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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

SEAN KENNY AND GEOFF DRYSDALE

Rural Consulting Group, Warrnambool, VIC, Australia. www.ruralconsultinggroup.com.au

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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Correspondence: Sean Kenny, 1 Ardlie St, Warrnambool, VIC 3280, Australia. Email: sean@ruralconsultinggroup.com.au

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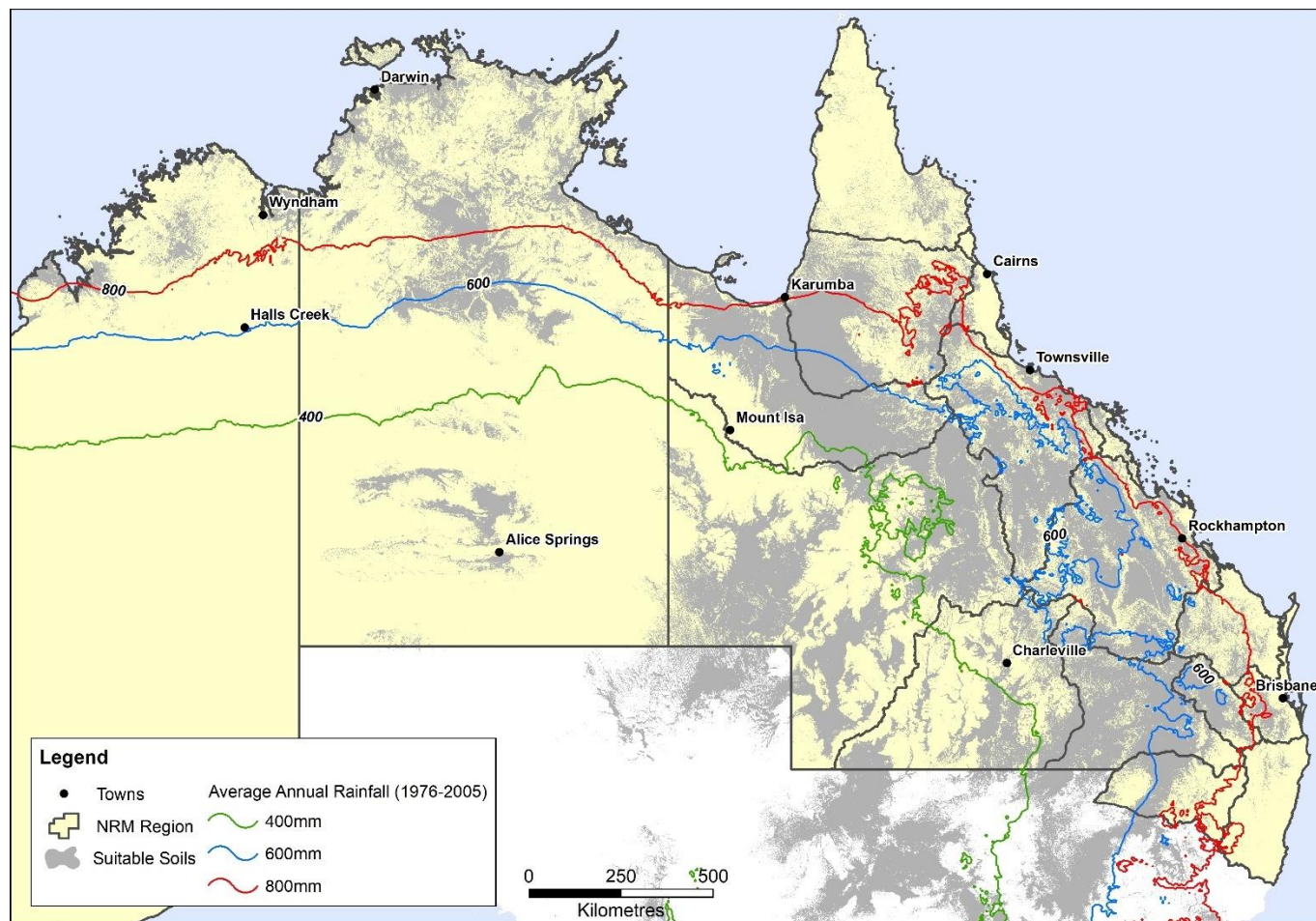
Figure 1. Soils suited to leucaena (depth >1 m with pH >5.5) in rainfall zones across northern Australia.

