped with a prototype of a patented seed-scarification device. Naegele (2005) summarized the crucial points in leucaena management, while this information is also accessible on the INTTAS website [Glatzle et al. (2004, 2006, 2007); Klassen et al. (2007); Naegele et al. (2007)].

As a consequence of the active technology promotion, the area sown with leucaena in the Paraguayan Chaco increased rapidly to an estimated 10,000 ha within a few years, almost all of which (99%) was sown in twin rows at a distance of 5–10 m into existing grass pastures (mostly Gatton panic). This was achieved after either total soil tillage or tillage of strips within the pasture (Figure 5), or, in more humid regions, sowing in combination with a crop (Figures 6 and 7). Animal production (finishing steers or bulls) per unit area and per head increased remarkably with the incorporation of leucaena (Table 1; Figure 8). The responses in productivity to sowing of leucaena are generally smaller in summer than in winter, when grass quality is low (Figure 9). About 5% of the total area sown with leucaena is represented by high density stands, used as fodder banks, mostly in smallholder dairy farms in the Chaco and in Eastern Paraguay. These are either directly grazed on an hourly basis or used by cut-and-carry, partly offered as chopped fodder while milking (Cabrera 2005). Dairy cows that had access to leucaena produced up to 2 liters more milk per day than those from the control group that grazed on Gatton panic pasture only (Klassen et al. 2007).

Figure 4. Label of a bucket of Tarramba seed, harvested, processed and marketed in Paraguay under Australian license.

Figure 5. Leucaena sown in twin rows into Gatton panic pasture, previously tilled in strips.

Figure 6. Leucaena establishment in twin rows accompanied by a sorghum crop in the first year.

Figure 7. Leucaena establishment with zero-tillage in strips in a soybean crop in humid Eastern Paraguay.

Table 1. Carrying capacity and liveweight production per ha of steers grazing Gatton panic alone and Gatton panic with leucaena sown in twin rows (Glatzle and Klassen 2004). AU = Animal Unit = 450 kg live weight.

Pasture	Stocking density (AU/ha)	Liveweight gain (kg/ha)
Gatton panic	1.1	211
Gatton & leucaena	1.7	476

Grazing period: 15.7.2003 to 15.4.2004, at Rio Verde, Chaco. Steers had been inoculated with *Synergistes* ruminal microflora.

Figure 8. Brahman bulls grazing leucaena sown in twin rows in Gatton panic pasture.

Figure 9. The presence of leucaena in pastures boosts animal performance, particularly in winter, when grass is dry and of low quality.

The present situation and leucaena persistence

When external funding of the R&D project INTTAS ended in 2007, the services provided to farmers could no longer be maintained. Seed production became virtually a matter of farmers' own initiatives (which presented few concerns in Paraguay as labor costs are low and minimal seed is required per hectare). Mechanical seed scarification is available nowadays from a private seed grower, and ruminal fluid containing *Synergistes* from a local cooperative in the Chaco. However, the absence of active promotion and associated services offered from a single entity has considerably reduced the rate of expansion of leucaena feeding systems during the past 10 years. Furthermore, major areas of well-established leucaena pastures have been progressively lost, particularly in zones with an average annual rainfall of <800 mm and with silty, powdery soils (fluvisols and others, very common in the dryer parts of the Chaco), where termites and rodents (tuco tuco, *Ctenomys* spp.) killed increasing numbers of leucaena plants, thinning out the stands. This is certainly due to the fact that these rodents and certain species of termites prosper particularly well on these light-textured soils in the dryer areas of the Chaco. In more humid zones, however, on clay soils and coarse sands, leucaena has usually persisted very well for at least a decade, even when a high saline ground water table was present (which apparently does not affect deep-rooting leucaena). In some years with particularly heavy frosts, leucaena not only lost its leaves but also died back to the base, from where plants re-sprouted vigorously in the next spring. Today, we consider that the total area sown to leucaena in Paraguay has found an equilibrium slightly below the 10,000 ha level, with a balance between newly established leucaena pastures and those lost due to rodents and ants.

However, particularly among smallholders, leucaena has been well adopted as a source of forage and firewood, and is very common in fodder banks in the home gardens of small-scale producers.

Conclusions

Leucaena is a highly productive and valued tropical/ subtropical forage legume, well adapted to most regions of Paraguay. While the mimosine toxicity problem prevented earlier integration into the country's feeding systems, introduction of the mimosine-degrading bacteria in 2003 removed this impediment. From that time, the area sown to leucaena (either in twin rows into grass pastures or as high-plant-density fodder banks) increased rapidly until it found a new equilibrium between new establishments and die-offs, mainly due to pests. Today, on hundreds of Paraguayan farms (large-scale as well as smallholders) leucaena represents an integral part of the feeding systems, mainly for steer fattening and dairy cow supplementation. Although the initial dynamics of leucaena expansion have slowed down considerably, the past decade can be considered as a consolidation phase, which allowed the documentation of where leucaena is well adapted and persistent. Hundreds of thousands of hectares of country in Paraguay are suitable for leucaena, the respective technology packages are available and improved animal performance has been demonstrated. If another promotional campaign (which would require some funding and considerable enthusiasm) could be mounted, it might trigger renewed interest in leucaena with another increase in area sown and corresponding increases in animal production.

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(Note of the editors: All hyperlinks were verified 16 August 2019.)

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Leucaena feeding systems in Cuba

Sistemas de alimentación con leucaena en Cuba

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Keywords: Beef production, environmental benefits, grass-legume mixtures, milk production, profitability, protein banks, tree legumes.

Introduction

The utilization of leucaena (*Leucaena leucocephala*) for ruminant production by farmers in Cuba began during the 1980s based on the concept of protein banks covering 100% of the grazing area. In the last decade, a National Program to promote silvopastoral systems with leucaena in the livestock production sector was developed with the participation of 1,543 cattle farms with an emphasis on milk production. The cattle farms occupied 20,000 ha of which 7,000 ha was as protein banks, while the remaining area was planted with leucaena in association with grasses. Most of the work was carried out within the research agenda of the Instituto de Ciencia Animal (ICA).

The commercial varieties of leucaena used were mainly cv. Peru and to a lesser extent cv. Cunningham. The area of each livestock farm ranged from 20 to 70 ha. The work was developed with producers from both the State and non-State sector.

Establishment and plant management

Soil preparation for sowing was with strips when the existing grass was retained (star grass – *Cynodon nlemfuensis*) or with full cultivation when a new grass was introduced (guinea grass – *Megathyrsus maximus*). Following inoculation of the seed planting occurred in double rows 0.70 m apart, with 3–4 m inter-row spacing to achieve plant populations of 7,000–8,000 trees/ha; fertilizer was not used. There were problems with weediness during the establishment phase, and with overgrazing and general management of the pastures, partly due to a lack of economic resources. The first grazing after sowing occurred when a plant height of 120–140 cm was reached (Ruiz and Febles 2012).

After 4 years of growth, plants were pruned to limit woody growth and maximize edible biomass production. The height of pruning was 0.5 m with decumbent star grass and 1 m with the more erect guinea grass. Pruning occurred from January to March to maximize availability of forage during the dry season or from April to June when quicker regrowth was required.

Physiology of the rumen

Ruminal bacteria capable of degrading mimosine and DHP were isolated for the first time in Cuba (Galindo et al. 1995), and their persistence in the rumen of animals under normal feeding conditions was confirmed. Other studies showed that there was no mimosine in the rumen of the cattle, sheep and goats consuming leucaena, and levels of DHP were non-toxic (Galindo et al. 2012). Hence, the inclusion of leucaena in the ration of animals even at levels up to 100% are considered not to represent a potential danger for animal feeding in Cuba.

The effects of the inclusion of 4 levels of leucaena (0, 20, 40 and 60%) in a ration with star grass for rams was evaluated and it was shown that it was possible to include

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high levels of leucaena in the diet (Galindo 2001). The legume inclusion improved total digestibility of both fiber and dry matter consumed, and the nitrogenous fractions of the rumen contents suggested that conditions for microbial protein synthesis and by-pass protein availability for post-ruminal absorption were enhanced (Galindo et al. 2012).

Analysis of blood metabolites in fattening bulls with free access to grazing of 100% leucaena showed normal values of the thyroxine and tri-iodothyronine hormones (Castillo et al. 2012).

Animal production based on leucaena

Dairy production

With leucaena, associated with guinea grass, production per milking cow was 8–9 L/day (Jordán 2001); annual production increased from 2,790 to 6,344 L/ha, and total milk production from the project area rose from 53,056 to 119,136 L. The Holstein cows were supplemented with 196 g concentrate/L of milk and stocking rate increased from 2 to 2.7 animals/ha. Milk production per cow in the leucaena-guinea grass system was similar to that of cows fed N-fertilized guinea grass pasture and supplemented with 588 g concentrate/L milk. The milk contained adequate levels of total solids (12–13%), fat (3.5–3.7%) and protein (3.2–3.3%) (Jordán 2001). Likewise, with crossbred animals (more than 66% Holstein) production ranged between 8 and 10 L/cow/d (Figure 1). There was a close link between the increase in milk production and biomass of leucaena on offer (Jordán 2012).

Figure 1. Grazing of leucaena-star grass pasture by dairy animals.

Performance of females

F1 animals (10 months of age and 150 kg mean weight), in 6–8 rotationally grazed leucaena-star grass paddocks (5–6 days occupancy) without fertilizer application or supplementation, and with a stocking rate of 2.0–2.5 animals/ha, gained 450 g/d (Mejías 2004; 2008). The results were similar to those obtained by a second group under equal grazing conditions on a grass-only pasture but supplemented with 2 kg concentrate/animal/day. *Bos taurus* animals with an initial weight of 285–300 kg reached puberty at 22 months with 77% first service conception rate. Calf birth weights were greater than 35 kg. In these systems more than 90% of the animals reached a body condition between 3.0 and 3.5 (Zarragoitia et al. 1992). As above, results were similar to those obtained by a group under equal grazing conditions on grass-only pastures but supplemented with 2 kg concentrate/animal/day.

Beef production

Gains of 620 g/animal/day were recorded in a rotationally grazed leucaena-guinea grass pasture with a stocking rate of 2 animals/ha. These gains were 147% higher than on the grass-only paddocks (Castillo et al. 1989).

When using natural grasses associated with leucaena at a stocking rate of 2 animals/ha and rotationally grazing 4 paddocks, weight gains were 600 g/animal/day, when supplemented during the dry period with sugarcane or molasses and urea to 3%. Without leucaena, weight gains were 500 g/animal/day (Castillo et al. 1999).

On a leucaena-star grass pasture, grazed at 3 animals/ha, daily gains of 781 g/animal were achieved without supplementation (Castillo et al. 2012). Slaughter of the animals occurred at 400 kg live weight and 26–27 months of age with a hot carcass yield of 54% and 7–8% of fat (Figure 2). The results obtained were similar to those obtained on star grass without leucaena but fertilized with 100 kg N/ha/year.

Figure 2. Grazing of leucaena-star grass for beef production.

Improvement of the environment

In a leucaena-guinea grass system, the initial plant population of approximately 1,100 leucaena plants/ha was adjusted to 400–600 plants/ha after 4 years to avoid the negative effects of shade on the growth of the grass. The chemical composition of the soil was improved by the recycling of nutrients, and there was an appreciable contribution of N from biological fixation and decomposition of the litter (Lok et al. 2005). The structural stability of the soil increased with time as soil carbon storage was increased (Lok 2012), with the added environmental benefit of reduced methane gas emissions (Galindo et al. 2012).

Biodiversity increased when leucaena was present (Lok 2005), and earthworms reached highest frequency with predominance of the species *Polypheretima elongata*, *Onychochaeta elegans* and *Diplotrema* spp. Other indicators of biodiversity were the increased frequency of Arthropoda followed by Annelida in the brown soils planted with a mixture of guinea and star grasses and leucaena; and of Arthropoda, followed by Annelida, in red soils planted with guinea grass and leucaena (Lok 2012).

With time, there was an increase in predatory *Heteropsylla cubana*, but the population did not reach harmful thresholds. The incidence and stability of the bio-regulating *Chilocorus cacti* increased as well (Valenciaga 2003).

Animal health

There was no harmful effect of mimosine or its derived product DHP (hydroxipyridone) on vital organs such as the liver, thyroid, heart and thymus, and blood indicators were not affected when leucaena-star grass was fed to livestock (Castillo et al. 2012). In comparison with grass-only diets, gastrointestinal nematode infestations were reduced by 66% when leucaena was included. The main genera of parasites found were, in order of importance, *Haemonchus*, *Oesophagostomum*, *Cooperia* and *Ostertagia* (Soca et al. 2007). Body composition was also improved with a decrease of diarrhea and respiratory diseases (Soca 2005).

Economic impact on production systems

In the livestock farms where this legume has been introduced, gross returns/ha/year ranged from 1,898 to 4,056 Cuban pesos, and the benefit:cost ratio increased in the range of 2.5–4.5. The economic analysis indicated that a lower proportion of income was needed to cover production expenses (Cino et al. 2006; 2011). Particularly positive aspects were savings in the use of concentrates and a decrease in production costs.

The results obtained suggest that the present leucaena technology is an economically viable option for livestock production in Cuba and other tropical countries. Further research on its application and adoption is indicated.

Dissemination of knowledge

All personnel in the productive sector who participated in the technology transfer process were systematically trained. Particularly the need for systematic technical assistance in the early stages of technology transfer became evident.

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*ILC2018 Poster and Producer paper**

Use and performance of leucaena (*Leucaena leucocephala*) in Venezuelan animal production systems

Uso de leucaena (Leucaena leucocephala) *en sistemas de producción ganadera venezolanos*

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Keywords: Alley hedgerow systems, protein banks, silvopastoral systems, tree legumes.

Silvopastoral systems

One of the limitations for the efficient production of meat and milk in livestock systems of Venezuela is the scarcity of high-protein forage from plants adapted to the acid soils and prolonged droughts of the Llanos (savannas). The Llanos cover an estimated area of 15–20 M ha predominantly in the southeast and southwest of the country. They are mainly covered with native grasses (*Trachypogon* spp.), which have low carrying capacity (0.10–0.25 AU/ha; 1 AU = 450 kg bovine).

In Venezuela silvopastoral systems are found mainly in the tropical dry forest (1,000–1,200 mm average annual rainfall, AAR) of the savanna plains and the very dry tropical forest (800–900 mm AAR) and semi-arid (700 mm AAR) environments of the country (Escalante 1985). Other important production areas are south of Lake Maracaibo in Zulia State and the intra-montane valleys in the central states of Aragua, Carabobo, Yaracuy, Portuguesa and Cojedes, as well as the highland dairy cattle ranch areas in the states of Táchira, Mérida and Trujillo.

Despite the presence of some forage tree species that are well adapted to savanna conditions, such as samán (*Samanea saman*), matarratón (*Gliricidia sepium*) and guácimo (*Guazuma ulmifolia*), their potential for intensive use in agroforestry systems has not been realized. Use of these species has been limited to living fences and providing shade for livestock. Only *G. sepium* has been used in alley/hedgerow pastoral systems to a limited extent (Escalante 1985).

Use of leucaena

Livestock systems utilizing leucaena (*Leucaena leucocephala*) were developed and promoted in the 1970s and 1980s by various organizations, including the National Center of Agricultural Research (CENIAP), the Venezuelan Central University (UCV) and Zulia University (LUZ). Leucaena was used as a protein bank, alley/hedgerow grazing systems and living fences and more recently in intensive silvopastoral systems. The uptake of leucaena as a strategic component for dairy cattle has allowed farmers to increase the carrying capacity of their land as well as animal productivity.

In 2003 it was estimated that 800–1,500 ha of leucaena forage systems had been established in Venezuela, distributed mainly in the states of the western central zone: states of Zulia, Falcón, Lara, Yaracuy, Táchira, Trujillo, Barinas, Portuguesa, Cojedes and Aragua (Espinoza et al. 2003). At the present time it is estimated that the area planted with leucaena has significantly increased due to farmers's interest.

A significant limitation in the adoption of leucaena forage systems has been the limited availability and high cost of planting material. This is particularly the case for protein banks where high densities of 10,000–20,000 plants/ha are required. Farmers have identified reduced establishment costs, increased availability of high quality seed and of affordable good quality nursery seedling stock as options for accelerating the adoption of leucaena planting. In an attempt to reduce cost of seed and improve its availability, they often obtain seeds from neighbors and

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establish their own nurseries to develop seedlings to transplant at the beginning of the wet season. Seeds are inoculated with *Rhizobium* spp. provided by either commercial companies or government agencies. Before planting, weed control is carried out and fertilizer is applied. First grazing commences 4–5 months after planting, when plants have reached a height of 150–200 cm.

Dairy producers who establish protein banks usually introduce the cattle for direct browsing of a small plot (e.g. 1,000 m^2, depending on the size of the herd) for 2 hours after milking. After the plot has been browsed sufficiently the leucaena plants are pruned at a height of 90–120 cm and allowed to regrow for 75–90 days before they are grazed again.

The alley/hedgerow system is also used in dairy production areas. Twin rows (100 cm apart) of leucaena plants are established, with 50–100 cm between plants within rows. The twin hedgerows are usually separated by grass alleys (inter-row space) of 4 m wide. The estimated plant density of leucaena in these systems is 4,000–8,000 plants/ha (Figure 1). Animals graze the grass and browse the leucaena plants; after that the trees are pruned.

Figure 1. Pasture alley/hedgerow system of African star grass (*Cynodon nlemfuensis*) with twin hedgerow of *Leucaena leucocephala* at Fundación para el Desarrollo Agrícola, DANAC Foundation, Yaracuy State, Venezuela. Photo: E.E. Escalante.

In 2002, a diversified multi-stratified intensive silvopastoral system of 4.2 ha was established at the DANAC Foundation, Yaracuy State. In plots 20 m wide a central row of leguminous trees, e.g. samán, cují (*Prosopis juliflora*) and cañafistola (*Cassia moschata*), was established to provide shade, comfort and edible pods. Five rows of leucaena were planted on each side of the central leguminous tree row, at a spacing of 1 × 1 m within a guinea grass (*Megathyrsus maximus* syn. *Panicum maximum*) pasture. This system requires a leucaena plant density of 5,000 plants/ha. Teak (*Tectona grandis*) and other valuable wood species were planted in the borders around the plots as living fences (Figure 2). The system increased the carrying capacity from 1 AU/ha to 3 AU/ha (Escalante et al. 2011) and daily milk yields by 1.5 L/cow.

Figure 2. Intensive multi-stratified silvopastoral system of 5 leucaena rows in a guinea grass (*Megathyrsus maximus* syn. *Panicum maximum)* pasture with teak (*Tectona grandis*) planted around the border and samán (*Samanea saman*) in the middle of the grazing plot, established at the DANAC Foundation, Yaracuy State, Venezuela. Photo: E.E. Escalante.

Selected scientific studies

In studies conducted by FONAIAP (Fondo Nacional de Investigaciones Agropecuarias) in Zulia State, the agronomic performance of 90 leucaena accessions was evaluated (Faría-Mármol 1994). Dry matter (DM) yields of up to 10.4 t/ha were obtained for accessions CIAT 17129 and 10.9 t/ha for CIAT 17128, subjected to 9 harvests over a period of 315 days. CIAT 17129 produced almost 4 times as much edible DM in the rainy season as in the dry season (8.5 t/ha vs. 2.2 t/ha) and crude protein (CP) concentration was 27.3% in the wet and 21% in the dry season.

A survey of 60 randomly selected dual-purpose farms in Trujillo State determined the level of adoption of leucaena as a grassland improvement strategy (Osechas et al. 2008). Pastures on most of the farms were based upon either guinea grass or African star grass (*Cynodon nlemfuensis*). The survey found 21.1% of the farmers used *L. leucocephala* as a protein supplement for grazing livestock. Leucaena pastures were intensively grazed for 2–4 days, then rested for 30–40 days. Mean milk yields of cows and animal liveweight gains of beef cattle were 5.12 L/cow/d and 389 g/hd/d, respectively during the rainy season.

A study carried out by Torres et al. (2002) determined the optimal distance of sowing configuration for leucaena seed production. A planting configuration of 2 × 2 m increased seed yields and seed size and weight in comparison with 1 × 1 m. Seed quality (germination percentage) was not affected.

The forage quality of leucaena, matarratón and casco de vaca (*Bauhinia forficata*) was compared in terms of crude protein, ash and ether extract concentrations (Blanco et al. 2015). Leucaena had the highest values for crude protein (28.6%), ash (17.2%) and ether extract (7.3%) concentrations. This demonstrates the excellent nutritive value of leucaena as a protein supplement to tropical grass forage.

Rodríguez et al. (2015) conducted a study to compare the agronomic performance of leucaena and mulberry (*Morus* spp.). Leucaena grew taller than mulberry (124 vs. 94 cm; P<0.01) and produced higher DM yields (295 vs. 210 g/plant; P<0.01); it was most productive when harvested at a cutting height of 50 cm.

Conclusions

The review of literature and the author's personal experience suggest that there is still great potential for leucaena to improve the carrying capacity and productivity of beef and dairy systems in the Venezuelan savannas and other milk production areas. Additional research effort is required to determine if leucaena systems are adapted to the acid infertile savanna soils, where a marked dry season combined with poor quality grasses is a severe limitation for efficient livestock production.

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*ILC2018 Keynote Paper**

Tarramba leucaena: A success story for smallholder bull fattening in eastern Indonesia

Leucaena Tarramba: Un caso de éxito para el engorde de toros en el este de Indonesia

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Abstract

Leucaena (*Leucaena leucocephala*) cv. Tarramba was first introduced to eastern Indonesia (East and West Nusa Tenggara Provinces) as part of an ACIAR project in 2001–2003. Its superior value was recognized immediately as it: was preferred by cattle over local leucaena; was less affected by psyllids; provided better dry season growth; and produced poles suitable for construction. In on-farm Bali bull feeding demonstrations, Tarramba leucaena doubled weight gains compared with traditional practices, enabling the most progressive farmers to win local bull-fattening competitions. Owing to strong demand for seed, the East Nusa Tenggara Assessment Institute for Agriculture Technology, in collaboration with the Provincial Livestock Department, assisted smallholders to establish seed orchards to ensure that professionally produced and packaged Tarramba seed was available for commercial sale. By the end of the ACIAR involvement, approximately 2,000 kg of Tarramba seed had been distributed to farmers, in addition to farmer-to-farmer seed sales. Approximately 800,000 ha of land in East Nusa Tenggara Province is suitable for Tarramba leucaena so the potential for this legume to contribute to beef production in the region is huge. Tarramba is now contributing to forage development in other parts of Indonesia as well as in Timor-Leste.

