Final report

Legume Best Management Practice in the Brigalow Belt bioregion

Project code: B.PAS.0354

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Date published: 2 November 2022

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PUBLISHED BY
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NORTH SYDNEY NSW 2059

Meat & Livestock Australia acknowledges the matching funds provided by the Australian Government to support the research and development detailed in this publication.

Abstract

The Brigalow Belt bioregion is important for the beef industry as it produces 44% of the gross value of agricultural production from grazing in Queensland. Pasture legumes have been identified as the best long-term option to increase productivity; however successful adoption rates remain low. This project conducted research integrated with an extension program to work with graziers and advisors to increase productivity in the Brigalow Belt through more reliable and successful adoption of legumes.

Four hundred and twelve graziers and farm advisors attended 23 workshops on legume management. Grazing businesses sowed 42,000ha of legumes (73% of businesses sowed legumes, average of 258ha/business) after attending the workshops and these businesses intend to sow an additional 111,200ha (average of 617ha/business) over the next five years.

Research trials indicate that current varieties of Caatinga stylo (*Stylosanthes seabrana*) and *Desmanthus virgatus* are likely to be persistent in the long-term in southern inland Queensland, however other species of desmanthus and stylo are unlikely to persist. Research trials have shown establishment methods developed in other climate zones (e.g. monsoonal) fail in the competitive pastures of the Brigalow Belt, however better agronomic practices dramatically improve the reliability of legume establishment. Adoption rates of improved agronomy remain low and should be a focus of future extension programs. Additional research and extension is required to support the beef industry to realise the production benefits from widespread and successful adoption of legumes.

Executive summary

Background

Pasture legumes have been identified as the best long-term option to increase the productivity and returns from both rundown sown grass pastures and native pastures in the Brigalow Belt bioregion. Despite impressive results from legumes in trials and some commercial pastures, the area successfully established with legumes remains very low in the Brigalow Belt.

This project endeavoured to increase the productivity of grass pastures in the Brigalow Belt (primarily in southern and central Queensland but also extending into north Queensland) through supporting more *reliable* and *successful* adoption of legumes.

The Brigalow Belt bioregion is an important region for beef production in northern Australia as it carries a high proportion of the cattle herd and supports relatively high stocking rates with high animal performance (i.e. reproduction and growth rates). The Brigalow Belt bioregion carries approximately 50% of Queensland's beef herd, producing 44% of the gross value of agricultural production (GVAP) from grazing. Queensland has 47% of Australia's cattle herd.

Objectives

The overall objective of this project was to facilitate widespread and successful (high productivity and persistence) adoption of pasture legumes in the Brigalow Belt bioregion. The project conducted field-based research to develop management practices to improve the *reliability* of legumes, especially their establishment into existing grass pastures and engaged industry through an extension program. Specific objectives included:

- Developing management recommendations from research and commercial results and package them into new extension products.
- Engage with groups of graziers to develop legume management plans, trial practices on farm and sow commercial paddocks to legumes.
- Test the persistence of legume varieties in southern inland Queensland where no historical trial sites exist.
- Test the impact of alternative agronomic practices on legume establishment.

Methodology

A coordinated extension program supported landholders to assess their management options, develop a plan and implement on-farm practices to successfully adopt legumes. The extension program was linked to three research and development activities to develop and demonstrate management practices that improve establishment reliability and long-term performance of legumes in grass pastures.

The four main components to the project were:

1: Extension activities:

- Industry engagement in learning-based extension activities (workshops and field days).
- On-farm demonstrations conducted by workshop or field day participants.
- Detailed on-farm trials.
- Extension materials developed on legume management.
- Case studies developed on graziers' experiences with establishing and/or managing legumes in the Brigalow Belt bioregion.

2: Legume persistence trials to test long-term persistence in the southerly latitudes of Queensland (i.e. Darling Downs, Goondiwindi and St George districts).

3: Legume establishment research trials to test the impact of better agronomic practices when establishing legumes into existing grass pastures.

4: Fertiliser research trials to test the impact of phosphorus fertiliser on legume establishment.

Results/key findings

Extension program results

A key output from this project was to review past and current research results and commercial experience to develop agronomic management recommendations specifically for the Brigalow Belt bioregion to more effectively and reliably establish legumes and to maintain productivity in the long-term. It was essential to improve Brigalow Belt specific management recommendations because research results had shown that commonly used establishment practices developed in other climate zones failed to produce adequate legume populations in most years. The improved recommendations were packaged into a full-day workshop that facilitated graziers through a process to review research results and apply the management recommendations to their own property and situation.

The legume management workshop was delivered to 23 groups of graziers and farm advisors. Four hundred and twelve people attended the workshop, which represented 317 businesses of which 226 were grazing businesses. Graziers have sown 42,000ha of legumes (average of 258ha per business that sowed legumes) since attending the workshop and intend to sow an additional 111,200ha over the next five years (average of 617ha/business). 118 on-farm trials were initiated with graziers involved with this project.