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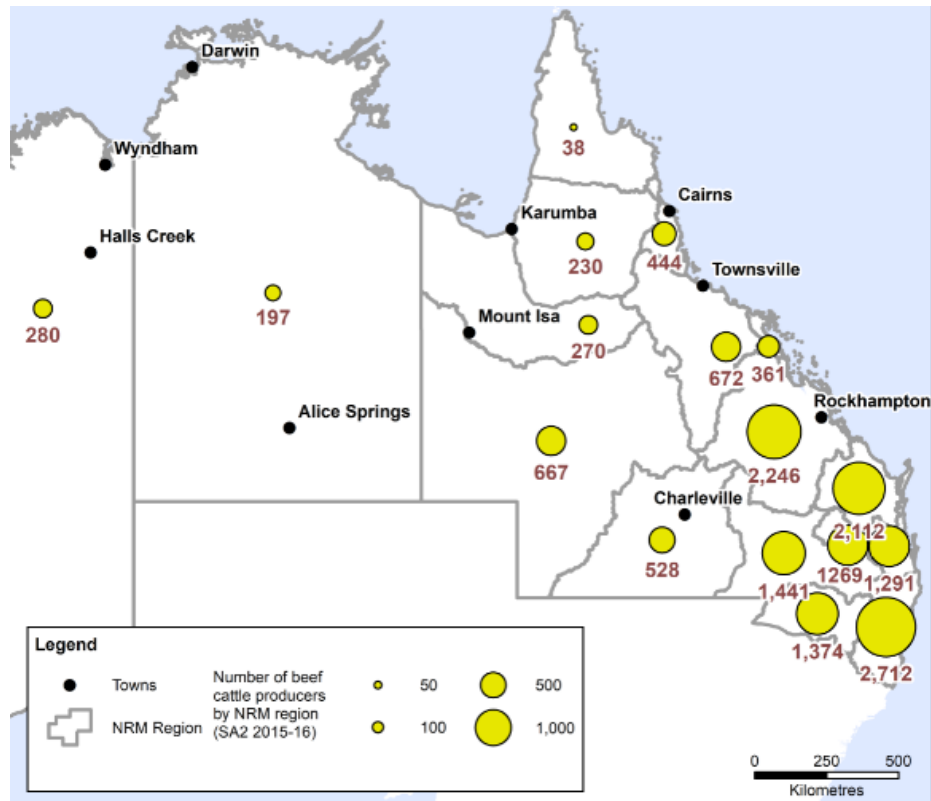
Figure 2. Number of beef cattle producers in NRM regions across northern Australia.
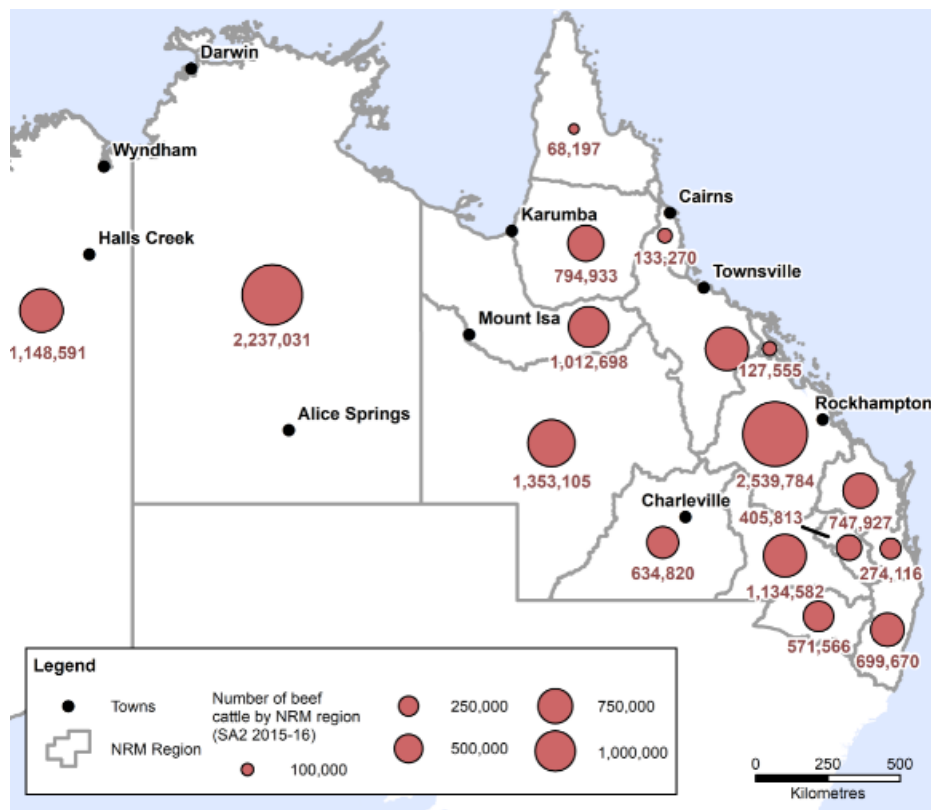

Figure 3. Number of beef cattle in NRM regions across northern Australia.