Keywords: Liveweight gains, seed production, tree legumes.

Resumen

Leucaena (*Leucaena leucocephala*) cv. Tarramba se introdujo por primera vez en el este de Indonesia (provincias de Nusa Tenggara Oriental y Nusa Tenggara Occidental) como parte de un proyecto de ACIAR en 2001–2003. Inmediatamente se reconoció el valor superior de este cultivar, debido a: fue preferido por el ganado en comparación con la leucaena local; fue menos afectada por psílidos (insectos de la familia Psyllidae); creció mejor en la época seca; y produjo postes de madera para la construcción. En demostraciones de engorde de toros de la raza Bali *(Bos javanicus*), se duplicaron las ganancias de peso vivo de los animales con el cv. Tarramba en comparación con las prácticas tradicionales, lo que les permitió a algunos agricultores innovadores ganar concursos locales de engorde de toros. Debido a la fuerte demanda de semilla, East Nusa Tenggara Assessment Institute for Agriculture Technology, en colaboración con Provincial Livestock Department, trabajó con pequeños agricultores para establecer semilleros con el fin de asegurar que la semilla de Tarramba sea producida y empacada profesionalmente, y estuviera disponible en el mercado. Finalizado el proyecto de ACIAR, se habían distribuido aproximadamente 2,000 kg de semilla de Tarramba, además de las ventas de semilla de agricultor a agricultor. Solo en la provincia Nusa Tenggara Oriental existen aproximadamente 800,000 ha de tierra apta para la leucaena cv. Tarramba; por tanto su potencial para contribuir a la producción de carne en la región es muy alto. El éxito de Tarramba en el este de Indonesia está ahora contribuyendo al desarrollo de leucaena en otras partes del país, así como en Timor-Leste.

Palabras clave: Árboles leguminosos, ganancia de peso, producción de semilla.

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Introduction

Leucaena leucocephala or 'Lamtoro' has been well known for decades in eastern Indonesia. However, until the early 2000s, apart from limited usage of what was termed 'local' leucaena for feeding cattle in Sumbawa and Timor (Nulik 1998; Piggin and Nulik 2005; Panjaitan et al. 2014), there was minimal on-going interest in the species. This resulted from inadequate knowledge by many farmers of the value of the species as fodder for cattle as well as to the availability of relatively large areas of native grassland for free grazing (Kana Hau et al. 2014). Many farmers in Indonesia believed that the 'local' variety of leucaena was unpalatable to cattle. Finally, the arrival of the psyllid insect (*Heteropsylla cubana*) in the late 1980s devastated existing stands of leucaena and put an end to further plantings.

The introduction of Tarramba leucaena to Indonesia

Leucaena leucocephala cv. Tarramba (syn. accession K636) was released for commercial use in 1995. It was described as more cold- and frost-tolerant than other varieties of *L. leucocephala* available at the time, but not competitive with other *Leucaena* spp., such as *L. diversifolia* and *L. pallida*, known for their cool tolerance at high elevations in Hawaii. However, it was known to display some tolerance of the leaf-sucking insect *Heteropsylla cubana*, largely due to its ability to continue growth through lateral branching while under psyllid pressure. Trials in Hawaii and Australia showed it to be superior in growth and yield to other accessions of *L. leucocephala* available at the time, when infested by the psyllid (Dalzell et al. 2006). It also displayed less branching than cv. Cunningham, being quite arboreal in growth habit.

It was not until 2001–2003 that cultivar Tarramba was introduced to eastern Indonesia (East and West Nusa Tenggara Provinces), as a component of the ACIAR project 'Leucaena management in West Timor and Cape York'. There was immediate recognition of the superior value of Tarramba leucaena, which was found to be preferred by cattle over other available cultivars/varieties, less affected by psyllids, leafier and lasting longer into the dry season, thus providing better growth through to the peak of the dry season, and to produce suitable poles for door and window frames, house construction and other uses (Kana Hau and Nulik 2012). Understanding the barriers to adoption of leucaena (Kana Hau et al. 2014) was the major achievement of the ACIAR project, as cv. Tarramba now has a huge reputation among Government officials and farmers alike; it is widely accepted as vastly superior to 'local' varieties and cv. Cunningham.

Success with smallholder cattle fattening enterprises

Apart from the improved characteristics of the cultivar outlined above, Tarramba leucaena demonstrated excellent results in on-farm trials with smallholders (Shelton 2017).

A one-year feeding experiment to study growth of Bali cattle (*Bos javanicus*) from weaning to market weight during the first phase of the ACIAR project demonstrated to farmers that feeding Tarramba leucaena to cattle doubled weight gains compared with their traditional practices (Figure 1). In particular, a ration comprised of a mixture of Tarramba leucaena with grasses and fresh cassava tubers was among the most popular adopted by collaborating farmers. Using this method of feeding, yearling weaned calves increased weight from an initial average of 90–100 kg to 250–300 kg within 12 months. Conventionally, this market weight is achieved at 3 years of age after intensive stall feeding or at 4–5 years of age from traditional free grazing on native grasslands.

Figure 1. Bali bulls fed Tarramba leucaena.

The most efficient farmer participant in this feeding demonstration won a beef cattle fattening competition with his Bali bull that had reached 400 kg at 2 years (Figure 2). The achievement was published in the local newspaper with a statement from the farmer concerning the benefits of the feeding ration he had applied. Other participating farmers from the new areas developed with Tarramba in the Fatuleu Region of Kupang district also started to win championship awards in the 2018 local beef cattle competitions.

There is now strong demand for seed of Tarramba leucaena in these regions. Accordingly, much effort has been devoted to both the technical aspects of seed production and the logistics of establishing an on-going seed supply network.

Figure 2. Bali bull fed leucaena wins fattening competition.

How smallholders grow, manage and feed Tarramba leucaena

The East Nusa Tenggara Assessment Institute for Agriculture Technology, in collaboration with the Provincial Livestock Department, worked with smallholders to increase the number of seed orchards of this cultivar.

The village of Kuenheun in Timor was initially chosen due to lack of contamination with local naturalized leucaena and the enthusiastic support of the local authority. Procedures were introduced to ensure that a professionally produced and packaged product was available for commercial sale (Figures 3–4).

Tarramba seed was distributed to farmers and propagated in a variety of ways to produce seedlings, including in polybags (Figure 5) and from bare-stem gardens (Figure 6), for transplanting in the field when seedlings were >50 cm tall. They were protected from grazing until they reached a height of >4 m.

Figure 3. Mature seed of Tarramba leucaena.

Figure 4. Tarramba leucaena seed produced by smallholders.

Figure 5. Seedlings grown in polybags ready for transplanting.

Encouraged by the good price for seed due to the high demand, in the second phase of the ACIAR project new village areas were developed and contributed to the supply of seeds.

Figure 6. Bare-stem seedling showing where it is to be cut prior to transplanting.

Some farmers independently produced and sold Tarramba seed, while others marketed Tarramba foliage (Figure 7), as a secondary product, to other farmers in the nearby villages and to the nearby cattle market at Lili in West Timor. Farmers adopted a practice of preserving those branches that produced pods, while cutting branches that did not produce seeds to feed to their animals or to sell to other farmers. Other farmers intercropped their Tarramba leucaena with horticultural crops (Figure 8).

Figure 7. Tarramba leucaena cut-and-carried for feeding.

Figure 8. Regrowth of Tarramba leucaena after cutting intercropped with dragon fruit.

Farmers obtained excellent prices for good quality Tarramba seed, e.g. farmers from Oebola Dalam received up to A$ 4,500 for 600 kg of Tarramba seed in 2015. During the life of the project, almost 3,000 kg of Tarramba seed were collected and approximately 2,000 kg seed were re-distributed to various locations within and outside the Provinces of East and West Nusa Tenggara. Seed production has continued to increase and by November 2018, almost 5,000 kg of seed were sold for distribution to various places in Indonesia and to Timor-Leste (Kana Hau and Nulik unpublished data).

The most acceptable seed production system resulted when farmers grew their own trees on their own land, as farmer group plantings encountered problems in effectively sharing the proceeds from sale of seed.

Conclusions and Recommendations

Tarramba leucaena has been successfully introduced and developed in eastern Indonesia, where it provides not only good quality forage for smallholder cattle fatteners, but also cash income from the sale of seed, which is in strong demand.

The success of Tarramba is contributing to forage development in other parts of Indonesia (Sumatra, Kalimantan and Java) and in Timor-Leste.

The demand for Tarramba seed continues to increase and is indicative of the interest in expanding the use of forage tree legumes for fattening cattle. Seed production is best conducted on individually owned land as profit-sharing from communal village plantings has created difficulties.

In East Nusa Tenggara Province alone, there are >800,000 ha of suitable land available to grow Tarramba. Accordingly, there is a huge potential market for seed for the next 20 years. Ultimately, a private investor or investors should be encouraged to organize the seed business to ensure a sustainable market supply as demand increases.

The superiority of leucaena cv. Tarramba for the dry conditions of eastern Indonesia, especially for marginal lands (coral limestone Mollisols and Alfisol soils) of eastern Indonesia (West Timor, East Nusa Tenggara and Sumbawa, West Nusa Tenggara), and its multiple uses will ensure expanding demand for seed to supply the increasing demand for beef from other parts of Indonesia.

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*ILC2018 Keynote Paper**

Leucaena feeding systems in India

Sistemas de alimentación con leucaena en la India

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Abstract

Since its introduction to India in 1976 *Leucaena leucocephala* ssp. *glabrata* has spread rapidly, especially in the last couple of decades, mainly due to its use as either firewood or pulpwood. Use of its foliage for feeding livestock has been mainly a by-product of this activity. The foliage is highly nutritious because it has high protein concentration and good palatability, and the tree can withstand repeated defoliation. Research carried out by Indian scientists on leucaena has focused on mainly agronomic management, agroforestry studies of mixed cropping systems, mimosine toxicity, germplasm testing and economic evaluation. Feeding leucaena has had a positive impact on the dairy industry in particular. It is rarely purchased for fodder and is usually poached by smallholders from existing plantations, most of which are established by animal rearers for their own purposes. More widespread use of leucaena for fodder could be achieved in India by introducing varieties with either reduced seed production or sterile ones, which can be easily propagated vegetatively. In addition, psyllid resistance, suitable mechanized harvesting methods and training livestock owners in proper management of leucaena trees should help in making this high quality fodder more popular in India.

Keywords: Fuelwood, leguminous tree fodders, pulpwood, silvopastoral systems.

Resumen

Desde su introducción a la India en 1976, *Leucaena leucocephala* ssp. *glabrata* se ha dispersado rápidamente, especialmente en las últimas dos décadas, sobre todo debido a su uso como leña o pulpa para papel. El uso de su follaje para la alimentación de ganado ha sido más bien un subproducto de esta actividad. El follaje es de alto valor nutritivo debido a su alta concentración de proteína y buena palatabilidad; a su vez esta especie arbustiva puede soportar defoliaciones frecuentes. Investigaciones llevadas a cabo en la India se han centrado en el manejo agronómico, estudios agroforestales en sistemas de cultivos mixtos, toxicidad de mimosina, evaluación de germoplasma y análisis económicos. La alimentación de ganado con leucaena ha tenido un impacto positivo sobre todo en la producción de leche. La leucaena es rara vez comprada para la utilización como forraje; generalmente los productores extraen su follaje de plantaciones existentes que en su mayoría son establecidas por criadores de ganado para sus propios fines. Un mayor uso de leucaena como forraje en la India se puede lograr mediante la introducción de variedades con escasa producción de semillas o hasta estériles, que se puedan propagar fácilmente en forma vegetativa. Además, variedades resistentes a los psilidos, métodos de cosecha mecanizada adecuados y capacitación de los propietarios de ganado en el manejo adecuado de los árboles de leucaena deberían contribuir a que este forraje de alta calidad se vuelva más popular en la India.

Palabras clave: Árboles forrajeros leguminosos, leña, pulpa para papel, sistemas silvopastoriles.

Introduction

Leucaena leucocephala ssp. *leucocephala* (shrubby 'common' type) is supposed to have been introduced into India from Mexico more than a century ago as a fast-growing species for afforestation. It spread rapidly into various habitats (Ghate 1991) and became naturalized. After Dr J.L. Brewbaker (University of Hawaii) supplied

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seeds of *L. leucocephala* ssp. *glabrata* (arboreal 'Hawaiian giant' or 'Salvador' type) in 1976, the popularity of leucaena rapidly increased, mainly through the efforts of the Bharatiya Agro Industries Foundation (BAIF), Pune.

Leucaena leaf and small stems are a nutritious feed for all kinds of animals because they contain high protein concentration and are highly palatable, while the plants can withstand repeated defoliation.

The semi-arid climate in many parts of India and the pressure on land use have increased the importance of tree and shrub fodders as components of feeds for ruminants compared with grasses or grass-herbaceous legume pastures. Many fodder trees are not cultivated and the landless population, which owns small herds of sheep and goats, depends on accessing shrubs and tree feed resources growing near the villages, on roadsides and community lands (Raghavan 1990). Although most trees and shrubs used for animal feed are self-sown, in some traditional farming systems in India, trees are planted with crops to provide sources of fuel and feed (Chen et al. 1991). Therefore, though the arboreal type of leucaena is a relatively new introduction to India, the farming system in which it is used is generally a traditional one.

Research and development

Five areas of research have been the focus of concerted efforts by Indian scientists: agronomic management to optimize sustained yields; agroforestry studies of mixed cropping systems; mimosine toxicity; germplasm testing; and economic evaluation (Hegde and Gupta 1994).

Some of the more extensive data on the effects of varietal or spacing differences on forage yields of leucaena in India are from BAIF Research Development Foundation (Relwani et al. 1983). The Indian Grassland and Fodder Research Institute (IGFRI) at Jhansi conducted a series of leucaena alley farming trials with crops such as maize, sorghum, buffel grass, millet and napier grass with generally beneficial outcomes (Gill et al. 1982, 1983; Gill and Patil 1983, 1984, 1985).

From a survey of leucaena toxicity status based on assays of urinary DHP excretions, it was concluded that India is one of the 8 countries protected from toxicity by the presence of *Synergistes jonesii* (Jones 1994). However, more recently Pattanaik et al. (2007) reported that mimosine was rapidly converted to 3,4-dihydroxypyridine (3,4-DHP) post-ingestion resulting in poor animal performance on otherwise high-quality pasture. While mimosine toxicity can be potentially severe, it is relatively short-term and is manifest only when animals are first introduced to high leucaena diets. Their rumen microflora have an ability to fully degrade mimosine in high (>50%) leucaena diets within 2 weeks from initial introduction (Ghosh et al. 2007).

Adoption

Adoption of improved pasture systems such as those with leucaena is very low owing to limited land availability, low producer confidence, establishment issues and costs and psyllid attack on existing varieties.

The pattern of adoption of leucaena in the M. Nidamanuru village of Andhra Pradesh state (Saigal and Kashyap 2002) is representative of the situation in most parts of India. The farmer who originally brought leucaena to the area placed advertisements in the local papers and sold seeds from his plantations to farmers. Over the next few years, leucaena planting spread rapidly in the village and in 2000, most farmers had some part of their land planted to leucaena. Timber from stems was initially sold as firewood for tobacco curing barns but subsequently the pulpwood market developed and farmers began growing leucaena to sell to the pulpwood industry. Leucaena plantations had a positive impact on the dairy industry with village milk production increasing from 50–60 L/day to 900–1,000 L/day, due to the increased availability of nutritious fodder in the form of leucaena leaf. Fat content of the milk also reportedly increased. Landless and marginal farmers were apparently the main beneficiaries, as expenditure on buying fodder from the market was reduced by more than a third. Leucaena foliage was obviously poached from the plantations and not purchased from their owners. While damage caused to the plantations through lopping and grazing was significant, surprisingly, according to the authors of the report, plantation owners did not perceive this as a major problem and most did not object to it. In the experimental plantations of cvv. Tarramba and Wondergraze on Nimbkar Agricultural Research Institute (NARI) lands leafy branches are also often seen broken and taken away by the surrounding livestock owners.

To illustrate adoption by a specific farmer, an interview was conducted with Mr Vikram Dattatray Yadav on 16 May 2018 (Figures 1–3). His farm is located at Yadav Wasti, Kala Odha, Shiravli, Tal. Baramati. He had planted 0.4 ha of leucaena in 2016 using seed of variety K8 bought from BAIF for INR 225/kg (1 USD = 68 INR). He planted rows 120 cm apart with 30 cm spacing within rows, and supplied drip irrigation every 4 days. He fertilizes with goat manure and cuts 4 times per year. Rogor (dimethoate 30 EC at 30 mL/15 L water) or Nuvan (dichlorvos 76 EC at 40 mL/15 L water) is sprayed for psyllid control during winter.

Figure 1. Mr Yadav's leucaena plantation.

Figure 2. Re-sprouting leucaena in Mr Yadav's plantation.

Figure 3. Mr Yadav's goats feeding on leucaena.

Mr Yadav has 74 Osmanabadi goats that he feeds either leucaena or lucerne twice a day – the amount offered is not weighed. While he observed that his goats gained weight at a relatively faster rate when fed leucaena than any other fodder, his fodder supply from the 0.4 ha was insufficient for the 74 goats year-round. There is currently no ready market for the wood produced.

Profitability

Under rainfed conditions, leucaena variety K636 (marketed in Australia as cv. Tarramba), either as a pure stand or in intercropping systems, recorded higher gross and net returns than arable cropping in Andhra Pradesh (Prasad et al. 2011). The main product was wood for industrial use.

At our institute (NARI), in 5 plantations with a total area of 3.5 ha, we have planted cvv. Wondergraze and Tarramba, which we intend to use for fodder and seed production, at a density of 2,644 plants/ha. During the first year, estimated fresh edible biomass production from cutting every 4 months was about 4,000 kg/ha per harvest. The expenditure including establishment and cutting costs came to INR 30,000/ha/yr, giving a cost of about INR 2.50/kg fresh edible biomass produced. Therefore the sale price of fresh fodder should be at least INR 3/kg. Since leucaena fodder can be easily harvested from naturalized areas at no cost, there is a limited market for the sale of leucaena forage. However, the main problem was that there were no buyers for the wood of small size (3–5 cm diameter), as in the last 2–3 years, availability of liquid petroleum gas for cooking, even in rural areas, has increased tremendously. Such a venture has a chance of becoming profitable only if the wood can be used for industrial purposes such as production of paper pulp.

Future relevance

Some of the main reasons why leucaena was shunned by many farmers in India were its prolific seeding and resultant weediness. Moreover, being an aggressive species it was seen to adversely affect the growth of other species in agroforestry systems. Varieties such as K8 were also very susceptible to the psyllid pest (*Heteropsylla cubana*), which is especially damaging during the coldest 4 months (winter). While the trees do recover and there is rarely any mortality, growth and fodder yield suffer. In spite of high protein deficits in ruminant nutrition, leucaena is still underutilized in states like Kerala, owing to limited land availability for planting, low biomass yields and difficulty in harvesting (Raj et al. 2016).

To overcome the problems of weediness and psyllids, the outstanding hybrid KX2 shows promise as it is psyllid-resistant as well as practically seedless. However, since its saplings have to be produced by vegetative propagation, supplying the quantity of planting material desired by farmers at an affordable price has proved difficult. The new variety, cv. Redlands, recently released in Australia, may offer a partial solution, as it is psyllid-resistant and easy to propagate from seed, although the weediness potential remains. However, under a pasture-based model, ease of propagation from seed is definitely a major advantage for any fodder species.

Many farmers contacted by us reported 'difficulty in harvesting' as the main reason for leucaena not being used as widely as it should. They need to be made aware of planting patterns whereby double-row hedges of leucaena can be formed, which can be trimmed every 3–4 months by cutting at 1 m height from the ground. Depending on the spacing between the hedges, grasses such as buffel (*Cenchrus ciliaris*) or *Chrysopogon fulvus* can be planted once leucaena is established. Mechanized harvesting using small tractor-mounted machines may be another solution to the problem.

Companies like J.K. Paper Ltd. have established clonal seed orchards by first identifying Candidate Plus Trees from the existing plantations and then rooting the coppiced cuttings from these trees in mist chambers. The saplings so developed are either utilized for setting up clonal seed orchards or establishing mother plants in raised beds filled with sand as a source of juvenile coppice cuttings for mass production. Thus farmers are supplied with either seeds or rooted cuttings. Similarly, leucaena clones have also been developed by ITC Limited with their current planting level of about 3,000 ha/year (Kulkarni 2013 pers. comm.).

Conclusions

At present, large-scale plantations of leucaena like those in Queensland, Australia are rarely seen in India, but leucaena is quite commonly utilized as a fodder by livestock farmers. The source is leucaena trees from industrial plantations (such as for paper pulp), roadside trees and trees on field boundaries.

Availability of psyllid-tolerant cultivars which are sterile or seedless, but can be easily and cheaply propagated via cuttings, will go a long way in popularizing leucaena fodder in India. Small tractor-mounted or stand-alone harvesting machines, if available, should lead to more widespread use of this highly palatable, high-protein feed in India.

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ILC2018 Poster and Producer Paper*

Leucaena as basal feed for meat goats in Prachuapkhirikhan Province, Thailand

Leucaena como alimento base para cabras de carne en la provincia de Prachuapkhirikhan, Tailandia

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Keywords: Cut-and-carry feeding, small ruminants, tree legumes.

