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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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