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.
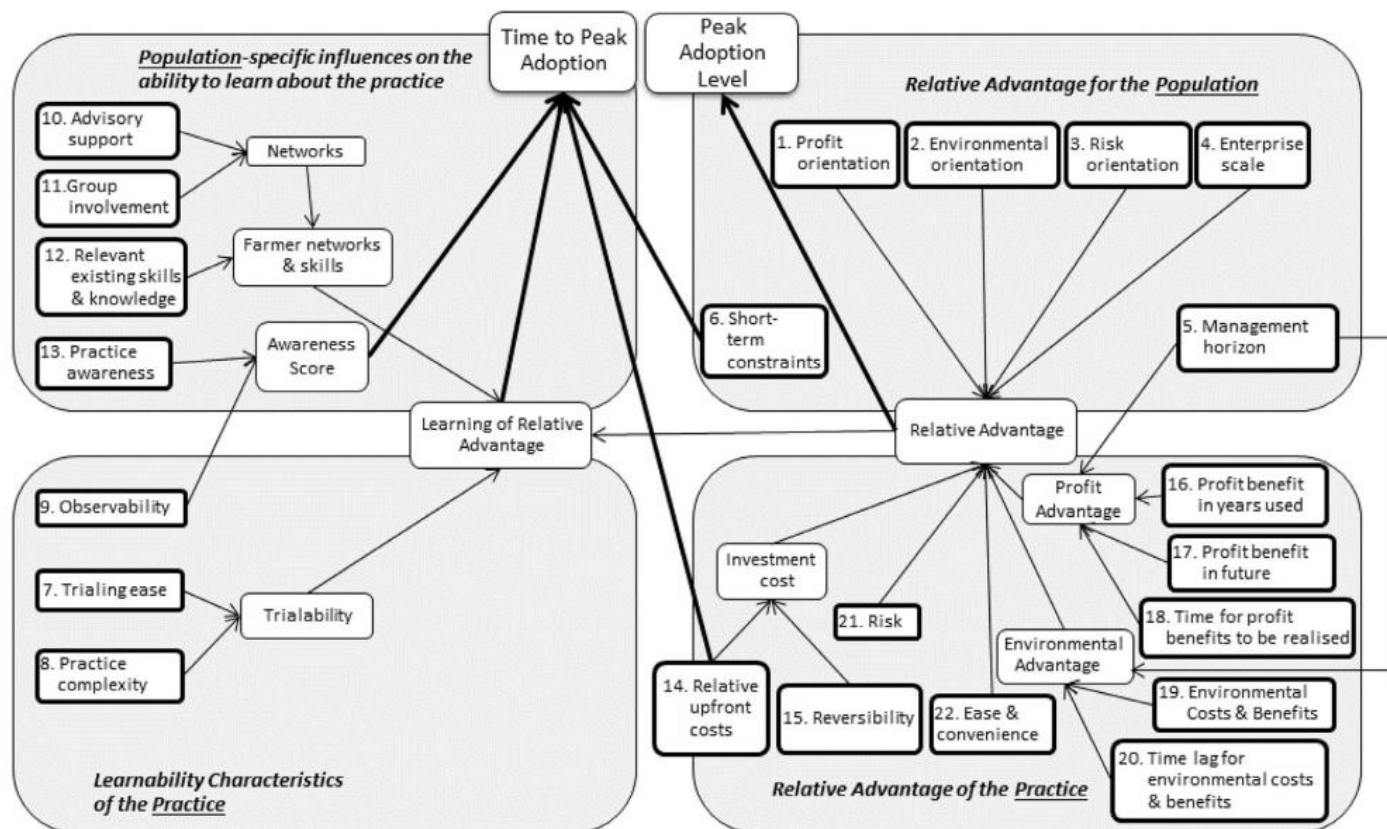

Figure 4. The conceptual framework of influences on peak adoption level and time to peak adoption (from Kuehne et al. 2017).

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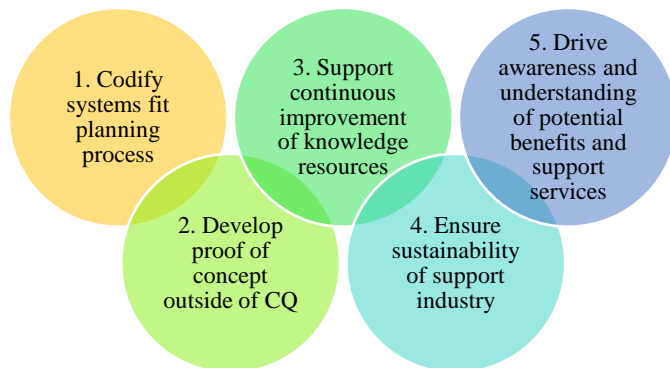
The logic of the 5 actions can be understood as follows:

- 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?

Acknowledgments

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(Note of the editors: All hyperlinks were verified 4 August 2019.)

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