Introduction

Goat rearing for meat and milk has long been practiced in Thailand, mostly associated with the Thai Muslim community. The Department of Livestock Development (DLD 2018a) estimated the total number of goats in Thailand in 2017 at 653,000 with 34.3% located in the south. The productivity of goats depends largely on availability of pasture and other sources of feed, which vary with site. This paper reports on the use of leucaena (*Leucaena leucocephala*) for goat feeding in Prachuapkhirikhan Province, which covers 6,368 km^2 in the central part of Thailand.

Goat population and number of farmers in Prachuapkhirikhan Province

Prachuapkhirikhan Province is ranked 4th in terms of goat numbers in Thailand with 39,260 goats or 6% of the country's total. Most are meat goats with 50% Boer goat infusion (Table 1). While some male goats are castrated, most are left entire and fattened.

Based on recent statistics of the Department of Livestock Development (DLD 2018b), 36% of goat farmers in Prachuapkhirikhan keep 1–20 head, 29% keep 21–40, 19% keep 41–60, 11% keep 61–100 and only 5% keep more than 100 animals.

Table 1. Numbers of goats and farmers in Thailand and Prachuapkhirikhan Province in 2017 (DLD 2018b).

	Meat goats		
	Male	Female	Farmers
All of Thailand	182,645	442,745	50,758
Prachuapkhirikhan	15,163	23,852	918
	Dairy goats		
	Male	Female	Farmers
All of Thailand	8,586	18,988	1,780
Prachuapkhirikhan	99	145	13
	Total		
	Goats		Farmers
All of Thailand	652,964		51,851
Prachuapkhirikhan	39,259		925

Production systems and feeding

Breeding of kids for meat goat production

There are 2 production systems in this group:

a. A semi-intensive system in which breeding goats are grazed for 4–6 hours per day (Figure 1) on naturally occurring plants such as leucaena, desmanthus, *Pithecellobium dulce* and native grasses. Fresh leucaena is fed as a supplement in pens in the evening at a rate of 3–5 kg/hd/d. The pens are in either elevated houses with slatted flooring or on the ground.

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b. An intensive system (zero grazing) practiced mostly as a part-time activity and generally on a small scale with approximately 30–40 head per farm. After finishing their main activity as a contingent worker in other agricultural activities, farmers cut leucaena, which is available naturally along the roadsides or in a public area, to feed their goats (Figure 2). While the basal feed is leucaena, napier grass (*Cenchrus purpureus*; syn. *Pennisetum purpureum*), pangola grass (*Digitaria eriantha*), ruzi grass (*Brachiaria ruziziensis*) and native grasses may be added. Farmers feed fresh leucaena at 7–10 kg/hd/d, in the morning and in the evening. Goats consume leucaena leaf, young stems, pods and bark (Figures 3 and 4). The chemical composition of the leucaena varies with plant part. Unpublished data from Prachuapkhirikhan Animal Nutrition Research and Development Center indicate that leucaena leaf contains about 23% crude protein (CP), 19% crude fiber, 9% fat and 44% nitrogen-free extract. Bark contains 12% CP at 50 cm height and 15% CP at the tip of the stem; young pods contain 23% CP and pods with seeds contain 21% CP. In both systems, does kid twice per year and produce 2–3 kids/year. Farmers sell weaned kids at about 15 kg (3–4 months of age) or continue feeding them for 4–5 months before selling them at about 25–30 kg live weight.

Figure 1. Free grazing.

Figure 2. Leucaena collected along roadside.

Figure 3. Goats consuming leucaena leaf.

Figure 4. Non-edible leucaena stem residue after feeding.

Meat goat producers

Farmers generally buy weaned kids at 15 kg live weight and feed for 4–5 months to about 25–30 kg live weight achieving weight gains of 100–150 g/d. Goats are sold by weight. In general, goat management is a confined intensive system. Other than grasses, leucaena has gained wide acceptance among goat farmers as a suitable basal feed due to its wide availability naturally and its high crude protein concentration. Goats are fed with combinations of feed sources, which vary among farms and seasons, including:

a. Chopped leucaena (Figure 5) or chopped leucaena mixed with napier grass 1:1 supplemented with 300 g of pelleted concentrate feed with a total of 16% CP (e.g. 50% maize grain or broken rice, 10% rice bran, 26.5% coconut meal, 10% leucaena leaf meal, 1.5% urea, 1% dicalcium phosphate, 0.9% salt and 0.1% sulphur), half being fed in the morning and half in the afternoon.
b. Chopped leucaena mixed with corn silage 1:1 (Figures 6 and 7).
c. In the dry season, when production of leucaena is low, farmers feed leucaena and pineapple waste from pineapple jam factories.

There are no reports of toxicity symptoms due to mimosine and the main constraint that goat farmers face is low production of leucaena in the dry season.

Figure 5. Chopping leucaena.

Figure 6. Leucaena and corn silage.

Figure 7. Leucaena and corn silage fed to goats.

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*ILC2018 Keynote Paper**

Leucaena feeding systems in Myanmar

Sistemas de alimentación de ganado con leucaena en Myanmar

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Abstract

Agriculture and livestock provide the main source of income for farmers in Myanmar. As feeds with low nutritive value and digestibility are traditionally used for animal feed, alternative feed sources of better quality are needed to improve production levels. While concentrates can be used to improve the quality of diets, this leads to high feed costs. To solve this problem, researchers in Myanmar conducted trials to replace some concentrates with leucaena. The nutritive value of leucaena in Myanmar is relatively the same as found in other countries. Control of leucaena toxicity was also studied in Myanmar by isolating mimosine-degrading bacteria and managing the feeding of leucaena. While farmers in Myanmar are aware that leucaena can be fed to livestock and can be toxic to animals, they have limited knowledge of the real benefits of leucaena as a feed for animals. Research to demonstrate the potential of leucaena feeding to animals in Myanmar and efforts to promote establishment of leucaena stands are urgently needed.

Keywords: Feeds, nutritive value, tree legumes, tropical pastures.

Resumen

La agricultura y la ganadería constituyen la principal fuente de ingresos para los agricultores de Myanmar. En vista de que tradicionalmente se usan forrajes de bajo valor nutritivo y digestibilidad para la alimentación animal, se necesitan fuentes de alimentación alternativas de mayor calidad para mejorar los niveles de producción. Si bien se podrían usar concentrados para mejorar la calidad de las dietas, esto conduce a altos costos de alimentación. Para resolver este problema, investigadores en Myanmar realizaron experimentos para reemplazar algunos concentrados con leucaena. El valor nutritivo de la leucaena en Myanmar es similar al que se encuentra en otros países. En Myanmar también se estudiaron el control de la toxicidad de la leucaena mediante el aislamiento de bacterias que degradan la mimosina, y el manejo de la leguminosa para la alimentación animal. Si bien los agricultores en Myanmar saben que la leucaena puede ser usada como alimento para el ganado, su conocimiento sobre los beneficios actuales de esta especie para la alimentación animal es aún limitado. En Myanmar se necesitan con urgencia tanto trabajos de investigación para demostrar el potencial de leucaena como alimento para los animales como apoyo para promover la siembra de leucaena.

Palabras clave: Forrajes, leguminosas arbóreas, pasturas tropicales, semilla, valor nutritivo.

Introduction

Increasing human population densities highlight the priority that must be placed on efficient land use for the production of food and plantation crops. Globally, this demographic pressure leads to increased emphasis on the development of productive and intensive livestock and agricultural systems (Aung Aung 2007). Livestock production contributes a large portion of household income in developing countries. The economy of Myanmar is largely based on agriculture and livestock are a vital component of the nation's economy; livestock and

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fisheries contribute about 9% of total GDP with the private sector contributing 99% of livestock production (Hla Hla Thein 2017).

Seventy percent of the population of Myanmar reside in rural areas and 64% of the population are farmers, who derive their main income from agriculture. Livestock production is closely linked with agriculture as farmers use cattle as draught animals and utilize agricultural by-products as feed. Some farmers raise pigs and village chickens as a small-scale backyard system. Smallholder livestock farmers obtain draught power, local transport and manure as fertilizer from their draught animals. Eggs, milk, meat and hides are products/by-products which contribute to household income (Hla Hla Thein 2017).

Crop residues are the main source of animal feed, especially during the dry period, with rice straw being the most abundant and widely used feed in many Asian countries including Myanmar (Trung 1987). These agricultural fibrous residues have severe nutritional limitations, being low in digestibility and crude protein, and high in fiber and anti-nutritional factors such as lignin, silica, gossypol, etc. To achieve satisfactory animal performance, supplementation with concentrates, which are expensive, is needed to overcome the nutritional limitations of the feeds.

Farmers in Myanmar currently use commercial feeds for monogastric animals, resulting in high inputs and costs. The other concern with monogastric animals is that they often compete with humans for food.

To solve these problems with ruminants and monogastrics, supplementation with fodder tree legume leaves was studied as leguminous forages are high in protein and soluble carbohydrates.

Leucaena (*Leucaena leucocephala*) is a palatable, digestible and nutritious forage for cattle, buffalo, sheep, goats, chickens and other animals (ter Meulen et al. 1979) as it provides a valuable source of protein, energy, vitamins and minerals for rumen bacteria (van Tol 2004) and is quite versatile. It can function: (a) as a source of firewood and timber; (b) in controlling soil erosion (Dijkmann 1950); (c) in providing shade for other plants; (d) in maintaining the fertility of the soil; (e) as a possible bio-herbicide (Xuan et al. 2006); (f) in reducing cattle methane emissions (Shelton and Dalzell 2007); and (f) as nutritious forage for animals (NRC 1977). Leucaena foliage and young branches supply both nutrients and roughage, forming an almost complete ruminant feed and being widely used as forage for cattle in tropical agriculture (Shelton 1998). It can also be utilized for monogastrics. D'Mello and Thomas (1978) demonstrated that the N-corrected metabolizable energy (ME) for poultry is 8.3 ± 0.74 MJ/kg DM. Gieseke (1984) stated that leucaena leaves contained 4.39 ± 0.8 MJ/kg DM and seeds contained 4.19 ± 1.8 MJ/kg DM. In Myanmar, leucaena is used as a protein source in urea-molasses multi-nutrient blocks for ruminants (Ni Ni Maw et al. 2002) and is a potential feed for animals in the dry season (Aung Aung 2018). However, there is still limited information on leucaena in Myanmar. This paper describes the research carried out and feeding systems involving leucaena in Myanmar.

Nutritive value of leucaena in Myanmar

As in other countries, research workers in Myanmar have conducted research on the nutritive value of leucaena (called Bawzagaing in Myanmar) as an animal feed (Mehm Ko Ko Gyi 2002).

Concentrations of various nutrients in leucaena leaves are as follows: crude protein (22.2–30.1%), neutral detergent fiber (8.2–28.6%), acid detergent fiber (6.6–20.0%) and ether extract (5.3–8.2%) (Ni Ni Maw et al. 2002; Khin Htay Myint 2005; Wink Phyo Thu 2010; Moe Thida Htun 2012; Dezin Soe Lwin 2014).

Nutritive value of leucaena reported from different regions and seasons showed little variation and was similar to results from other countries.

Experiments on feeding leucaena to animals

Ruminants

Many researchers in Myanmar have conducted feeding trials involving leucaena diets for ruminants. In the experiment of Khin Htay Myint (2005), diets for goats based on rice straw with leucaena at 25 and 50% of the diet showed similar nutrient digestibilities to diets containing rice straw and sesame cake (all diets isonitrogenous at 18% crude protein). However, in the experiment of Aung Aung (2007), sheep fed a diet containing 40% leucaena showed toxic symptoms and lower digestibilities of nutrients than sheep fed a diet without leucaena. In this experiment, it was also discovered that sheep could be fed leucaena at 30% of the diet without adverse effects as was reported by Jones (1979), while Moe Thida Htun (2012) reported similar findings to those of Aung Aung (2007). However in contrast, another experiment reported no adverse effects in sheep fed a diet containing 50% leucaena (Wink Phyo Thu 2010) with the same digestibility as for sheep fed on a diet without leucaena. Recently, goat kids fed a diet containing 30% leucaena increased liveweight at a rate of 80 g/d (Khin Ngu Wah Htun 2018); fecal worm egg counts were reduced by 70%. Yin Moe Aung (2018) also showed that including leucaena at 30% in a diet for calves reduced fecal worm egg counts, while Han Zin Maung (2018) showed that calves fed a diet containing 30% leucaena had comparable weight gains with calves fed a conventional feed without leucaena. Feed cost was lower in the calves fed diets containing leucaena.

Poultry

Small-holders use leucaena as a green feed for poultry to aid in the prevention of cannibalism. Aye Kyi (2003) compared different levels of leucaena leaf meal (0, 2, 4 or 6%) included in a conventional concentrate ration for layer hens for 15 weeks. Hens fed on the diet containing 4% leucaena showed higher egg production (88%) than hens fed the other diets (85.1, 84.7 and 84.8%, respectively). A similar experiment with broiler chickens (0, 1, 3 and 4% of leucaena in the diet) was conducted by Aye Aye Maw (2004). In her experiment, feed conversion ratio (FCR) of chickens fed on the diet containing 4% leucaena also showed the highest value. In both experiments, supplementation with leucaena showed lower feed costs for the poultry. Although mild symptoms of leucaena toxicosis such as goitre and weakness of bones were observed, there was a tendency for FCR for broiler chicks fed on diets containing 6% leucaena seed to be better than for those on a conventional diet (Khin Thida Win 2014). In another experiment, Naing Htun Aung et al. (2015) recommended that 4% of leucaena leaf meal should be included in the diet of chicks from 21 days of age (because economic returns in the broilers were better and there were no serious adverse effects).

Leucaena toxicity and attempts to overcome this problem in Myanmar

Researchers in Myanmar offered leucaena to animals as the sole diet but encountered problems. Sheep fed a diet containing 50% leucaena showed symptoms of toxicity such as decreased feed intake, alopecia and emaciation (Aung Aung 2007) plus regurgitation of green digesta (Moe Thida Htun 2012). When goats were fed leucaena at 50% of the diet, symptoms similar to those in the previous experiment were observed (Dezin Soe Lwin 2014). In poultry, osteoporosis and bone ossification were observed with leucaena feeding (Khin Thida Win 2014), but there is little information on leucaena toxicosis on-farm.

Aung Aung (2007) developed and isolated a subspecies of *Klebsiella pneumoniae* from steers in Germany, which was transferred to sheep in Myanmar. Sheep inoculated with those microbes showed no clinical signs of leucaena toxicosis when fed a diet containing 50% leucaena. Moe Thida Htun (2012) conducted a study with sheep being fed gradually increasing amounts of leucaena leaves. For the first week, the sheep were fed leucaena at 10% of the diet and the level was increased by 10% each week until it reached 50% of the diet, which was thought to be a toxic level for sheep. However, the sheep showed no toxic symptoms and *Bacillus cereus* was isolated and identified from the rumen liquor of those sheep. The mimosine-degrading *Bacillus cereus* microbes were then transferred to goats (Dezin Soe Lwin 2014), which consumed a diet containing 50% leucaena without showing clinical symptoms of mimosine toxicity. In contrast, the control goats without inoculation continued to display toxic symptoms.

Niang Htun Aung et al. (2015) found that chicks showed leucaena toxicosis when fed a diet containing 6% leucaena but not after 21 days of age. Other reports suggest that chicks can tolerate 4–6% leucaena in the diet (NRC 1977) without developing symptoms of toxicity. It may be that at low levels of leucaena in the diet, toxic levels for chickens are not reached.

Feeding of leucaena to animals in the field

Farmers in Myanmar have very limited knowledge of the benefits of feeding leucaena to animals. A case study in 10 townships from Yangon Region (75 farmers), Nay Pyi Taw Council (50 farmers) and Mandalay Region (125 farmers) in 2016 revealed that, while 80% were aware that leucaena could be used as animal feed, only 30.5% actually fed it to stock. There was wide variation between regions. In Yangon Region 65% of farmers rarely used leucaena as an animal feed. However, those in Nay Pyi Taw Council regularly fed leucaena to cattle and goats, collecting leucaena branches from the roadsides to feed their goats at home, often hanging the branches to minimize wastage. No information is available on amounts of leucaena offered to goats and cattle. Farmers consider that feeding leucaena reduces costs of production and also increases weight gains in ruminants and pigs.

In Mandalay Region, leucaena is abundant on roadsides and as fences for estates and cropping lands. Farmers allow cattle to graze communal lands, where leucaena grows, and consume leucaena. With the aid of the Australian Centre for International Agricultural Research (ACIAR), leucaena trees were provided to farmers to grow along fence lines of houses for feeding goats during the rainy season. Most farmers from Mandalay Region and Nay Pyi Taw area consider leucaena has potential to provide foliage for feeding animals in the dry season. There is a need to collect data on the amount of leucaena being fed to the animals and on the effects of leucaena on daily liveweight gains of the animals, and any possible toxic side-effects.

Table 1 summarizes the knowledge situation of the farmers regarding leucaena and Figure 2 depicts collecting of leucaena foliage.

Table 1. Knowledge of farmers regarding leucaena feeding and toxicity in various regions of Myanmar.

Description	No. of farmers	Answer (%)		
		Yes	No	Unsure
Know that leucaena can be fed to stock	250	80.4	19.6	-
Actually feed leucaena	250	30.5	69.5	-
Know of leucaena toxicity	250	20.8	60.9	18.3
Want to plant leucaena	250	55.0	40.0	5.0

Figure 1. Farmers collecting leucaena to feed their animals.

Conclusion

Information on the distribution and genetic diversity of leucaena in Myanmar is limited, but farmers indicate there is insufficient leucaena available for animal feeding. Further research is recommended to investigate why farmers in some areas rarely feed leucaena, so that extension programs to increase adoption can be mounted. Further programs to promote the establishment of leucaena plantations for feeding animals in close collaboration with rural communities in Myanmar are warranted.

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*ILC2018 Keynote Paper**

Adoption of leucaena-based feeding systems in Sumbawa, eastern Indonesia and its impact on cattle productivity and farm profitability

Adopción de sistemas de producción basados en leucaena en Sumbawa, Indonesia Oriental, y su impacto en la productividad bovina y rentabilidad del sistema de producción

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Abstract

Leucaena has been fed to cattle by the Balinese community in Sumbawa and West Sumbawa districts on Sumbawa Island since the 1980s. However, prior to 2011, this practice was not adopted by the local Sumbawanese farmers. Since then, a model leucaena-based cattle fattening system was developed in Sumbawa and West Sumbawa districts in a collaborative research project between the Assessment Institute for Agricultural Technology (BPTP), University of Mataram and The University of Queensland (UQ) funded by the Australian Centre for International Agricultural Research (ACIAR), followed by a scaling-out project involving collaboration between the University of Mataram and CSIRO (Applied Research and Innovation Systems in Agriculture - ARISA project) funded by DFAT (Department of Foreign Affairs and Trade) promoting public-private partnerships. Further promotion of leucaena-based fattening systems occurred in Dompu, Sumbawa, through a project with the University of Mataram and Massey University funded by the New Zealand Ministry of Foreign Affairs and Trade (MFAT). By the end of October 2018, more than 2,500 farmers on Sumbawa Island were practicing leucaena-based cattle fattening. The main drivers of adoption of cattle fattening with leucaena were: (1) The high growth rates achieved (0.4–0.6 kg/d for bulls fed 100% leucaena and 0.66 kg/d when maize grain was added to the leucaena basal diet) compared with 0.16 kg/d for the traditional system, combined with high profitability; (2) the needs of farmers being met in terms of relevance and cultural appropriateness; (3) field extension staff being well trained and mentored, and respected by the farmers; (4) the local government being highly supportive of leucaena-based cattle fattening; and (5) additional benefits being increased dressing percentage and high carcass quality. The rapid increase in the use of leucaena for cattle fattening in eastern Indonesia is expected to have a significant positive impact on household incomes as well as on regional economic growth.

Keywords: Cattle fattening, farmer income, growth rate, tree legumes.

Resumen

Leucaena ha sido usada, desde la década de 1980, para la alimentación de bovinos por la comunidad balinesa en los distritos de Sumbawa y Sumbawa Oriental pertenecientes a la isla de Sumbawa. Sin embargo, previo al 2011 esta práctica no fue

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adoptada masivamente por los agricultores locales. Desde esa fecha en adelante, se desarrolló un sistema modelo de engorde de bovinos basado en leucaena en dichos distritos en un proyecto de investigación colaborativa entre el Assessment Institute for Agricultural Technology (BPTP), la universidad de Mataram y la universidad de Queensland (Australia), financiado por el Centro Australiano para la Investigación Agrícola Internacional (ACIAR), y seguido de un proyecto de ampliación de escala con la colaboración entre la universidad de Mataram y la Organización de Investigación Científica e Industrial del Commonwealth (CSIRO; Proyecto ARISA: Applied Research and Innovation Systems in Agriculture), financiado por el Departmento de Relaciones Exteriores y Comercio de Australia, el cual promueve las asociaciones público-privadas. Los sistemas de engorde basados en leucaena se promovieron también en Dompu, Sumbawa, mediante un proyecto con la universidad de Mataram y la universidad de Massey (Nueva Zelanda), financiado por el Ministerio de Relaciones Exteriores y Comercio de Nueva Zelanda. A fines de octubre de 2018, más de 2,500 productores en la isla de Sumbawa adoptaron el engorde de bovinos a base de leucaena. Los principales impulsores de la adopción de esta tecnología fueron: (1) las altas ganancias de peso de los toretes (0.4–0.6 kg/d cuando la ración fue 100% leucaena y 0.66 kg/d cuando se añadió grano de maíz a la dieta basal de leucaena), en comparación con 0.16 kg/d en el sistema tradicional, además de una alta rentabilidad; (2) tecnología adaptada a las necesidades de los agricultores en términos de relevancia e idoneidad cultural; (3) extensionistas bien capacitados y orientados, además de respetados por los agricultores; (4) fuerte apoyo por parte del gobierno local de la tecnología de engorde de bovinos a base de leucaena; y (5), como beneficio adicional, mayor porcentaje y alta calidad de la carcasa. Se espera que el rápido aumento en el uso de leucaena para el engorde de ganado en el este de Indonesia tenga un significativo impacto positivo en los ingresos de los productores, así como en el crecimiento económico regional.

Palabras clave: Engorde de ganado; ingresos, leguminosas arbóreas, tasa de crecimiento.

Introduction

Beef consumption per capita in Indonesia is low at 1.5 kg/person/yr in 2000 and 2.5 kg/person/yr in 2015. However, local supply plus imports, mainly from Australia, are limited and the tight supply-and-demand relationship is reflected in the retail price of beef, which has quadrupled from 2000 to 2015 (Waldron et al. 2015; Shelton and the Project Team 2017). This has led to changes in policy in recent years, with large amounts of frozen buffalo meat and beef being imported from India. A projection by the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) suggested that the value of national beef consumption in Indonesia will increase 13-fold from 2009 to 2050 (Gunning-Trant et al. 2015).

The Indonesian Government has initiated programs to boost domestic beef production in an endeavor to achieve self-sufficiency. The majority of cattle in Indonesia are kept by about 6.5 M smallholder farmers, supplemented by a small number of much larger cattle ranches and larger feedlots, especially in Java and Sumatra.

Lifting the productivity of smallholder-fattened cattle to meet the increasing demands of the Indonesian population for beef has been nominated by provincial agencies as one of the most important ways to improve the incomes of the rural poor. The Indonesian provinces of West Nusa Tenggara (NTB) and East Nusa Tenggara (NTT) (Figure 1) have been identified as areas with high potential for expansion of smallholder beef production.

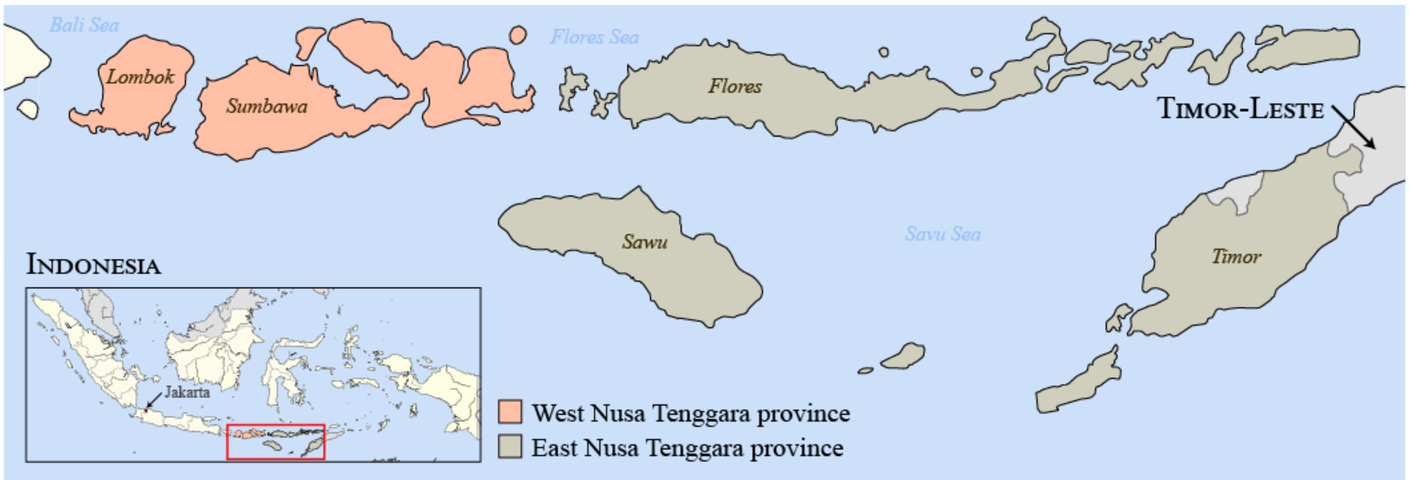


Figure 1. Map of Indonesia showing West Nusa Tenggara, with the islands of Sumbawa and Lombok, and East Nusa Tenggara provinces.

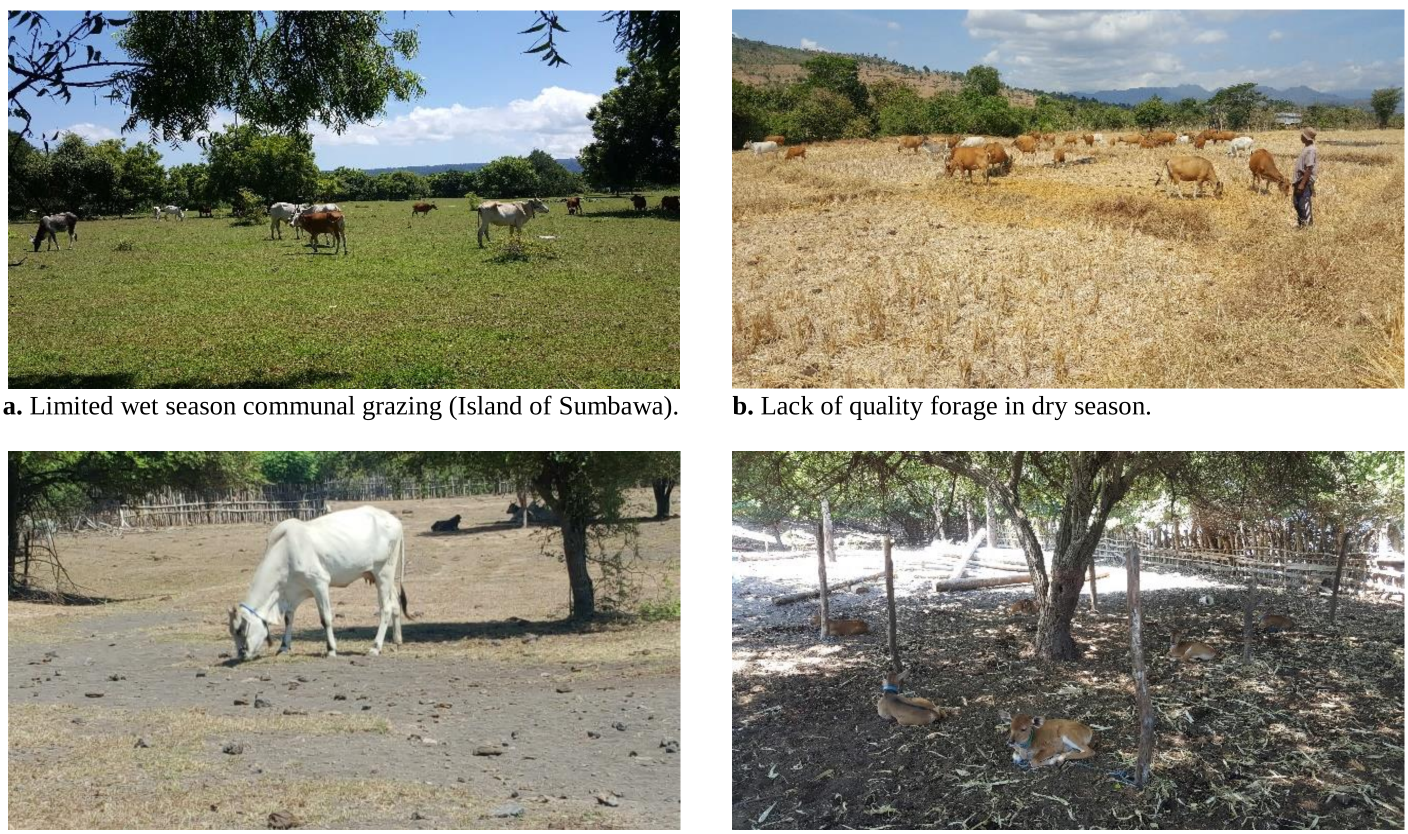
Currently, smallholder fattening systems in these regions are characterized by irregular, slow turn-off and poor carcass quality, largely resulting from very poor nutrition of cattle fattened under traditional feeding systems, which comprise cattle free-grazing on native rangeland or on rice stubble after crop harvest (Figure 2). This has negative consequences for the overall cattle population in Indonesia because too many young females are slaughtered to meet the growing demand for beef rather than being retained for breeding.

Prospects for expansion of the smallholder sector are constrained by:

1. Low production efficiency due to: low growth rates (0.15–0.25 kg/d); low calving rates (~65%); high calf mortality (10–20%); low sale live weights (averaging 250 kg); low carcass dressing percentages (48%); low genetic potential of local breeds; and poor management of the herd.
2. Socio-economic limitations due to: poor understanding of opportunities for improvement of smallholder cattle fattening enterprises; lack of knowledge and experience in forage improvement; problems with supply of credit; limited availability of land; and poor extension services and training.

In 2011, a 5-year collaborative research project between the Assessment Institute for Agricultural Technology (BPTP), University of Mataram and The University of Queensland (UQ), funded by the Australian Centre for International Agricultural Research (ACIAR), was initiated to improve smallholder cattle fattening systems based on promoting the use of forage tree legumes entitled 'Improving smallholder cattle fattening systems based on forage tree legume diets in eastern Indonesia and northern Australia' (LPS-2008-054). The project focused on the most viable option to improve diet quality in eastern Indonesia, which was to feed cattle with the foliage of high-quality forage tree legumes (FTL). The successful cattle fattening model was then scaled-out by a CSIRO/DFAT (Department of Foreign Affairs and Trade)-funded project promoting public-private partnerships, and further supported by a New Zealand Ministry of Foreign Affairs and Trade (MFAT)-funded project based in Dompu, Sumbawa.

Examples of such systems, in which cattle were fattened on FTL, already existed in Indonesia. Sesbania (*Sesbania grandiflora;* known locally as turi) was fed in south-central Lombok in NTB, and leucaena (*Leucaena leucocephala;*



a. Limited wet season communal grazing (Island of Sumbawa).

b. Lack of quality forage in dry season.

c. Lack of forage in dry season.

d. High calf mortality due to inadequate nutrition.

Figure 2. Lack of adequate forage severely limits nutrition of beef cattle in eastern Indonesia.

known locally as lamtoro) was fed in Sumbawa District in NTB and in Amarasi District of NTT. Both species were capable of greatly improving the protein nutrition of cattle. These systems were locally successful, but were not widely adopted outside these regions despite similar physical and socio-economic conditions.

This paper reports findings from the ACIAR and other projects in terms of: the history of cattle fattening in Sumbawa; the impact of leucaena-based fattening on cattle productivity and quality and farm profitability; and the progress made with an extension strategy designed to promote the uptake of leucaena planting and feeding for fattening cattle by smallholder farmers.

Early history of cattle fattening in Sumbawa

The use of leucaena for cattle feeding in eastern Indonesia was originally thought to occur mainly in the Amarasi District of West Timor (Piggin and Nulik 2005). However, in August 2010, as the ACIAR project got underway, we discovered that leucaena feeding was common practice for Balinese communities in Sumbawa and West Sumbawa districts. These Balinese communities had been using leucaena to fatten cattle since the 1980s with very little input from government agencies, or adoption by the local Sumbawanese farmers. The Balinese communities had very little cropping land and grew leucaena to fatten cattle on the steeper slopes behind their villages as their main source of income. In contrast, the Sumbawanese farmers had greater areas of land and spent most of their labor and time on cropping activities in the wet season, while raising cattle traditionally on communal grazing lands.

Balinese settlers first came to Sumbawa in the 1970s to work in the shrimp nursery. However, incomes from the shrimp nursery were not sufficient to support their families, so they acquired low-value steeper dryland nearby and planted crops, especially maize. In the 1980s, a Government scheme provided a couple of cows to some households and they managed to breed and grow a small herd. With previous experience from Bali that leucaena could be fed to cattle, they began growing leucaena to feed cattle and it became a common practice within this community. The leucaena was planted with support from an International Fund for Agricultural Development (IFAD) program. Initially the leucaena variety used was brought from Bali but was of unknown origin. Later, a variety called 'Lamtoro Gung' was used; it was found to be *L. leucocephala* cv. Cunningham, originally imported from Australia. By 2010, there were more than 100 Balinese households in the Sumbawa and West Sumbawa districts, who were feeding leucaena as the sole diet for fattening cattle. One of these Balinese villages (Jatisari) became a demonstration site for the new ACIAR project to describe and promote leucaena-based cattle fattening to other farmers in these districts.

Methods

The ACIAR project commenced by conducting a survey of 21 farmers and collecting data from 276 Bali bulls between 2011 and 2016 to determine the characteristics of the leucaena-based cattle fattening used by the Balinese in the hamlet of Jatisari in Sumbawa district on Sumbawa Island. Parameters measured included area of land planted to leucaena, length of fattening period and the growth of the Bali bulls (*Bos javanicus*) including bull live weight, average daily gain (ADG), feed offered including amount of leucaena in the diet and purchase and sale weights (Panjaitan et al. 2014; Shelton and the Project Team 2017).

In concurrent controlled animal trials, Dahlanuddin et al. (2014) studied the growth rate of Bali bulls and lactating cows fed leucaena hay compared with native or introduced grass, and the effect of supplementing with maize grain, maize stover and mineral mix.

Results

Survey of cattle production, profitability, carcass percentage and meat quality

The survey revealed that:

1. Farmers had an average of 2.8 ha of land with 0.8 ha (0.1–5.0 ha) of planted leucaena. They purchased bulls with an average live weight of 191 ± 41 kg at 18 ± 7 months of age and fattened them for periods averaging 127 ± 58 days (Panjaitan et al. 2014).
2. The average percentage of leucaena in diets throughout the year was 80% with 13% maize stover and 7% native grass. The percentage of leucaena was highest (100%) in the wet season, and lowest (approximately 50%) in October, when limited availability of leucaena meant farmers supplemented diets with crop residues.
3. Based on more than 3 years of monitoring (Figure 3) daily liveweight gains of Bali bulls ranged from 0.4 to 0.6 kg/d (Dahlanuddin et al. 2014; Panjaitan et al. 2014) on these rations. This was at least double the ADG of Bali bulls (0.2 kg/d) achieved in the traditional rearing system. ADGs 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%), and the most efficient individual farmers achieved monthly maximum weight gains ≥0.8 kg/d, which is close to the genetic potential of Bali bulls.

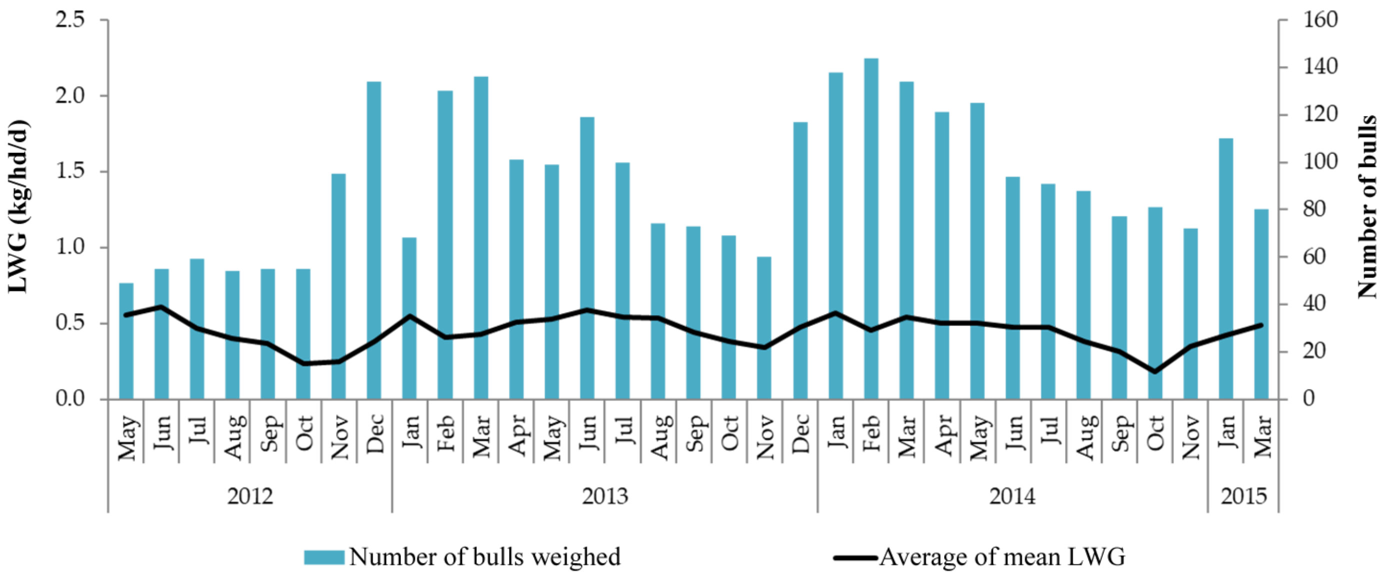


Figure 3. Liveweight gains and number of cattle fattened in Jatisari village, Sumbawa.

Pen-feeding trials

In controlled animal trials, Dahlanuddin et al. (2014) reported that the growth rate of Bali bulls fed 100% leucaena hay was 0.47 kg/d, more than double the growth rate of Bali bulls fed native grass. When leucaena hay was supplemented with 10 g maize grain (DM)/kg LW, growth rates increased to 0.66 kg/d (Dahlanuddin et al. 2018). In another experiment, Bali bulls fed 100% fresh leucaena ad libitum gained 0.50 kg/d; this growth rate reduced to 0.46 and 0.39 kg/d when maize stover was substituted for fresh leucaena at 25 and 50% of the diet, respectively (Soares et al. 2018).

Feeding high levels of leucaena hay (leaf and thin branches) to lactating cows increased milk production and calf growth. The milk production of cows fed leucaena hay ad libitum and 10 g maize grain DM/kg LW was 2.1 kg/d, double the milk production of cows fed 8-week-old regrowth of king grass ad libitum. Consequently, pre-weaning calf growth was significantly higher when cows were fed leucaena plus maize grain (0.37 kg/d) than when cows were fed king grass (0.16 kg/d) (Dahlanuddin et al. 2016).

As part of the IFSCA (Innovative Farming System and Capability for Agribusiness) project, a collaborative program between Massey University, New Zealand and University of Mataram, a feeding trial was conducted in Dompu district of Sumbawa using 20 growing Bali bulls fed: 100% leucaena ad libitum + 5 g rice bran DM/kg LW/d; 85% leucaena and 15% gliricidia mix ad libitum + 5 g rice bran/kg LW/d; 70% leucaena and 30% gliricidia mix ad libitum + 5 g rice bran/kg LW/d; or 55% leucaena and 45% gliricidia mix ad libitum + 5 g rice bran/kg LW/d (all diets supplemented with mineral mix at 3% of rice bran). Bulls in all treatments grew at 0.4–0.5 kg/d with no significant differences in growth rate between diets.

Meat quality

In response to anecdotal evidence that leucaena feeding results in dark meat and yellow fat, 5 bulls from the Dompu trial (fed fresh leucaena ad libitum plus 5 g rice bran/kg LW/d and mineral mix supplement) were slaughtered to measure carcass dressing percentages and meat quality. Carcass dressing percentages exceeded the average carcass dressing percentage of Bali bulls grazed traditionally and slaughtered at an abattoir in Sumbawa (52.4% vs. 48%). Meat quality tests (O. Yanuarianto pers. comm.) demonstrated that meat color of leucaena-fed bulls was cherry red and fat color was white. These parameters plus tenderness and marbling scores were similar to those from local beef animals considered as ‘grade one’ beef by Indonesian standards (W. Yulianto pers. comm.). Marbling score was low (mean of 2.4 on a 0–9 scale), which was mostly genotype-related.

Profitability of leucaena-based feeding systems

Based on the production parameters above, an economic analysis was conducted on cattle fattening on a leucaena-based diet in Jatisari (for details see Waldron et al. 2015). Production regimes are quite variable and speculative in the village, as knowledgeable and entrepreneurial farmers have become skilled at estimating weights and the fattening potential of feeder cattle, and adjusting fattening numbers according to periods for seasonal feed availability and prices. While this variability should be taken into account, this section reports values for a 'representative (typical) household', with scenarios explored in Waldron et al. (2015).

Compared with other areas of eastern Indonesia, bull fattening on leucaena in Jatisari was highly profitable, especially in the wet season, primarily because of the high growth rates (0.5 kg/d) achieved. As a result, households can grow and turn-off cattle relatively quickly (e.g. growing from 130 kg to 200 kg in 140 days).

With these high growth rates farmers have expanded pen operations to an average of 10 head on leucaena during the wet season. There are large 'upfront' land, labor and capital costs in developing this capacity (IDR 6.5 million for pens and IDR 1.7 million for 3,000 leucaena trees; USD 1 = IDR 14,000). However, if house-holds can meet these costs (as a household, community or with external support), costs are low when spread over 20 years and hundreds of cattle. Variable costs – transport and veterinary – are also low. Transport costs are not significant as households source feeder cattle from their own herds, a nearby trading area or traders, and cattle are sold at the farm gate.

With regard to revenue, cattle prices (about IDR 37,000/kg live weight in 2015) were lower on Sumbawa than for Lombok (because of the transport and permit costs), but markets were competitive and buoyant. As mentioned, farmers seek favorable alignments between the input (feeder cattle) and output (finished cattle) prices. While farmers use some of the manure from pens on nearby fields and leucaena trees for firewood, cattle sales make up 99% of revenue.

After accounting for these costs and revenues, farmers earn gross profits of up to IDR 160,000 per day from cattle fattening. However, a typical household also incurs significant capital costs (for expensive cattle) and, more importantly, significant labor costs (for 10 cattle on leucaena). A typical household spends 5.7 person hours per day doing cattle work, the majority of which is for forage collection, followed by pen work and buying/selling cattle. However, even after taking these costs into account, the 'returns to labor day' (i.e. the amount made per 8 hours of work) was IDR 185,000. This is far higher than off-farm work (IDR 50,000 per day). It is important to note, however, that the returns per person day are far lower in the dry season (IDR 31,000) when weight gains are lower (0.35 kg/d) and accordingly households reduce the number of cattle on feed (to 3 head).

Based on the results of the Applied Research and Innovation Systems in Agriculture (ARISA) project impact assessment study (R. Caudwell pers. comm.), the leucaena-based cattle fattening system increased net income by 60% over the base case where leucaena was not fed.

Adoption of leucaena-based cattle fattening system in West Nusa Tenggara Province

The ACIAR project was also designed to test the hypothesis that: "FTL feeding practices can be successfully transferred to neighboring districts provided the constraints for diverse groups of farmers were identified and effectively tackled through participatory adaptive research and 'Roll-Out' efforts, and provided specific technical issues that might limit their use were resolved".

An extension strategy was developed with the following key components:

1. Awareness-raising regarding the use and benefits of FTLs in cattle farming;
2. Adaptive on-farm trials and demonstration of FTL management systems;
3. Capacity building on the management and use of FTLs;
4. Facilitation of access to inputs and services related to FTL management;
5. Support for FTL/cattle farmer groups; and
6. Establishment and fostering of inter-institutional relationships.

We found that there was a lack of understanding of the nutritional needs of animals, and especially of fattening bulls, and the comparative nutritive values of the various feeds available to smallholder farmers. Many farmers did not understand the large differences in nutritional value among various forage resources, especially the superiority of leucaena compared with rice straw, crop residues, grasses or banana stems. Another reason for not adopting leucaena was concern about leucaena toxicity, which proved to be a short-term problem, as cattle quickly adapted even when on 100% leucaena diets.

The establishment of on-farm demonstration sites was a critical component of this work (Figure 4). These sites allowed for the assessment and refinement of practices and the development of extension materials, and were used for cross-visits to promote good management practices to other farmer groups. An integrated package was developed comprising recommendations for the establishment, management and feeding of leucaena, and included recommendations for provision of water, hygiene and health. The project also recommended a basic model fattening shed (kandang) which could be easily replicated by farmers or farmer groups, in single or multiple units, either exactly as recommended or modified to suit local construction materials.

a. Leucaena seedling nursery

b. Leucaena bare stems ready for planting

c. Leucaena rows inter-planted with maize

d. Leucaena ready for harvest

e. Freshly harvested leucaena

f. Fresh leucaena being fed to Bali bulls

Figure 4. Establishing, harvesting and feeding of leucaena for cattle fattening in Sumbawa.

Barriers to and opportunities for adoption

Initially, there was very slow adoption by local Sumbawanese farmers even after they were taken to the Balinese village to observe the system in operation (Figure 4).

The project team then approached some local innovative farmers, rather than farmer groups, who had started to plant and use leucaena. This included a radio technician, who was interested in planting forages on his own land to feed goats. After several visits by the project team, these individual farmers became convinced to plant the new variety of leucaena, cv. Tarramba, and began fattening some young bulls. They soon found the system to be very profitable and became trainers for other farmers. Since then, the adoption rate has increased, driven by these local examples and by the high cattle prices obtained for fattened bulls. By the end of 2015, 535 farmers were involved in the leucaena-based fattening system in West Sumbawa and Sumbawa districts at various stages of adoption (Shelton and the Project Team 2017).

The barriers to and opportunities for adoption of FTL in Indonesia are now well understood. Our findings were first presented in the paper by Kana Hau et al. (2014), and an updated list of barriers and opportunities for adoption was described in the final report to ACIAR on Project LPS/2008/054 (Shelton and the Project Team 2017) under the principal categories: Nature of the innovation; technical constraints; project leadership and staffing; engagement with farmers; socio-economic and agribusiness issues; and Government policy and involvement.

Applied Research and Innovation Systems in Agriculture (ARISA) project

Commencing in 2016, a collaborative research project was initiated between the University of Mataram and Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia as part of the Applied Research and Innovation Systems in Agriculture (ARISA) project funded by the Australian Department of Foreign Affairs and Trade (DFAT). While this new initiative was aimed at improving incomes by developing partnerships between the private sector and farmers, the most successful activity was a continuation of scale-out of the intervention to improve supply of high quality forages using leucaena.

By October 2018, 2,500 farmers (direct adoption from other farmers) in Sumbawa and West Sumbawa districts had adopted leucaena fattening. These farmers initially used a local leucaena variety, which they had harvested from wild leucaena growing on roadsides or forest margins, which had survived the psyllid infestations in the 1980s. Based on survey figures from June 2018, 733 new farmers on Sumbawa and West Sumbawa had planted the improved more psyllid-tolerant cultivar Tarramba and 133 of them were already fattening their cattle with this new cultivar (Figure 5). The total area planted to cv. Tarramba was 567 ha.

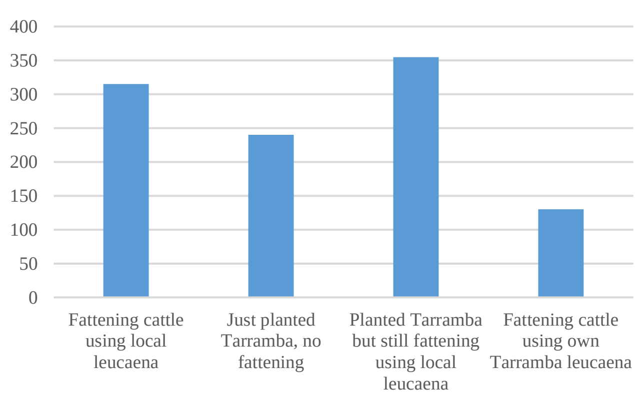


Figure 5. Numbers of farmers directly adopting leucaena-based cattle fattening in Sumbawa and West Sumbawa districts at various levels of adoption.

Innovative Farming System and Capability for Agribusiness (IFSCA).

The number of newly planted leucaena areas continued to increase rapidly and the practice was scaled-out to the neighboring district of Dompu through the IFSCA project, a collaborative program between Massey University, New Zealand and University of Mataram. The aim of this project was to increase income from cattle-crop (especially maize) integration by improving capacity of all participants in the value chain. One of the interventions was to scale-out proven innovations in cattle production, one of which was the leucaena-based cattle fattening system. Through this project, more than 200 farmers have been involved in cattle fattening using leucaena as the main component of the diet. The number is increasing rapidly and is expected to at least double in the next financial year.

Conclusions

Having one community, e.g. the Balinese community in Sumbawa and West Sumbawa districts, feeding leucaena successfully to cattle for decades does not necessarily mean that another community, e.g. the local Sumbawanese farmers, would adopt the strategy, partly due to cultural and communication barriers.

It took a combined research effort between BPTP, the University of Mataram and The University of Queensland, supported by ACIAR, DFAT and MFAT, to develop a model leucaena-based cattle fattening system, which was then introduced to the Sumbawanese farmers to dramatically change the situation. This, combined with a well-planned extension strategy including on-farm demonstrations, resulted in more than 2,500 Sumbawanese farmers (1,050 directly influenced by the project plus more than 1,000 copying farmers) on Sumbawa Island adopting cattle fattening based on leucaena by October 2018, 7 years after the study commenced.

The main drivers of adoption of fattening with leucaena were:

1. The high growth rates achieved compared with the traditional system, combined with the high cattle price (up to IDR 50,000/kg live weight) that resulted in high profitability;
2. The needs of farmers being met in terms of relevance and cultural appropriateness to local cattle production systems, land being available for planting leucaena and input costs being low;
3. Field extension staff being well trained and mentored, so they gained the respect of the farmers;
4. The local government being highly supportive of leucaena-based cattle fattening, and actively supporting

adoption by farmers. With the improved availability of leucaena, local government was successful in attracting additional central government funding for cattle development on the island;

5. Increased carcass dressing percentage compared with traditionally fattened Bali bulls and meat characteristics being of high quality; and
6. Observing farmers of their own ethnic community successfully practicing the system of feeding.

The adoption of leucaena-based cattle fattening has proven to be a very effective forage improvement strategy in the dry areas of eastern Indonesia. Using similar strategies to those employed should improve uptake of new technology in similar situations in the region. Rapid increase in the use of this cattle-fattening strategy in eastern Indonesia is expected to have a significant positive impact on household incomes as well as on regional economic growth.

Acknowledgments

Data presented in this paper are from results of ACIAR LPS/2008/054, CSIRO - University of Mataram ARISA and Massey University - University of Mataram IFSCA projects. We thank ACIAR, DFAT and MFAT for funding support for these projects.

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ILC2018 Keynote Paper*

Economic analysis of cattle fattening systems based on forage tree legume diets in eastern Indonesia

Análisis económico de sistemas de engorde de ganado basados en árboles leguminosos forrajeros en Indonesia Oriental

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Abstract

Research and government agencies in eastern Indonesia have identified 2 systems with potential to increase productivity and incomes of small-holder cattle producers: improved cattle feeding practices through forage tree legumes (FTL); and the development of more efficient and specialized cattle-fattening systems. Extensive research has been conducted on production and technical aspects of FTL-fattening systems, but there is a gap in research on economic incentives for households to adopt the systems. This paper provides an economic analysis of a leucaena-fattening system in a village in West Timor. It draws on trial data from associated technical research projects and detailed semi-structured interviews with farmers and other stakeholders to populate a bio-economic model built for the research. Under all measures of profitability, leucaena-fattening systems in representative households are profitable in the wet season. Importantly, 'returns to person days' are higher than off-farm incomes. The activity generates cash income, increasingly required to meet cash expenses in modern rural Indonesian society. However, returns vary considerably between households, are considerably lower in the dry season and, as would be expected, are sensitive to relative prices of feeder and finished cattle.

Keywords: Household budgeting, leucaena, profitability, small-holders, West Timor.

Resumen

Instituciones de investigación y desarrollo en Indonesia Oriental han identificado dos sistemas con potencial para aumentar tanto la productividad bovina como los ingresos de pequeños productores de ganado en la región: prácticas de alimentación mejorada de los animales mediante forraje de árboles leguminosos; y el desarrollo de sistemas de engorde de ganado más eficientes y especializados. A pesar de amplias investigaciones sobre aspectos técnicos y de producción de los sistemas de engorde basados en árboles leguminosos forrajeros, aún existe una brecha en la investigación sobre incentivos económicos para que los productores adopten los sistemas. Este trabajo presenta un análisis económico de un sistema de engorde de ganado basado en leucaena en una aldea en Timor Occidental, Indonesia. Basado en datos de experimentos de proyectos de investigación técnica y entrevistas semiestructuradas con agricultores y otras partes interesadas, se desarrolló un modelo bioeconómico específico para esta investigación. Bajo todas las medidas de

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rentabilidad, los sistemas de engorde con leucaena en fincas representativas son rentables en la estación lluviosa. Es importante destacar que los retornos a la mano de obra empleada son más altos que eventuales ingresos provenientes de actividades no agrícolas. El sistema estudiado genera ingresos que son cada vez más requeridos para cubrir los gastos pertinentes a la moderna sociedad rural en Indonesia. Sin embargo, los retornos varían considerablemente entre las fincas, son considerablemente más bajos en la estación seca y, como es de esperar, son sensibles a la relación del precio de compra de animales para engorde y el de venta de los animales para el matadero.

Palabras clave: Leucaena, pequeños productores, presupuesto familiar, rentabilidad, Timor Occidental.

Introduction

The province of Nusa Tenggara Timur (NTT) in eastern Indonesia faces substantial development challenges. The province is one of the least developed in Indonesia, with a per capita GDP one-quarter of the national average. In 2017 incomes of 25% of the rural population of NTT were below the poverty line (Rp 329,136 or AU$ 32 per month), compared with the national average of 13% (BPS 2018). Agriculture is a central economic activity in NTT, and livestock production makes up 16% of agricultural GDP. There are 60,000 livestock producers in NTT, the majority of whom own cattle (DGLAHS 2013), three-quarters of which are small-holders with 1–10 head (Mullik 2012). In particular parts of NTT, cattle sales can represent more than 80% of the family's cash income (Nimmo-Bell and ICASEPS 2007). Cattle also play a social role for ceremonies and as a source of 'savings' that can be cashed-in to meet large cash outlays including housing, school fees, health and transport.

In response to high beef prices over a sustained period, cattle numbers have almost doubled in the past decade from 555,000 in 2007 to more than one million in 2017 (BPS 2018). However, productivity is low as indicated by annual turnoff rates of just 13%, due to low weaning rates and long periods of slow growth to reach sale weight, for either slaughter or live cattle export (Waldron et al. 2012). Cow-calf production is conducted mainly in extensive grazing systems in NTT and various measures have been taken to improve reproduction and reduce calf mortality (Copland et al. 2011). The emergence of a cattle-fattening sector has potential to increase growth rates to reach sale weights at an earlier age and to create demand for feeder cattle (from the cow-calf sector). Of particular interest in relation to this paper, cattle-fattening has the potential to generate positive cash flows that are increasingly required in a society transitioning from a subsistence to a cash economy.

Forage tree legumes, particularly leucaena, have been identified as a central feed source for the development of the small-holder cattle-fattening sector. This has given rise to a body of literature on the impacts on cattle growth of feeding tree legume forage (e.g. Dahlanuddin et al. 2014, 2019; Shelton and the Project Team 2017). However, there has been a dearth of studies to verify the economic incentives for households to take up and sustain the systems, which is the focus of this paper.

Methods

Sites

The economic analysis on which this paper draws was conducted across 3 sites in the provinces of NTT and NTB, which have differing characteristics. This paper focuses on the West Timor village site of Oebola, where Bali bulls are fattened in pens on a leucaena-based diet. Leucaena is strip-planted with corn. The system is widely applicable to other areas of West Timor including Kupang and Amarasi, which are the largest cattle-producing areas in NTT. Results for the Sumbawa site of Jati Sari are reported in this issue (Dahlanuddin et al. 2019), including cattle systems, history, adoption, productivity, economics and meat output from the village.

The model

To assess household structures and incentives for FTL-based fattening, a bio-economic model was developed for a representative cattle-fattening household in Oebola. It is a partial budget, insofar as it focuses on the activity of leucaena production and cattle fattening. It is also a steady-state budget, with production and returns assessed over a specified fattening period, which is almost always less than 365 days. The focus on leucaena-fattening means that the model accounts for virtually all direct cost and revenue items. However, the budget does not account for environmental externalities including soil enrichment and reduction in over-grazing.

It is problematic to conduct a 'with and without' economic analysis of leucaena-fattening systems. Small-holders did not fatten cattle as a specialized activity prior to the extension of the systems. As elaborated in the 'scenarios' section of the paper, it is economically unviable to fatten cattle on a diet of crop residues and grasses, and grain is prohibitively expensive. Thus this analysis begins with a detailed discussion of a single scenario of fattening with leucaena, namely a representative (typical) household in Oebola fattening 4 cattle in the wet season, with average prices over the period. Alternative scenarios – based on season, weight gains and prices – are then examined to test production and income effects. The model reports on various measures of profitability, the most relevant being 'returns to labor'. All budget items and formulae are explicitly stated in Excel spreadsheets that are publically available on request. All values are expressed in Rupiah and the exchange rate adopted is Rp 10,000 to AU$ 1 in 2014 when the research and fieldwork was conducted.

Data

Production data for the research were drawn from ACIAR project LPS/2008/054, which monitored 8 households in Oebola during 2013 and 2014 with a total of 30 head of cattle between them (Pakereng 2015). Price data collected from the monitored households were cross-referenced with meetings with traders and butchers and with weekly beef price data (MoA, various years). Costs and sales data were collected through focus groups and semi-structured interviews with 5 farmers. Village-level data were used to place the farmers in context and to establish a 'representative' or 'typical' fattening household, which is reported in this paper. Fieldwork was undertaken in August 2012, May 2014 and July 2015.

Results

Background on Oebola village

The budgeting for NTT focuses on Oebola village, Fatuleu Sub-District, Kupang District, West Timor. The system is based on corn cropping with strip-planting of leucaena and the fattening of Bali bulls in pens owned by individual households, all of which immigrated from other parts of Indonesia. In 2015 village statistics reported 276 households with an average of 4.2 household members. Household cropland sizes were 0.5–1 ha per household but some households had up to 2 ha split into parcels. Cattle were grazed collectively on village land and sometimes government forest land. Ninety-five percent of households earned a living from agriculture for both own consumption and sales. The main crops were corn (a single crop in the wet season), pumpkins and beans. Livestock included cattle, pigs and chickens. There were 1,453 cattle in the village, i.e. an average of 5.3 head per household. Cow-calf production in grazing systems predominated and calves were usually taken through to slaughter age. Many households bought-in feeder cattle to use in specialized feeding operations and most households fattened only 1 or 2 head at a time, with a maximum of 8.

Cattle fattening in Oebola

The budget results are summarized in Table 1 and detailed throughout the rest of the paper. Based on average results of monitored households (Pakereng 2015) the representative household sourced 4 bulls from its own herd or bought them in, with a starting live weight of 189 kg. Feeding periods were variable but averaged 170 days. There was a large difference in feed regimes and weight gains between seasons. In the wet season, bulls were fed a diet amounting to 2.5% of their body weight, comprised of 80% FTL (60% leucaena, 20% gliricidia), 17.5% native grasses and leaves and 2.5% corn silage. Average daily weight gain (ADWG) was 0.4 kg/d and bulls were sold at 257 kg live weight. In the dry season bulls were fed only 40% FTL (30% leucaena, 10% gliricidia) plus 60% native grasses and leaves and ADWG was only 0.2 kg/d, with bulls sold at 223 kg live weight.

Revenues

Cattle sales accounted for 98% of all cattle revenues for the household. Prices for both feeder and finished cattle were Rp 29,000/kg live weight in July 2015 (with price variations discussed in scenarios below). The model also accounted for revenue from manure and timber. While these were only 2% of total revenues, they were significant as a percentage of value added from fattening (finished cattle cost minus feeder cattle cost) at 7 and 12%, respectively. Of the manure produced (35% of DM intake), 10% was sold (Rp 250/kg dry), 20% was used for fertilizer (valued based on the substitution of urea and NPK fertilizers) and 50% was unused (which can have negative environmental impacts). The remainder (20%) was used for biogas which was valued based on reduction in household labor spent collecting firewood (1 hour per day) and kerosene usage for cooking and light in the household. The branches of leucaena trees were used for firewood. If 2 branches were used per cut (every 120 days) then 3,600 branches were collected over the fattening period with a value of Rp 100,000.

Capital investments

The representative household made capital investments in items used for multiple household activities over extended periods. The cost (both cash and labor) was amortized over the economic life of the asset and attributed to cattle fattening over the fattening period.

Table 1. Revenues, costs and returns (in Indonesian rupiah; 1 AU$ = 10,000 Rp) on leucaena-based cattle fattening for a representative household in Oebola village, West Timor, and weight gain and price scenarios. Highlighted cells refer to the scenarios analyzed in the paper and the key indicator of 'returns to labor'. Source: Author calculations; all values are expressed for a fattening period for the number of cattle specified, except 'returns to labor', which are expressed on a per day basis.

BUDGET SUMMARY - over fattening period	Wet season - representative household	% of category	Dry season - representative household	Wet - best performing	Wet - worst performing	Wet - price increase 15%	Wet - price decrease 15%	Grass-corn stover diet
Main parameters								
Cattle								
ADWG (kg/day)	0.4		0.2	0.8	-0.2	0.4	0.4	0.15
Weight exit of household (kg)	257		223	325	155	257	257	214.5
Feed								
DM intake (kg/head/day)	5.6		4.1	6.4	4.3	5.6	5.6	5
Proportion FTL in diet	80%		40%	80%	80%	80%	80%	0%
Prices								
Cattle purchase price (Rp/kg LW)	29,000		29,000	29,000	29,000	29,000	29,000	29,000
Cattle sales price (Rp/kg LW)	29,000		29,000	29,000	29,000	33,350	24,650	29,000
Revenues	**30,468,838**		**26,512,614**	**38,363,979**	**18,626,126**	**34,940,638**	**25,997,038**	**25,534,375**
Cattle sales	29,812,000	98%	25,868,000	37,700,000	17,980,000	34,283,800	25,340,200	24,882,000
Manure	556,838	2%	544,614	563,979	546,126	556,838	556,838	552,375
Leucaena branches	100,000	0%	100,000	100,000	100,000	100,000	100,000	100,000
Costs (excl labor and capital)	**23,274,655**		**23,308,655**	**23,274,655**	**23,274,655**	**23,274,655**	**23,274,655**	**23,152,777**
Capital investments								
Depreciation of leucaena, pens, water, motorbike, biogas	185,778	1%	185,778	185,778	185,778	185,778	185,778	182,900
Production costs								
Cattle purchase	21,924,000	94%	21,924,000	21,924,000	21,924,000	21,924,000	21,924,000	21,924,000
Fuel and water	237,534	1%	271,534	237,534	237,534	237,534	237,534	118,534
Veterinary and additives	364,000	2%	364,000	364,000	364,000	364,000	364,000	364,000
Cattle marketing	228,000	1%	228,000	228,000	228,000	228,000	228,000	228,000
Crop shading and moisture	335,342	1%	335,342	335,342	335,342	335,342	335,342	335,342
Gross profit	**7,194,183**		**3,203,959**	**15,089,324**	**-4,648,529**	**11,665,983**	**2,722,383**	**2,381,598**
Less capital costs (feeder cattle and infrastructure)	1,938,169		1,938,169	1,938,169	1,938,169	1,938,169	1,938,169	1,938,169
Net profit (excl own labor)	**5,256,013**		**1,265,789**	**13,151,155**	**-6,586,698**	**9,727,813**	**784,213**	**452,638**
Divided by family labor, of which	86		105	86	86	86	86	94
Capital investments	0.8	1%	0.8	0.8	0.8	0.8	0.8	0.6
Cattle purchase and sales	8	9%	8	8	8	8	8	8
Feeding costs	56	65%	75	56	56	56	56	64
Kandang work	21	25%	21	21	21	21	21	21
Hours per day on cattle fattening	**4.0**		**4.9**	**4.0**	**4.0**	**4.0**	**4.0**	**4.4**
Returns to labor (person days)	**61,463**		**12,097**	**153,788**	**-77,024**	**113,756**	**9,170**	**4,821**

To meet dietary requirements of the 4 bulls, the household required a total of 1,200 trees with a 120-day interval between harvests, strip-planted on the land of the household. Planting costs included fencing, purchase of seeds, nursery (poly bags, bedding, shade cloth) and transplanting (labor and transport). The modest up-front costs (Rp 308,000 in cash and 13 person days labor) were negligible when depreciated over 40 years.

The costs of constructing a pen (nails, wire, timber, cement, sand, gravel, reinforcing, troughs, roof and other items) were higher than for trees (Rp 1.35 million) but also low when depreciated, given a lifespan of over 20 years and fattening 160 cattle. The 'design capacity' of the pen was 5 head. Given the actual number (4 head) and time not on feed (26 days) capacity utilization was 72%, which increased overhead costs per head.

The cost of a motorbike (used to transport feed and marketing of cattle) was high but the machine was used for fattening for only 20% of the time and was depreciated over a life-span of 15 years. Most households had a well that lasts 15 years at a cost of Rp 1,500,000 plus the costs of meals for workers that dig it. Biogas facilities (pits and converters) are commonly installed in West Timor to use effluent from the pens. Equipment is free (as part of a government program) but costs are incurred for meals for installers and household labor, especially to dig the pit and for maintenance (cleaning out pits and lines).

When costs of all capital items were amortized, depreciation costs totaled Rp 186,000 per fattening period. Together, these made up <1% of total costs and were eclipsed by other costs, so appear to be small. However, it is important to note that these are up-front costs (in land, labor and capital) that can be significant for households when first investing and can be a barrier to adoption. While loans are available through formal and informal channels including banks with subsidized loans, traders and profit-sharing arrangements with other households (Waldron et al. 2012), households usually use their own limited savings for these infrastructure items.

Production costs

Production costs are incurred specifically for cattle fattening on a daily basis or within the fattening cycle and are directly linked to production volumes. Feeder cattle purchase costs accounted for 94% of total costs. Self-produced bulls were valued as an opportunity cost (that could otherwise be sold) or as a cash cost when bought in. Costs of cattle purchases, mainly from a nearby live cattle market, included search costs (telephone, fuel and household labor), trucking and broker fees. Cattle were sold to traders at the farm gate and so incurred negligible sale costs.

After leucaena has been established there are no additional cash costs but there are significant labor costs for collection and transport. In the wet season all members of the household traveled an average of 1 km (range of 0.5–5 km) to collect forage twice per day, taking 1.5 hours. Motorbike fuel was Rp 700 per day. The collection of native grasses and leaves in the wet season was less time-consuming because it comprised the smaller part of the diet but was more labor-intensive to collect from scattered trees and bending over to cut grass. Labor costs to collect native grasses and leaves in the dry season were high (2 hours per day). Corn stalks were fed after harvest (at the end of the wet season), which required labor for cutting, transport and storage over a few days but little after that.

Several households in the group paid Rp 240,000 per year for access to group water supplies (access, pipe maintenance, fuel for pump) of which about 30% was used for cattle fattening. The household spent 30 minutes per day collecting and distributing water to the troughs in the pen. The household spent another hour per day in cleaning pens and cattle management.

Veterinary costs included vaccination (for anthrax and haemorrhagic septicaemia to allow for live export), one medical check (from local vet), a vitamin supplement and a small amount of salt. The total veterinary treatment costs (Rp 364,000 over a fattening period) were the second highest cash outlay.

Crop shading and moisture competition were included as additional costs of production. When 1 ha of corn is planted in the wet season and strip-cropped with leucaena, it is assumed that the grain yield (2,400 kg/ha) is reduced by 10%. Valued at Rp 3,000/kg, the forgone revenue is Rp 720,000 or Rp 335,000, when allocated over a fattening period.

Returns to cattle fattening

The returns (or profits) were estimated in different ways to provide different measures of profitability. Subtraction of costs from revenues provided 'Gross profit', which was positive in the wet season (at more than Rp 7 million over the fattening period) but declined to less than half of this in the dry season. Capital costs were deducted from gross profits to give 'Net profit'. Few households took out loans, but an opportunity cost was applied to the money invested in cattle that could otherwise be invested. The interest rate on a deposit in a savings account was used to value the opportunity cost of capital (8%). For large and expensive inputs like feeder cattle, the opportunity costs of capital were significant.

The next section on family labor reports the labor inputs into cattle fattening. The majority of labor was used on feed collection and watering, followed by work in pens, then by cattle marketing. Labor input into infrastructure was allocated over the fattening period and was small. The total labor inputs were converted into hours per day in cattle fattening (i.e. 4 hours for 4 cattle in the wet season), then converted into an 8-hour working day (i.e. half a day).

'Net returns' were divided by total labor input to derive 'Returns to labor', which provided the most useful indicator of profitability. This provided an indication of the profits from cattle production that a household was making from their own labor and management, and allowed comparison with other farm and off-farm work. Results for the representative household suggested that returns to cattle fattening in the wet season were positive (Rp 61,463), which compared favorably with average off-farm work (Rp 45,000). Comparisons were not so favorable in the dry season. At Rp 12,097 per day, income was at or below the poverty line. However, it must be considered that cattle can be produced all-year-round compared with off-farm work, which can be seasonal or inconsistent. Farmers may also be attracted to the customs and pride of running their own enterprise.

Budget results from 1 ha of corn in Oebola using (low) yields from 2015 and 2016 suggested that returns to person days were comparable with cattle fattening in the wet season. Because of its central role in household consumption and cash sales and its agro-climatic suitability, farmers in Oebola continue to grow corn. While strip planting of leucaena reduces corn yields (by 10%), it is integrated into the corn cropping, and not a substitute activity.

Scenarios

While the discussion above examined an average household in 2 seasons, there is large variation between households and natural and market conditions. A range of scenarios are reported in Waldron et al. (2015) including changes to rations, weight gains, fattening period, price, capital investment, labor cost and sales channels. This paper examines just the major variables – weight gain and price.

Weight gain. Profitability of feeding in the wet season was far greater than in the dry season for the representative household. By far the most important determinant was the difference in ADWG (0.4 vs. 0.2 kg/d) due to diet and compensatory weight gain early in the wet season. The labor cost in collecting native grasses and leaves in the dry season was also slightly higher than collecting FTL leaves in the wet season. The differences in ADWGs lead to returns to labor of Rp 61,463 in the wet season more than 5 times the returns in the dry season (Rp 12,097).

Households in the group with highest gains in the wet season (0.8 kg/d) recorded very high returns (Rp 153,788), while those with lowest weight changes (-0.2 kg/d) operated at a heavy loss (Rp -77,024).

Prices. Profitability is also sensitive to market trends and especially the relative prices of feeder and finished cattle, which are a function of market conditions, weather, household conditions, the skills of buyers and sellers in appraising cattle (visually) and timing (ceremonies, the issue of export permits or when school fees are due). If finished cattle prices are 15% higher than feeder cattle prices, returns increase strongly by 86%, but if they are 15% lower than feeder prices, cattle fattening is barely a break-even activity (Rp 9,170).

Returns without FTL. It is also useful to examine returns to fattening without leucaena. This is done in the modelling by assuming a diet of improved grasses (80%) and corn stover (20%). However, this would not be possible throughout the wet season because corn is harvested at the end of the wet season, unless corn stover was carried over from the previous season or was purchased in. While the stover could be stored and used in the dry season, quantities of grass available would be insufficient or very time-consuming to collect. Weight gains are reduced to 0.15 kg/d, which is a generous assumption given comparisons in various feed systems and locations (Quigley et al. 2009; Panjaitan 2012; Dahlanuddin et al. 2014). Time to chop stover increases from 0.1 to 0.5 hours, and to collect grass and leaves from 1 to 2.5 hours. In this case, 'Returns to person days' are very low at Rp 4,821, indicating that cattle fattening is not biologically or commercially viable without leucaena.

Conclusions

Analyses reported in this paper confirm the intuitive understanding that cattle fattening on a leucaena-based diet is biologically and economically viable for most small-holders in West Timor under most conditions. Leucaena is a low-cost input, provides feed through the dry season (albeit at a lower yield) and generates reasonable weight gains. Cattle fattening is capital-intensive, but allows for rapid turnover of both cattle and capital. Cattle fattening is not land-intensive, can be done under various ownership (owner-keeper) arrangements, and is relevant for a wide range of households. These factors explain the growth of leucaena-fattening systems in NTT.

Growth in the sector could be disrupted if circum-stances differed. Beef prices were buoyant for most of the

2010s and market fundamentals remained strong, but prices have fluctuated in recent years (for policy reasons, including trade policy and domestic support), which may affect incentives. Cattle fattening with leucaena is relatively labor-intensive. In countries and regions where there are good alternative opportunities for work and wages, small-holders can be drawn out of cattle production (Waldron et al. 2018). While cattle fattening may provide reasonable returns for small-scale farmers (such as the representative household in this study), profits of AU$ 6 per day will not make them rich. Future growth in the sector may see the emergence of more large, skilled and entrepreneurial fattening-trading households, which could utilize leucaena sometimes through land and cattle-/land and labor-sharing arrangements.

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ILC2018 Poster and Producer Paper*

Preliminary assessment of rearing male buffalo calves on *Leucaena leucocephala*-buffel grass pasture in Maharashtra State, India

Valoración preliminar de cría de terneros bubalinos en una pastura de Leucaena leucocephala-Cenchrus ciliaris *en el estado de Maharashtra, India*

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Keywords: Animal growth rates, *Bubalus bubalis*, pasture, tree legumes.

Introduction

India's US$4 billion buffalo meat export industry relies mainly on the slaughter and processing of females that have stopped lactating. The potential for fattening of male buffalo calves (MBCs) for quality meat production was identified in 1995 in a report of the National Dairy Research Institute (Sharma et al. 1995): "Underfed MBCs after weaning are either starved to death or pushed to the slaughterhouse. Such malnourished calves, weighing 60 to 80 kg, yield only 30 to 35 kg carcasses of inferior quality. These calves, if reared on high energy diets up to a live body weight of 350 kg, may yield 180 kg carcasses of good quality". The rearing of MBCs could augment meat exports and provide raw material for the domestic leather industry, thereby developing a new avenue for rural employment.

Leucaena leucocephala is high quality forage, which is highly regarded in seasonally dry environments in eastern Indonesia, due to its excellent ability to produce year-round fodder if properly managed and regularly pruned (Panjaitan et al. 2014; Nulik and Kana Hau 2015). In previous research in India, no ill-effects on the general health of MBCs fed 70% of their dry matter requirements as *L. leucocephala* were observed, although daily bodyweight gains were less than 50% of those of the control group given 3.5 kg concentrates and 3.5 kg wheat straw daily (Gupta et al. 1986). This may have been due to reduced dry matter intake, lower levels of serum triiodothyronine (T3) and thyroxin (T4) and increased aspartate transaminase (AST) and alanine transaminase (ALT) activities in plasma as reported by Gupta (1995). ALT and AST are serum biochemical variables whose activities are considered as biomarkers for liver function, and synthesis of protein, albumin and globulin largely depends on the liver function status. T4 and T3 levels are considered valuable indicators of thyroid function in animals.

Given the contrasting results from previous experiments in India, the objective of this study was to conduct a preliminary assessment of rearing MBCs on leucaena-buffel grass pasture in a semi-arid part of the state of Maharashtra in India.

Materials and Methods

The study consisted of 2 experiments:

- Experiment 1: 1 December 2015–27 February 2016 (2 MBCs)
- Experiment 2: 5 January 2017–1 August 2018 (4 MBCs)

A pasture of *L. leucocephala* cv. Wondergraze + *Cenchrus ciliaris* cv. Laredo (buffel grass) was established on a 4,000 m^2 area at 'Tambmal' farm of the Nimbkar Agricultural Research Institute (NARI) by sowing 1 kg leucaena seed on 13 July 2015. Twin rows of leucaena were planted with inter-row spacing of 4.5 m. This was followed by sowing of 1 kg buffel grass seed on 13 August 2015 in the inter-row space (between the leucaena twin rows).

Another pasture was established on 8,000 m^2 at 'Madhura' farm at Jadhavwadi village near Phaltan,

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where buffel grass cv. Laredo was planted with slips in 2013. About 1,300 seedlings of leucaena cv. Tarramba were planted in this pasture at a spacing of 4 × 1 m in October 2016. Both pastures were located near Phaltan town (17.98° N, 74.43° E; 568 masl) on medium black basaltic soils. Growth of the leucaena seedlings was slow, presumably due to the competition from the buffel grass. *Gliricidia sepium* trees (gliricidia) were planted around the boundary of the experiment, and we planned to feed their foliage to the MBCs. However, even after repeated attempts, the calves refused to consume fresh, wilted or dried foliage of gliricidia.

In the first experiment, the 2 MBCs (about 7–8 months old and weighing 79 and 89 kg) were allowed to graze in the leucaena-buffel grass pasture for 3 months. The MBCs were removed from the pasture every Saturday evening and returned to it on Monday morning. This was a precaution against them being stolen over the weekend. During these 40 hours away from the pasture they were fed with sweet sorghum leaves and fresh leucaena forage from 3–5 trees (not weighed). The sorghum leaves were fully consumed, but some leucaena leaves were always left over.

The 2 MBCs were weighed weekly. After they showed satisfactory growth, they were sold and 4 additional MBCs (about 3–4 months old and 37–51 kg) were acquired on 5 January 2017 for Experiment 2. No measures were undertaken for internal or external parasite control in these 4 MBCs. They were shifted between the 2 farms (buffel or leucaena + buffel pastures at Madhura and Tambmal farms, respectively), depending on the availability of fodder, and were housed at night. It was decided to feed fresh leucaena fodder to them as much as possible, but sometimes due to its shortage, other fodders such as chopped sweet sorghum stalks (dried or fresh) or stripped sweet sorghum leaves were fed. For about half of this experiment the MBCs grazed buffel grass pasture and the other half leucaena-buffel grass pasture. The different feeds and the periods during which they were supplied to the MBCs are presented in Table 1.

The animals were difficult to handle despite being castrated (13 December 2017), making it difficult to weigh or measure them once they exceeded about 100 kg live weight, and there was no facility for weighing at Madhura farm.

The feed supplied was measured where possible (Table 1). Fresh leucaena forage (300 kg per week) was sent to Madhura farm for about 15 weeks during the second period of grazing. This was fed to the MBCs throughout the week either during the morning before they were taken to the buffel grass pasture or after bringing them back in the

Table 1. Feed offered to the 4 male buffalo calves (Experiment 2).

Dates	No. days	Grazing	Fresh leucaena leaves	Sorghum leaves	Other
5.1.17 to 5.2.17	32	-	Weight not recorded		
6.2.17 to 31.3.17	54	Buffel grass pasture	-	-	-
1.4.17 to 10.4.17	10	Leucaena-buffel grass pasture (day)	Buffel grass + leucaena leaves + sorghum leaves (all fresh) + fresh or dry chopped sorghum (total 100 kg)		
11.4.17 to 22.4.17	12	Leucaena-buffel grass pasture	-	-	-
23.4.17	1	Leucaena-buffel grass pasture	-	4 kg (at night)	-
24.4.17 to 8.5.17	15	Leucaena-buffel grass pasture	-	-	-
9.5.17 to 18.5.17	10	Leucaena-buffel grass pasture	12–15 trees per day (at night)	-	-
19.5.17 to 19.9.17	124	Leucaena-buffel grass pasture	-	-	-
20.9.17 to 25.4.18	218	Buffel grass pasture	300 kg once a week from 2.12.17 to 20.3.18 (15 weeks)	-	Solution of 200 g urea sprinkled on 5–10 kg buffel grass and fed 5 times from 29.12.17 to 27.1.18
26.4.18 to 7.6.18	43	Leucaena-buffel grass pasture	3,098 kg	-	-
8.6.18 to 1.8.18	55	Leucaena-buffel grass pasture	733 kg from 30.6.18 to 31.7.18 (4.5 weeks)	100 kg from 2.7.18 to 30.7.18	-
Total	574				

evening. Rainfall was measured at the Tambmal farm over the course of the experiments. Both farms have irrigation facilities and flood irrigation was provided on a weekly basis to the buffel grass pasture, while leucaena-buffel grass pasture received 3 flood irrigations in total during February and May 2017 and February 2018.

Figure 1. Four MBCs grazing in buffel grass-leucaena pasture.

Results and Discussion

Rainfall was variable over the 2 growing seasons. In 2017, 733 mm was received, which is about 200 mm above average, with 70% falling in September–October, while no rain fell in January, February, April, November and December. In 2018, 145 mm rainfall was received from January 1 to July 31, which is below average with no rain in January–March.

In Experiment 1, weights of the 2 MBCs increased to 125 and 137 kg, respectively, after 88 days in the leucaena-buffel grass pasture, giving growth rates of 466 and 716 g/d, respectively.

For Experiment 2, average daily gains for different pasture types are given in Table 2 with final weights of the 4 MBCs after 574 days ranging from 218 to 305 kg. Average daily gains ranged from 304 to 452 g/d, with the highest daily gains (582–970 g/d) during the trial occurring in the last 98 days when leucaena was fed.

Overall, growth rates were much higher when animals grazed leucaena-buffel grass pasture than on buffel grass alone (Table 2). Feeding leucaena forage on the buffel pasture increased weight gains but daily weight gains on leucaena-buffel grass pasture were 2.8 times greater than on buffel grass pasture.

No overt signs of mimosine toxicity were observed but hair was lost from the bodies of the MBCs by the end of the first year and there was no need to shave them as is the normal practice.

Table 2. Average daily gain (kg/hd/d) as affected by pasture type (February 2017–August 2018).

Sr. No.	Pasture type	No. days	Calf 1	Calf 2	Calf 3	Calf 4	Mean
1	Buffel grass	54	0.14	0.10	0.0	0.0	0.06
2	Leucaena-buffel grass	161	0.43	0.33	0.36	0.35	0.37
3	Buffel grass	229	0.36	0.30	0.26	0.44	0.34
4	Leucaena-buffel grass	98	0.97	0.76	0.58	0.75	0.76
Total	Buffel grass	283	0.25	0.20	0.13	0.22	0.20
	Leucaena-buffel grass	259	0.70	0.54	0.47	0.55	0.57

The cost of establishing the buffel grass-leucaena pasture on the 4,000 m^2 area was about INR 25,000 with 50% being spent on manual weed control. The cost of putting up a barbed wire fence around this pasture was INR 40,000. The 3–4 month old MBCs cost about INR 5,000 each. This makes the total cost of the operation INR 85,000. The price realized for 250–300 kg MBCs is INR 25,000–40,000 each. Even with the lower figure of INR 100,000 for 4 MBCs, about INR 15,000 net income can be expected from them in 1.5–2 years. This is expected to increase to about INR 75,000 from the next 4 MBCs kept on this pasture.

Conclusions

The study has demonstrated that the use of leucaena as a source of high quality protein feed can result in high levels of liveweight gain in MBCs compared with being fed grass alone and this can be highly profitable. Local farmers should be encouraged to take up the planting of leucaena to feed their buffalo male calves and possibly other ruminants as well.

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*ILC2018 Keynote Paper**

Potential of *Leucaena* spp. as a feed resource for ruminant animals in Thailand

Potencial de especies de Leucaena *como recurso forrajero para rumiantes in Tailandia*

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Abstract

While *Leucaena leucocephala* grows wild in Thailand, some *Leucaena* spp. have been introduced and evaluated for their edible forage yield and quality. Experiments on appropriate management were performed in different environments and productivity was found to be affected by species or cultivar. Environmental conditions, plant spacing, age of plant and cutting height significantly affected growth and performance. Edible forage yield was in the range of 5–6 t DM/ha/yr. Most species and cultivars contain high protein concentrations and are suitable for use as feed supplements as well as total ration for livestock. The effects of leucaena feeding on livestock are shown in lower mortality and increased productivity. While the leaf meal processing of leucaena for livestock feeding is increasingly recognized and practiced, cultivation of this crop is still minimal and insignificant. The role and importance of leucaena for livestock production, as well as its nutritional quality and factors which limit its use, are reviewed. The need for increased cultivation and integration of leucaena into local farming systems is emphasized. There is an urgent need to increase research support for the efficient cultivation of leucaena and an education campaign to dispel concerns about toxicity aspects.

Keywords: Livestock feeding, management, shrub legumes, utilization.

Resumen

A pesar de que *Leucaena leucocephala* crece en forma silvestre en Tailandia, se han introducido algunas otras especies de *Leucaena* para evaluar su rendimiento y calidad forrajera. Se realizaron experimentos sobre manejo apropiado en diferentes sitios y se encontró que la productividad es afectada por especie o cultivar. Las condiciones ambientales, la distancia entre plantas, la edad de la planta y la altura de corte afectaron significativamente su crecimiento y desempeño. La producción de forraje comestible estuvo en el rango de 5–6 t materia seca/ha/año. La mayoría de especies y cultivares registraron altas concentraciones de proteína cruda y se consideraron aptas para uso en alimentación de rumiantes tanto como suplemento como ración total. La alimentación de ganado bovino con leucaena se manifiesta en una menor mortalidad y mayor productividad animal. Si bien el potencial de leucaena para uso como harina de hoja en vez de forraje fresco es cada vez más reconocido y practicado, la adopción como cultivo es aún mínima. El rol y la importancia de la leucaena para la producción animal, así como su calidad nutricional y los factores que limitan su uso, son revisados. Se enfatiza la necesidad de incrementar el cultivo y su integración en los sistemas de producción agropecuarios locales. Además debe incrementarse la investigación para mejorar la eficiencia del cultivo de leucaena y apoyar campañas de educación para disipar las preocupaciones de los productores sobre posibles efectos tóxicos de la leucaena.

Palabras clave: Alimentación animal, leguminosas arbustivas, manejo, utilización.

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Introduction

Thailand is located at the center of peninsular Southeast Asia occupying 513,120 km^2; development has been generally based on agricultural production, which employs 49% of the labor force. Forty-six percent of the total land mass is engaged in the agricultural sector, of which 47% is incorporated in paddy fields, as rice is the most important crop grown in the country (Office of Agricultural Economics 2018). However, livestock production is very important to the Thai economy; beef cattle, dairy cattle, goats and buffalo are the most important ruminant livestock. In 2017 there were 4,876,228 beef cattle, 584,357 dairy cattle, 1,029,924 buffalo, 652,964 goats and 45,628 sheep (Department of Livestock Development 2018). Most ruminant livestock farmers in Thailand are small-holders; beef cattle farmers own approximately 6 cattle/farm and dairy farmers keep approximately 33 dairy cattle, while goat farmers have approximately 12 goats. Beef cattle are fed primarily grass plus agricultural and agro-industrial by-products, while dairy cattle are fed grass, rice straw and concentrates. Although many species of herbaceous legumes have been introduced and evaluated for use as a protein source in animal production systems, only 2–3 species are used commercially. The leguminous tree *Leucaena leucocephala*, native to Guatemala and Mexico, was introduced to the Philippines and Southeast Asia, including Thailand, during the period 1565–1825. It was previously used in Thailand for reforestation but was introduced to Thailand as an animal feed in 1962.

Agronomic evaluation under cutting

Manidool et al. (1976) compared 10 varieties of *Leucaena leucocephala* introduced from Australia, Hawaii, Ivory Coast, Taiwan, El Salvador and New Guinea in Pakchong, Northeast Thailand, where mean annual rainfall is 1,145 mm. With cutting 3 times per annum cv. Ivory Coast produced the highest leaf yield (9,500 kg DM/ha). These initial evaluations failed to lead to recommendations for use by farmers. Cultivar Cunningham was also introduced from Australia in 1972 and is the most widely used cultivar in Thailand. The leucaena psyllid, *Heteropsylla cubana* (Homoptera: Psyllidae), infests both the 'common' and 'giant' types of leucaena (*L. leucocephala* ssp. *leucocephala* and ssp. *glabrata*, respectively) resulting in leaf loss, which depresses yields. While all types of leucaena in Thailand are susceptible to the psyllid attack, the degree of damage ranges from moderate to severe throughout the country. Infestation is seasonal, occurring from October–November to April–May (Napompeth 1990).

In an attempt to counter the psyllid, resistant species and varieties of leucaena have been selected or bred. In 1996 *Leucaena* spp. from Oxford Forestry Institute (OFI) and from Australia were introduced to Thailand by Department of Livestock Development (Bureau of Animal Nutrition 2018). Eight accessions of *Leucaena* spp. were evaluated for psyllid resistance and edible forage yield during April 1996–March 1999, when planted in rows with spacing of 1 × 0.5 m (Figures 1 and 2). Three accessions, *L. pallida* OFI 137/94 (CQ 3439), *L. diversifolia* CPI 46568 [in Hughes (1998) listed as *L. trichandra*] and *L. leucocephala* K376, exhibited high psyllid resistance, but edible forage yield of *L. leucocephala* K376 (12.2 t DM/ha/yr) was higher than those of *L pallida* OFI 137/94 (9.2 t DM/ha/yr) and *L. diversifolia* CPI 46568 (4.2 t DM/ha/yr) with 17.7% crude protein (CP) (Thinnakorn et al. 2003).

Additional experiments on psyllid resistance and edible forage yields of leucaena were conducted in the central part of Thailand in Petchaburi Province (20 varieties), and in the northeastern part of Thailand in Nakhonratchasima Province during 1997–2001 (17 varieties). Both sites used cv. Cunningham as control. The best cultivar in Petchaburi was *L. leucocephala* hybrid K584 × K636, while good yields were obtained with *L. leucocephala* cv. Cunningham, *L. leucocephala* OFI 34/92 and *L. leucocephala* K636 (now = cv. Tarramba) (Polbumrung et al. 2003). In Nakhonratchasima performance of *L. leucocephala* OFI 34/92 was better than that of the other 16 accessions in terms of edible forage yield (8.3 t DM/ha/yr) and quality (22.5% CP). Leucaena was destroyed by psyllid infestation in a short period during the dry season (December–February) and *L. leucocephala* OFI 34/92 recovered better than the other accessions (Phaikaew et al. 2005). These results have been confirmed by Rengsirikul et al. (2011).

Crop management

Leucaena leucocephala OFI 34/92 produced annual yields of edible forage of 6 t DM/ha from 1.5 × 0.25 m spacing (Srisomporn et al. 2015). Research on different cutting intervals and cutting heights in Petchaburi Province in central Thailand indicated that leucaena can achieve annual yields of 24 t DM/ha at 100 cm cutting height and 25.7 t DM/ha with 10-week cutting interval (Ratchadapornvanitch et al. 2015). Chotchutima et al. (2016) reported that sulphur application (187.5 kg gypsum/ha) led to an overall higher total edible biomass yield (4.5 t/ha/yr) than without sulphur (2.3 t/ha/yr). The maximum rate of P fertilization (750 kg triple superphosphate/ha) produced the highest leaf, branch, woody stem and total biomass yields.

Figure 1. Evaluation of *Leucaena* spp. at Pakchong.

Figure 2. Experiment on the effect of row spacing on forage yield and quality of leucaena at Pakchong.

Chemical composition

Crude protein concentration in *Leucaena* spp. is high, ranging between 18.0 and 27.9% in different species and cultivars (Phaikaew et al. 2005; Table 1). Dry matter digestibility (nylon bag technique) at 48 h was in the range 43–80%. Ratchadapornvanitch et al. (2015) reported that, as in most plant species, CP concentration of leucaena decreases with increase in the cutting interval, declining from 21% for 6-week cutting interval to 16% for 12-week cutting interval. Ca concentration was 1.4% and P was 0.2%.

Animal production

Leucaena leucocephala is a valued fodder for ruminants, e.g. cattle, buffalo and goats. It can be grazed, fed fresh as cut-and-carry forage or conserved as hay or silage for feeding later. A number of studies have been conducted to evaluate the potential of leucaena to improve animal performance. A long-term study over 4 years in Srakaew Province in the eastern part of Thailand assessed the effects on reproductive performance of breeding does of feeding fresh *L. leucocephala* as the sole diet. Five crossbred Anglo-Nubian yearling does (20–25 kg body weight) and a 30 kg yearling buck were housed in a 10 × 10 m pen and fed only fresh leucaena leaf. Over the 4 years there were 54 kiddings resulting in 92 kids (38.9% single births, 51.8% twinning and 9.3% triplets). Mortality of kids at parturition was 3%. Average birth weight was 2.01 kg and weaning weight at 3 months was 9.43 kg. These data indicate that feeding fresh *L. leucocephala* for 4 years to breeding does should not affect their reproductive performance. They showed no symptoms of mimosine toxicity. The feeding regime was continued with some of the male goats to assess growth performance. Initial weight was 16.43 kg and final weight after 176 days of feeding was 26 kg, giving a growth rate of 54.6 g/d and a feed conversion rate of 13.3 g DM/g gain (Janthibordee and Kodepat 2009).

In a second study crossbred Anglo-Nubian goats rotationally grazing *Paspalum plicatulum* were supplemented with leucaena silage ad libitum or 14% CP commercial concentrate at 1% body weight. Conception rates, percentage of births and number of twins were higher on the leucaena treatment than on the concentrate treatment (Ted–arsen et al. 2017). In an experiment in Prachuapkhirikhan Province, 20 crossbred goats were used to compare the responses from feeding supplements of leucaena silage and commercial concentrate at 0.5, 1.0 and 1.5% body weight. Intakes of organic matter and CP and daily growth rates were greater for the leucaena treatment than for the concentrate groups, but the lowest feed cost was for the 0.5% concentrate supplement (Sengsai et al. 2015). Beef cattle receiving rice straw plus 4 kg of fresh leucaena leaves had significantly higher daily growth rates and total DM intakes than animals fed rice straw treated with urea-molasses (3% urea and 10% molasses). No symptoms of toxicity were observed during the feeding period of 364 days (Sanitwong et al. 1983). Buffalo fed dehydrated sugarcane tops supplemented with fresh leucaena leaves (12 kg/hd/d) gained 0.7 kg/hd/d more than buffalo fed dehydrated sugarcane tops alone (Sanitwong et al. 1986).

Table 1. Nutrient composition and dry matter digestibility (DMD) of edible material of different *Leucaena* species (Phaikaew et al. 2005).

Species	% (DM basis)							% DMD
	CP	ADF	NDF	Lignin	Hemicellulose	Mimosine	Tannin	(48 h)
L. leucocephala ssp. *glabrata* cv. Cunningham	23.1	23.7	34.7	8.2	11.1	3.2	0.9	75
L. collinsii ssp. *zacapana* OFI 56/88	24.6	23.2	35.0	6.4	11.9	2.4	0.5	75
L. collinsii OFI 52/88	25.0	25.5	36.2	8.5	10.7	3.2	1.8	73
L. diversifolia OFI 83/92	21.8	23.0	34.1	10.3	11.1	2.9	2.1	72
L. diversifolia ssp. *stenocarpa*[1] OFI 53/88	20.2	27.0	38.0	11.4	11.0	2.1	2.3	52
L. esculenta ssp. *esculenta* OFI 47/87	18.4	23.3	34.7	8.6	11.4	1.1	3.2	65
L. esculenta ssp. *paniculata*[2] OFI 52/87	22.3	24.9	38.0	10.0	13.1	1.6	0.9	67
L. lanceolata OFI 43/85	23.2	25.0	37.9	7.7	12.9	3.1	1.0	74
L. lempirana OFI 6/91	22.5	25.9	38.9	10.5	12.0	2.3	0.4	71
L. leucocephala ssp. *glabrata* OFI 34/92	22.2	23.9	35.9	8.6	12.1	3.3	1.1	80
L. macrophylla ssp. *nelsonii*[3] OFI 47/85	23.9	31.0	43.3	11.8	12.3	2.9	0.9	53
L. multicapitula OFI 81/87	23.6	35.4	44.0	3.5	3.6	2.4	0.5	58
L. pulverulenta OFI 83/87	20.0	25.4	35.9	12.0	10.4	2.2	3.4	44
L. salvadorensis OFI 17/86	19.8	29.3	42.2	10.0	12.8	2.0	0.3	69
L. shannonii ssp. *magnifica*[4] OFI 19/84	19.9	29.8	41.5	11.0	11.7	1.9	0.3	68
L. trichodes OFI 61/88	27.9	25.7	39.3	9.5	13.7	3.3	0.3	65
L. pallida OFI 137/94 (CQ 3439)	21.4	26.0	36.4	10.4	10.4	1.6	2.7	59

[1]In Hughes (1998) listed as *L. trichandra.* [2]In Hughes (1998) listed as "*Leucaena?* hybrid". [3]In Hughes (1998) listed as *L. macrophylla* ssp. *istmensis*. [4]In Hughes (1998) listed as *L. magnifica*.

Use of leucaena in farming systems

Leucaena is fed to animals in many forms in farming systems. Where it grows naturally, farmers have evolved feeding systems utilizing freshly harvested leucaena for feeding goats and cattle ad libitum, while in some areas wild leucaena is collected, chopped and ensiled (Phaikaew et al. 2012). Leucaena leaf meal is also fed as a supplement for dairy cows consuming grass. A number of farmers actually produce dried leucaena leaf for sale in different areas. One farmer in Nakhonratchasima Province produces dried leucaena leaf and sells it to dairy farmers in his area as well as to the commercial feed industry, which uses it for poultry feed. The amount of leaf meal produced is 80–90 t/month. Initially he alone harvested wild leucaena but the increasing demand for dried leucaena leaf for animals led to an increase in the number of leucaena producers and a decrease in the availability of wild leucaena. He planted about 2 ha of leucaena on his own land which he harvested every 2–3 months. This reduced his cost of production by reducing the cost of fuel to find and harvest wild leucaena. He also buys from other farmers who collect wild leucaena, while he does the processing, i.e. chopping and drying, before selling it to the feed industry (Chantarasiri et al. 2018). In Lopburi Province, farmers collect wild leucaena and sell it to a company, which then processes it. While the company has their own leucaena field of cv. Tarramba, established with seed bought from Australia, they encourage farmers to plant Tarramba for sale to the company. The company sells leucaena leaf meal as well as concentrate feed containing leucaena, and produces 50–80 t/d of leucaena leaf meal.

Constraints to leucaena production and adoption

While wild leucaena is used by livestock farmers in many places, its cultivation by farmers is limited. Establishment of leucaena is limited by the ready availability of wild leucaena and the fact that most farmers own less than 8 ha of land, which they use for diverse purposes. Another factor limiting cultivation of leucaena is the possibility of low germination in the field and slow seedling growth. To stimulate planting of leucaena the Department of Livestock Development commenced a project called 'Planted leucaena as edible fence'. Since people consume young leaves and seed pods of leucaena as a vegetable, if farmers plant leucaena they can harvest these components for food for the family, while the remainder will be left as feed for their animals. As part of the project leucaena seed can be obtained via livestock officers located in every province.

Unfortunately there is no satisfactory project implementation plan. While many farmers throughout the country feed their animals with leucaena, some are reluctant to do so because of the risk of mimosine toxicity, which might result in deaths of animals or decreased reproductive performance. While the purpose of pointing out possible toxic effects of mimosine is to make farmers aware of potential risks, it is important not to discourage the use of leucaena to feed ruminant animals. An education plan is needed to stimulate its use.

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ILC2018 Poster and Producer Paper*

Production of *Leucaena leucocephala* ‘silage’ for sale as animal feed: A case study from Sikiew District, Northeast Thailand

Producción de ‘ensilaje’ comercial de Leucaena leucocephala*: Un estudio de caso en el distrito de Sikiew, Noreste de Tailandia*

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Keywords: Forage conservation, forage utilization, shrub legumes.

Introduction

Worldwide, leucaena (*Leucaena leucocephala*) is used not only for fodder for livestock but also for fuelwood and human consumption. It was first introduced to Thailand a long time ago and has been used for reforestation for long periods. Leucaena has now become naturalized in many regions of Thailand. Farmers harvest this naturally occurring leucaena and use it to feed their animals in a number of ways. In Sikiew District, Nakhonratchasima Province, in Northeast Thailand, a group of farmers have adopted a novel approach and make ‘partial’ leucaena silage for sale.

Site characteristics

Nakhonratchasima Province, located in the lower part of Northeast Thailand (15º N, 102° E), consists of 32 districts with a total area of 20,494 km^2. For Sikiew District, annual average daily temperature is 27.4 ºC, average humidity is 71% and average annual rainfall is 970 mm, which is received in April–October (LNRHIC 2018). Sikiew District is in the upland area at 200–250 masl. Cassava, maize, sugar cane and livestock are the main agricultural products from the district (DOPA 2018).

Producing *Leucaena leucocephala* ‘silage’ in Sikiew District

In 2008, a group of 5 farmers was established to make ‘partial’ leucaena silage for sale. ‘Partial silage’ is the term used to describe fresh forage which is sealed in plastic bags but is often consumed before the full fermentation process associated with conventional silage making has been completed. Farmers collect wild leucaena, chop and pack it in bags and sell it in the form of fresh bagged leucaena. Currently 3 of these farmers continue to produce this feedstuff for sale. Mr Charoon is 1 of the 3 who continue to do so. Each day from 07:00 h to 11:00 h he, his wife and 2 workers collect wild leucaena in the village area (Figures 1 and 2), travelling up to 65 km in the dry season to obtain enough material. They transport the leucaena home in a utility at about 11:00 h, before chopping it with a small machine (Figures 3 and 4) and packing it into plastic bags (30 kg), which are tied tightly at the top (Figures 5–7). No special attempt is made to extract air before tying. The real cost of production is US$ 0.052/kg.

Livestock farmers buy this material once or twice a month for feeding to their stock (Figure 8) rather than having to obtain fresh forage daily. They immediately start feeding the material in a fresh state and continue to feed it out until the supply is consumed, which might take

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Figure 1. Harvesting wild leucaena.

Figure 2. Loading green leucaena onto truck.

Figure 3. Feeding leucaena through small chopper.

Figure 4. Chopped leucaena.

up to 30 days. No obvious spoilage occurs despite the exposure to air. The price charged is dependent on the distance between the village, where the 'silage' is made, and the livestock farm. While most customers are in the same district, some farmers are in another district, which is about 89 km away. The 'farm gate' price is US$ 0.049/kg, and the delivered price increases in proportion to the distance to the livestock farm, e.g. US$ 0.062/kg for nearby areas and US$ 0.072/kg for farms in other districts. Although cost of production is higher than the selling price, silage producers accept this arrangement because they deduct only costs of hired labor plus fuel from the amount they receive at sale to determine their net returns. Six dairy cattle farmers and 3 dairy goat farmers have contracted to purchase 3 t silage/month/farm.

A second leucaena producer conducts a similar business with only family labor. Each day he and his wife collect leucaena for 5 hours and spend 2 hours chopping it up and filling bags. He has 10 contracted farmers who purchase 3 t silage/month/farm.

Approximate chemical composition of 'silage' that they produce is as follows: CP 21.9%, crude fat 1.46%, crude fiber 16.4%, ash 7.7%, NFE 52.5%, ADF 37.8%, NDF 56.0%, ADL 9.6%, cellulose 28.2% and hemi-celluloses 18.0%.

Figure 5. Filling plastic bags with chopped leucaena.

Figure 6. Weighing filled bag.

Figure 7. Tying top of bag.

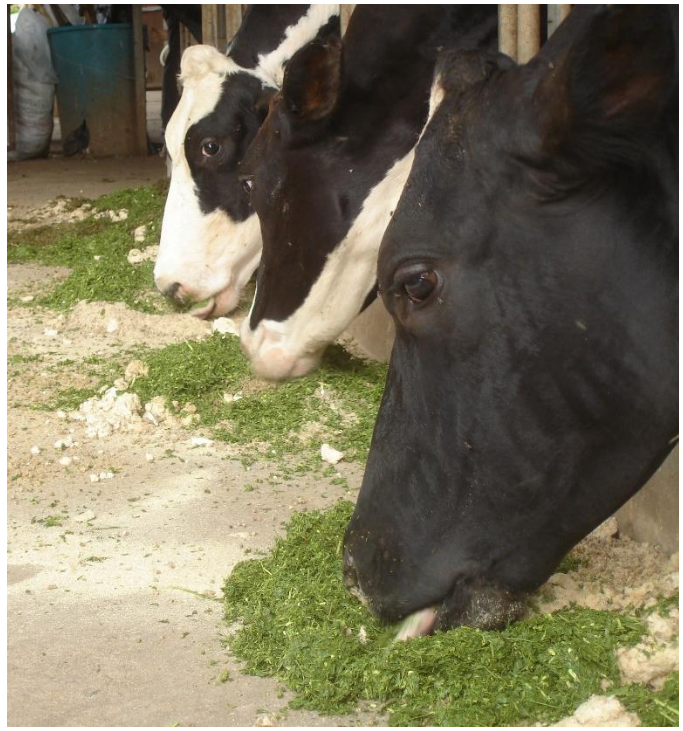

Figure 8. Dairy cows eating leucaena silage.

One of Mr Charoon's customers, Mr Wiwat established a dairy farm more than 10 years ago and feeds his cows (75% Holstein Friesian crossbreds) with Napier grass silage (4 kg/hd/d), leucaena (4 kg/hd/d), cassava peel (16 kg/hd/d) and 18% CP concentrate pellets (9–10 kg/hd/d). Average milk yield is 22–24 kg/hd/d, cost of feed for 1 kg milk is US$ 0.20 and price of milk is US$ 0.56/kg. While all cows conceive, the calving interval is 14–15 months. He has not observed symptoms of mimosine toxicity in his cows despite feeding leucaena for more than 10 years.

Another customer is a dairy goat farmer who feeds his goats with leucaena silage (2.4 kg/hd/d) plus 12% CP concentrate pellets (500 g/hd/d). Average milk yield is 9 kg/hd/d. The price of goat milk is US$ 1.38/kg.

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ILC2018 Poster and Producer Paper*

Leucaena in West Timor, Indonesia: A case study of successful adoption of cv. Tarramba

Leucaena en Timor Occidental, Indonesia: Un estudio de caso de adopción exitosa del cv. Tarramba

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Keywords: Extension methodology, smallholder farmers, tree legumes.

Introduction

Between 2013 and 2016 the sub-districts Fatuleu and Central Fatuleu in Kupang District of West Timor, Indonesia were selected to study the opportunities for and barriers to adoption of leucaena (*Leucaena leucocephala* cv. Tarramba) for growing and fattening cattle. These were sub-districts where the cultivation and use of leucaena was not normal practice such as has been reported for the sub-district of Amarasi (Nulik 1998; Piggin and Nulik 2005).

In collaboration with Dinas Peternakan (District and Provincial Livestock Service) and BPTP (National Assessment Institute for Agricultural Technology) in West Timor and with the support of ACIAR (Australian Centre for International Agricultural Research), a project was initiated to encourage farmers to adopt the growing of the psyllid-tolerant leucaena cv. Tarramba for feeding and fattening cattle. The selection of farmer groups to participate in the program was the result of collaboration between these agencies.

Description of villages

The study was conducted in 3 villages in Kupang District (sub-districts Fatuleu and Central Fatuleu), West Timor, Indonesia (Figure 1). Some details are presented in Table 1. Oebola Dalam village was selected in the initial phase of the adoption study, while the remaining 2 (Camplong II and Nunsaen) were selected in the second phase (Kana Hau and Nulik 2017). All 3 villages, comprising 7 farmer groups, have their own adoption stories, which have enriched our understanding of the opportunities for and barriers to successful adoption of leucaena in the District of Kupang.

History of leucaena in the region

Fatuleu and Central Fatuleu sub-districts were new to growing and using leucaena as fodder for cattle feeding. Prior to the introduction of Tarramba leucaena in 2001–2003, the communities free-grazed their cattle on communal lands, mainly for breeding, and sold bulls only when they needed cash.

At that time, only farmers in the sub-district of Amarasi, also in Kupang District, were known to feed up to 100% leucaena after the Indonesian Government's Livestock Services introduced a cattle-fattening program in the 1970s (Nulik 1998). However, there had been very little adoption of the concept in other areas. This approach has now changed following the introduction of Tarramba leucaena. The Bersaudara, Setetes Madu and Amtoas Farmer groups now concentrate mainly on fattening of Bali bulls, although some farmers still retain some cows for breeding on the free-grazing communal lands.

As grazing lands had been heavily grazed, they were invaded by *Chromolaena odorata* with the result that very little palatable forage was available for grazing. Animals would reach market live weight of 250–300 kg at 4–5 years of age or older and sometimes even failed to reach the target weight before sale. With the introduction of Tarramba leucaena forage, farmers now fatten bulls to reach market weight in 2–3 years. Some of our collaborating farmers were awarded championship medals during the 2017 yearly beef cattle competition in Kupang District (Annex 1a).

In terms of toxicity management, many farmers now understand that, when naïve cattle are first fed leucaena, they initially show symptoms of salivation plus loss of hair and appetite but adapt and recover in 1–2 months. As

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Figure 1. Map of eastern Indonesia, showing the three study villages (● Oebola Dalam, ● Camplong ll and ● Nunsaen) in the west of Timor Island, East Nusa Tenggara Province. Source: Wikipedia/ Ewesewes.

a result, farmers now gradually increase the amount of leucaena fed to animals initially until their health has recovered.

Table 1. Description of villages in adoption study.

Village	Participating farmer group	Tarramba area planted	Cattle operation
Oebola Dalam (Fatuleu)	Bersaudara	125 ha	Fattening and breeding
Camplong II (Fatuleu)	Setetes Madu Talekomonit Tunas Muda Sabu Bani Sanam Tuan	250 ha	Fattening and breeding
Nunsaen (Central Fatuleu)	Amtoas	150 ha	Fattening and breeding

Progress of adoption, early challenges and successes

The program began in the rainy season of 2012/13, following commencement of the ACIAR project in 2011. Progress with the farmer groups is described below and illustrated in Annexes 1a–1h.

Oebola Dalam village

The Bersaudara Farmer Group in Oebola Dalam consisted of individually-owned and clan-owned lands. The group started with no leucaena, relying on free-grazing, and at times during the dry season, the stealing of forages from the protected forestry area near the village. With our support, they planted 6 ha of Tarramba leucaena in the first year (2013) and approximately 25 ha in 2014.

Initially, the research team worked with just 5–6 innovators from the group of 20 farmers who were willing to participate in planting pre-grown poly-bag seedlings. At the beginning, some participating farmers doubted the wisdom of growing leucaena; wives protested that the family does not have cattle, and "we don't eat leucaena but corn". However, the participating members agreed to continue planting leucaena. As plants became established, farmers found that there was demand for fresh leucaena forage from the nearby weekly cattle market at Lili. This provided an opportunity for farmers to earn some cash for their daily needs and for cultural ceremony purposes. Farmers increased the area planted to Tarramba leucaena, selling fresh leucaena even during the dry season, when there was no other production from their dry land.

Free-ranging animals belonging to non-participating farmers were initially a serious concern for participating farmers at Oebola Dalam, and this discouraged some farmers from growing leucaena. Some participating farmers even abandoned their plots of leucaena when they were prematurely grazed by the free-ranging animals. However, during the next wet season, when they fenced their plots for planting corn, the grazed leucaena plants recovered and became well established.

Farmers found they could integrate corn cultivation with the establishment of Tarramba leucaena, thus affording protection to establishing leucaena seedlings. No fertilizer was applied to the leucaena other than that applied to the corn plants. This encouraged farmers to plant more leucaena.

Plant height was kept to about 1.5–2 m by regular pruning for cattle feeding. Pruning frequency was every 2–3 months during the rainy season and every 3–4 months during the dry season. Number of trees cut per day would depend on the number and weight of animals to feed and the production of forage per tree. Farmers used cut-and-carry feeding methods, as it gave better cattle daily liveweight gains.

Most farmers in the village now have established their own leucaena. They have continued to increase their area planted even after project activities terminated and currently the village has ~125 ha established. The head of the farmer group informed us that another 5 ha was being prepared for the 2018/19 planting season. The technology of planting and feeding Tarramba leucaena was spreading to the bordering villages and farmers.

Camplong II village

The Setetes Madu Farmer Group in Camplong II consisted of only clan-owned land (more than 100 ha) managed by the clan elders. The land was sparsely planted with cashew nut trees on the more fertile soils, while the majority of the land consisted of less fertile coral soils (Black Mollisols) invaded by *Chromolaena odorata* due to over-grazing by community cattle.

Planting of leucaena began in Camplong II in 2014/15. In general, adoption was faster in Camplong II, where 4 farmer groups were involved. Initially, the group planted 20,000 seedlings of Tarramba leucaena on 20 ha and found that leucaena grew well on the coralline soils.

The Setetes Madu group increased the area planted to leucaena each year to a current total of >50 ha. Currently all farmer groups (Setetes Madu, Tunas Muda, Talekomonit, Sabu Bani and Sanam Tuan) in the village of Camplong II, who have adopted the technology, have established ~250 ha of Tarramba leucaena. The area is increasing annually.

Setetes Madu farmers initially planted their 20 ha with the intention of producing and selling Tarramba seed and resisted harvesting their mature leucaena trees to concentrate on harvesting seed. The research team encouraged some participating farmers to establish a feeding demonstration using available weaned calves (5 calves) obtained from their free-grazing herd. This demonstration was successful and convinced them to expand cattle feeding with leucaena as they noticed the improved weight gain of their calves. Outside investors were attracted to establish a share-fattening cattle business with the group. The investor has contributed to the installation of a deep bore well to supply watering facilities (water tower tank, some on-ground tanks and solar panel pumping system) costing 1 billion IDR. These investments now support up to 60–70 bulls being fattened in each fattening period.

Nunsaen village

The Amtoas farmer group in Nunsaen village initially planted about 75 ha of *Sesbania grandiflora*. Their first plantings of Tarramba leucaena seedlings (pre-grown in a nursery) occurred under the existing *Sesbania grandiflora* plants with some direct seeding on newly cleared land. This created a problem with plant competition for leucaena at the outset. The farmer group of Nunsaen (Amtoas) has now established ~150 ha of Tarramba for cattle fattening, and for providing a high quality supplementary forage for their free-grazing animals.

Limitations/challenges and benefits to leucaena production

Biophysical – climate, soils

On sites with marginal soils such as on Sumba Island, Tarramba leucaena has not performed well. However in Timor, Tarramba leucaena is well adapted to the highly alkaline coralline soils (Mollisols and Alfisols) encountered in many areas, such as in Camplong II and Oebola Dalam villages. With the long dry seasons experienced, farmers have difficulty finding water for watering seedlings in nurseries; thus seedling preparation is often conducted in the early wet season (November-December-January) with transplanting of seedlings occurring in February-March-April, before the beginning of the dry season in May.

Economic benefits

The economic conditions of participating farmers and villages have improved significantly as a result of leucaena-based cattle fattening. When the project commenced at Oebola Dalam village, most farmers had houses with dirt floors and a palm-leafed roof; currently most farmers have constructed brick-walled houses with corrugated iron rooves. Using earnings from sale of seed and fattened cattle, some individual farmers were able to buy a motor cycle, or a pick-up utility (previously rented in the village) for cattle transportation to the market and for selling leucaena forage at the nearby cattle market. Farmers continue to look for economic opportunities.

The new economic opportunities being generated from leucaena plantings in the village include: (i) sale of fattened cattle; (ii) sale of Tarramba forage and seed; (iii) sale of bare-stem cuttings to neighboring farmers; (iv) plans to develop tall trees to harvest wooden poles for supporting cement floor construction for multi-storey buildings [5,000 Rupiah (AU$ 0.5) for each pole], or for housing construction (roofing, door and window frames etc.); and (v) other business opportunities such as car and motor cycle rentals.

At Setetes Madu site, when the project commenced, the meeting place was under the shade of a Kesambi tree (*Schleichera oleosa*). The co-operating farmers have now established an iron-roofed meeting house and some farmers own hand-tractors, while some have purchased motor cycles. Successful farms have become demonstration sites for many visitors, including Bupatis (Mayors), Provincial Governor and farmer groups who wish to learn about the successful conversion from free-grazing practices to intensive fattening with leucaena.

Future of leucaena development options

More research is needed on using leucaena leaf for supplementary feeding of calves during the dry season to reduce calf mortality, and on a comparison of the different techniques for plant establishment (poly-bag seedlings vs. 2–3 year plantlets from under or between mother trees). Combination plantings of leucaena with grass and herbaceous legumes as a conservation practice to improve food crop productivity and soil quality in the region should be investigated.

Conclusions and implications

The success of the farmer groups in Fatuleu and Central Fatuleu sub-districts in Kupang District of West Timor, Indonesia has changed agricultural practices and has improved economic conditions and livelihoods, land quality and thus farming conditions generally.

The success of adoption of Tarramba leucaena has encouraged and inspired many individual farmers, farmer groups, non-government organizations, Government staff and Bupatis (Mayors), including the Governor of the Province, to support and introduce the use of Tarramba leucaena for cattle feeding into their development programs and livestock development plans and practices.

The new Governor of NTT (2018–2023), after visiting the sites of Setetes Madu, Talekomonit and Sabu Bani farms, said that:

Last night when we discussed cattle farming in NTT, I had no courage to develop plans for a livestock development program; but today, you have showed me the improvement that is possible with lamtoro (leucaena), even on this marginal land. Now I have confidence that NTT can be significantly improved in cattle production if we can adopt these practices.

He immediately asked to purchase 1,000 kg of Tarramba leucaena seed from the farmer groups (Setetes Madu, Sabu Bani and Talekomonit) as a start to his beef cattle development program.

In conclusion, it is especially pleasing that, following the many benefits from the introduction of Tarramba leucaena, planting of this valuable forage source is being promoted by Indonesian Government agencies at National, Provincial and District levels after the ACIAR project ended in 2016.

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Annex 1

a. Bali bull fed leucaena wins bull-fattening prize.

b. Oebola Dalam village in wet season.

c. Oebola Dalam village in dry season.

d. Farmers seeding poly-bags with Tarramba leucaena.

e. Tarramba leucaena being cut-and-carried for feeding.

f. Bali bulls being fattened on Tarramba leucaena in Oebola village.

g. Newly elected Governor to Province of Nusa Tenggara Timor (white shirt) visiting Camplong II village.

h. Camplong II village in front of 9-month-old Tarramba leucaena.

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Seasonal growth of *Leucaena leucocephala* cv. Tarramba in dry land of west Sumbawa, Indonesia

Crecimiento de Leucaena leucocephala *cv. Tarramba en la región de sequía estacional del oeste de Sumbawa, Indonesia*

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Keywords: Forage acceptability, forage production, seasonality of production, tree legumes.

Introduction

Sumbawa Island in Nusa Tenggara Province is one of the main cattle-producing areas in eastern Indonesia. In 2017 the cattle population in Sumbawa was around 350,000 head (Dinas Peternakan Report 2017). Most cattle are raised in a traditional free-grazing system, where they are released to roam at will and find their own feed, which is obtained mainly from communal grassland and fallow land. Owing to the strongly seasonal rainfall in Sumbawa the production and availability of forage for cattle fluctuate during the year. While the annual rainfall is 1,400 mm, 88% falls in the months of November–April. Both availability and quality of feed in the dry season are poor. Availability of fallow land for grazing has been reduced as a result of the construction of a water reservoir, which is used to irrigate rice fields, resulting in more intensive use of land for rice and maize cultivation. In addition, communal grazing lands are being progressively invaded by weedy plants, such as *Chromolaena odorata, Lantana camara* and *Ziziphus mauritiana*, resulting in reduced grass production, forcing farmers to find alternative feed sources for their cattle. Improved forage species are needed to improve the nutritional regime for grazing livestock.

Wild leucaena (*Leucaena leucocephala*) has been used by farmers as a source of high protein feed for their cattle and recently the improved cultivar Tarramba was introduced to Sumbawa. Acceptance of cv. Tarramba by farmers should not pose a problem, as it is merely a change from a wild plant to a cultivated plant (Dahlanuddin et al. 2017). We conducted basic observations on the growth and biomass production of cv. Tarramba in a rain-fed grazing area of Sumbawa throughout the year and results are reported here.

Materials and Methods

The study was conducted in Seteluk village, Sumbawa District. To obtain seedlings for planting a raised seedbed was prepared and seeds of cv. Tarramba were spread at high density on the surface in mid-May 2015, covered with soil and watered daily. Four months after sowing, at the start of the rainy season in September 2015, plants, which had established from germinated seeds, were manually pulled from the ground, foliage was trimmed to about 40–50 cm and roots were severely trimmed (Figure 1) and plants transplanted into alluvial soil as bare stumps (Setiawan 2010).

There were 5 blocks consisting of 25 plants/block at spacings of 2 × 1 m. No fertilizer was applied. Plants were allowed to grow for 12 months and plant height and main-stem diameter were measured at monthly intervals. At 12 months after transplanting all plants were cut at 1.5 m above ground level. During the subsequent year, forage above 1.5 m was harvested every 2 months. Biomass was weighed fresh and subsamples dried in an oven at 70 °C until constant weight to determine dry matter percentage. For this, 10 plants were randomly sampled at each harvest in each block. At each harvest main-stem diameter was determined at 1.5 m above ground level and number of all new regrowth primary branches was measured. Following sampling the remaining plants in each block were cut to 1.5 m as well. All harvested material was weighed, fed to cattle and the consumed portion calculated, based on the unconsumed amount which was weighed. Data were then analyzed for average values and standard deviations.

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Figure 1. Leucaena seedling nursery and bare-stump seedlings ready for transplanting.

Rainfall received during the study (Figure 2) started in November 2015 about one month after transplanting the leucaena, and heavy rain continued until April 2016, with the heaviest falls during February. Some rain was received in September 2016, when the initial cut was applied to the plants. Relatively high rainfall continued from October 2016 to April 2017 with heaviest falls in December–February. For the 2016/17 rainy season, when biomass production was measured, the rainy season was wetter and longer than in previous years, e.g. when compared with rainfall registered 2013–2015 (essentially no rain during June–November).

Results and Discussion

Height

Tarramba grew very well in this study, achieving a height of 3.7±0.1 m at 12 months after transplanting into the field (Figure 3). This result confirms the previous work on the growth of Tarramba reported by Panjaitan et al. (2015). The highest growth rate (42±0.3 cm/month) was achieved during the peak of the rainy season (February–April) and the lowest (9±2.5 cm/month) during the driest months of September–October. The differences in growth rate in the different seasons reflected the different levels of plant-available water in the soil.

Although there were big differences in height increase between the wettest and driest months, cv. Tarramba continued to grow and produce biomass during the dry season. This was most likely a function of the Tarramba root system, which is sufficiently deep to allow access to water deeper in the soil profile. Pachas et al. (2018) showed that leucaena roots could reach as deep as 400 cm. Furthermore, a previous study by Nulik et al. (2013) showed that cv. Tarramba grows very well in vertisols and alluvial soils.

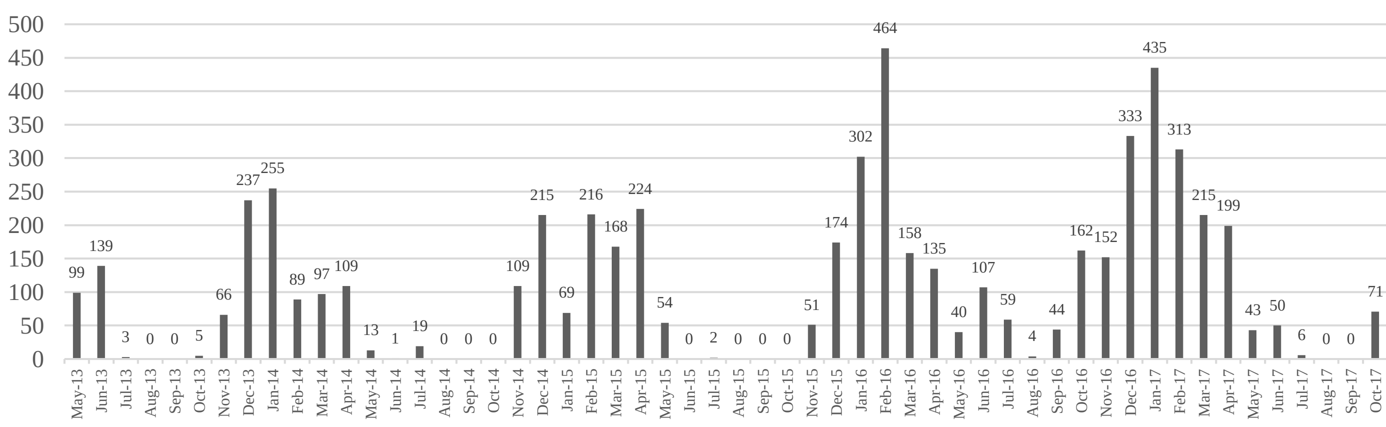

Figure 2. Rainfall during the study period in Sumbawa (BPS 2018).

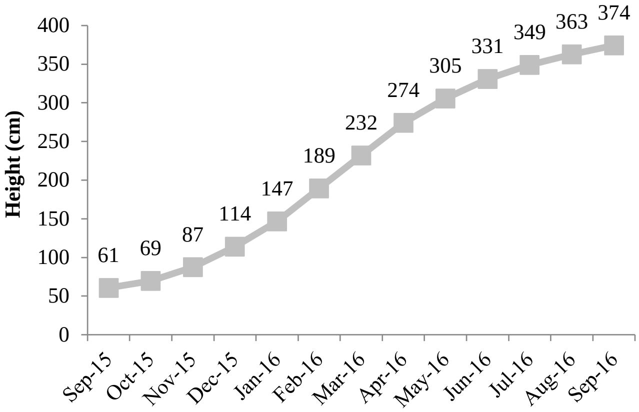

Figure 3. Progressive height of cv. Tarramba during the establishment year (2015-2016) under rain-fed conditions in Sumbawa.

Stem diameter

Main-stem diameter increased to 30 mm during the 12 months following transplanting but only a further 2.4 mm during the subsequent 12 months, when being harvested regularly (Figure 4). A longer study would be needed to determine what changes would occur as the plants matured. Since plants were cut regularly, the nutrients produced from photosynthesis during the harvesting period must have been used more for the formation of new branches and leaves than for growth of the main stem. The number of new primary regrowth branches produced between harvests remained relatively constant, varying between 13 and 15. This relatively constant number of primary regrowth branches enabled plants to produce a relatively constant amount of biomass (Figure 4) throughout the year, provided soil moisture levels were adequate.

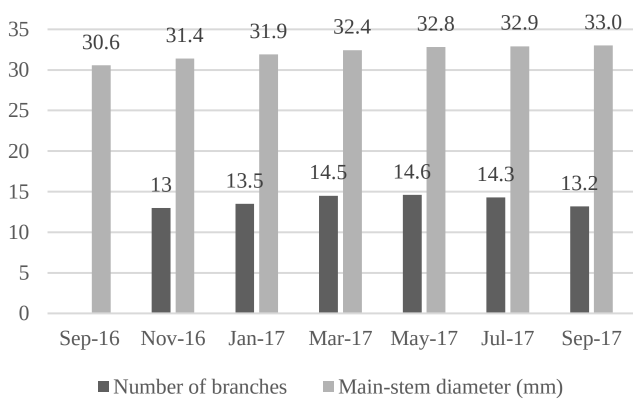

Figure 4. Main-stem diameter and number of primary branches of new regrowth produced by cv. Tarramba at 12 months after transplanting (September 2016) and at subsequent 2-monthly regrowth cuts under rain-fed conditions in Sumbawa.

Biomass production and forage consumption

Biomass production at the initial harvest 12 months after transplanting was 1.1±0.04 kg DM/tree, while subsequent regrowth (every 2 months) yields varied between 0.77 and 0.91 kg DM/tree (Figure 5). There was minimal variation in production between November and July but growth rates declined slightly in the July–September period to 0.77 kg DM/tree. Thus cv. Tarramba was able to produce significant amounts of biomass for cattle during both wet and dry seasons in this environment, suggesting it could be a useful feed source for cattle in rain-fed areas of Sumbawa.

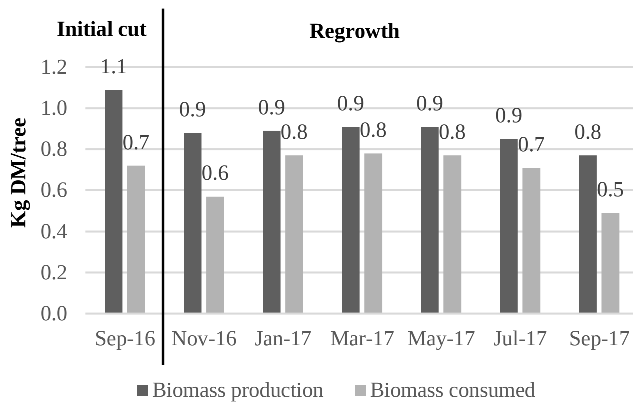

Figure 5. Biomass production and biomass consumed of cv. Tarramba at 12 months after transplanting (initial cut) and at subsequent 2-monthly regrowth cuts under rain-fed conditions in Sumbawa (2016-2017).

When the harvested forage was fed to cattle, the animals consumed an average of 76±11% of total harvested biomass (86±1% in the rainy season vs. 64±1% in the dry season) (Figure 5). The higher percentage of biomass consumed in the rainy season was due to a higher percentage leaf, softer branches and lower percentage of woody branches, making it more palatable for cattle. Although there were large differences in height increase in trees between wet and dry seasons (by a factor of 3–4), DM production varied by only 15.4% and consumed biomass by 37.2%, indicating that plants devoted more nutrients to woody growth in the dry season than in the wet. As these plants were in the development stage, results might have been different once trees matured. Thus longer-term studies are needed.

Conclusions

This study has shown that leucaena cv. Tarramba established well in the rain-fed areas of Sumbawa when planted by the bare-stump technique early in the rainy season and plants were allowed to grow until the late dry season before initial harvesting. Our findings suggest that Tarramba would provide a valuable feed source for cattle in Sumbawa in both rainy and dry seasons and support the findings of Dahlanuddin et al. (2019). Further studies are needed to determine the production of cv. Tarramba as plants mature as well as optimal harvesting regimes throughout the different seasons.

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(Note of the editors: All hyperlinks were verified 21 August 2019.)

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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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