Key findings from the extension program and project evaluation include:

- Strong interest in pasture legumes. There are a lot of graziers and farm advisors who are interested in improving productivity through adopting legumes. The extension program on pasture legumes should continue.
- Large opportunity to improve the reliability of legume establishment. Previous “poor results and establishment issues” were the third most common reason cited by graziers as a barrier to adoption of legumes after “cost/money availability” and “seasons/drought” which are issues outside of the control of an extension program. Research trials have shown that better agronomy dramatically improves the reliability of legume establishment but adoption levels remain low.
- Need more “local” examples of successful legume establishment and long-term production in commercial paddocks. Local examples are needed to provide strong evidence on the benefits of using better agronomy when establishing legumes, suitable varieties and long-term production benefits to improve adoption rates.
- Extension materials need updating and be made more accessible. A review of extension materials on sown pastures in the Brigalow Belt bioregion found that information published by independent organisations (e.g. DAF, CSIRO) requires updating. As a generalisation, independent extension materials required updating with recent research results or technology advances, in many instances were no longer publicly available, and more recently published information was fragmented (i.e. published as species or subject specific information rather than whole of pasture systems). The private sector materials were

generally more recently updated but were sales driven and, on some topics, provided recommendations that are contrary to research results. Updated extension materials are required to collate fragmented research results, ensure technical knowledge is not lost, provide independent advice and to improve access to the grazing industry.

- Preferred legume species have changed over the last decade. Desmanthus is now the legume preferred by graziers, whereas in 2010 focus groups with graziers, desmanthus was mentioned by only two out of six groups. Desmanthus has benefited from a rigorous and sustained marketing effort over the last decade. By contrast, Caatinga stylo has performed very well in research trials but has not had a large or sustained marketing effort and has a much lower adoption rate. Desmanthus (40%), leucaena (16%), shrubby stylo (14%) and Caatinga stylo (8%) are the top four legume species that graziers intend to sow in the next five years, however, there are nine other species that some graziers intend to sow.

Legume persistence

Early results suggest that Caatinga stylo and *Desmanthus virgatus* are likely to be persistent on loam and clay soil types in southern inland Queensland.

Results over the first few years suggest that current commercial varieties of *D. leptophyllus* and *D. bicornutus* are unlikely to be persistent. New varieties would be required for these two species to be useful in southern inland Queensland. Fine-stem stylo did not persist on loam soils in southern inland Queensland and should not be recommended.

The trials need to continue for longer before the long-term persistence of *D. pernambucanus*, shrubby stylo and leucaena can be determined.

Legume establishment

Poor establishment is the most common reason for failure of pasture legumes in existing commercial grass pastures, however, the most commonly used methods by graziers are low cost and low reliability. Fallowing to store soil moisture and control competition from the existing grass pasture dramatically improves establishment. Greater control of competition through the use of post-emergence herbicides can improve seedling survival and therefore establishment success, however, these herbicides are not registered for several important legume species.

Plot trials have shown that dramatically better and more reliable establishment of small-seeded legumes sown into existing competitive grass pastures is achievable through using agronomic practices that are commonly used by the grains industry (and graziers when establishing leucaena). For example, at the Goondiwindi clay trial site, long fallow treatments produced 800-1900kg of legume per hectare while cultivate at sowing treatments had either no plants or only a few very small plants that produced negligible biomass at 12 months after sowing. Industry needs to adopt more reliable establishment techniques when introducing legumes into existing grass pastures to realise their full potential to improve productivity and economic returns in the Brigalow Belt bioregion. The challenge for future participatory research and extension is to take the principles developed from the plot trial and adapt them to the paddock scale using commercial equipment. Demonstrating the impact of fallows on the early growth of legumes is a high priority for future extension efforts to improve adoption rates.

Fertiliser to improve legume establishment

Trials on phosphorus fertiliser use to improve legume establishment produced inconsistent results but trial design may have affected results. Phosphorus fertiliser increased the early growth of medics but did not improve Caatinga stylo or desmanthus growth. These trials were sown without grass which may not reflect fertiliser impact when sowing a grass with the legume.

Benefits to industry

This project has contributed to the northern Australian beef industry through working in the bioregion with the greatest gross value of production and working on the best long-term management option to improve productivity and economic returns in the region. Queensland runs 47% of Australia's beef cattle. The Brigalow Belt bioregion produces 44% of the gross value of agricultural production from grazing in Queensland. Pasture legumes have been identified as the best long-term option to increase the productivity and returns from both rundown sown grass pastures and native pastures in the Brigalow Belt bioregion.

This project conducted research and reviewed previous research results to develop more reliable legume management recommendations specifically for the Brigalow Belt bioregion climate and soils. The management recommendations were packaged into a one-day workshop. Graziers that attended the workshops conducted by this project represented 226 businesses (5.1% of businesses in the Brigalow Belt) run 279,000 head of cattle (5.6% of the herd in the Brigalow Belt), sowed 42,000ha with legumes since attending the workshop and they intend to sow an additional 111,200ha over the next five years. These grazing businesses manage 1.2% of Queensland's grazing lands and carry 2.7% of Queensland's beef herd.

Research conducted by the project team has improved the understanding of legume adaptation and persistence, methods to reliably establish legumes into existing grass pastures and worked with graziers to test the methods on farms.

Future research and recommendations

Research, Development and Extension (RD&E) recommendations focus on improving commercial results, reliability and long-term productivity from legumes in competitive grass pastures (especially buffel grass). High priorities for future RD&E to support widescale and successful legume adoption in the Brigalow Belt bioregion include:

1. Extension to improve the commercial reliability of legumes. A range of extension activities are required to update and improve access to information on pasture legumes, improve skills, promote adoption of key practices and develop commercial scale methods to reliably establish legumes.
2. Develop improved legume establishment methods. Research trials have demonstrated agronomic methods that can improve legume establishment at the plot scale that need to be adapted to be applied at the paddock scale. Research, development and demonstration is required to develop management solutions for weed control (e.g. registration of post emergence herbicides), commercial scale machinery (e.g. for rhizobia delivery to depth) and develop regionalised legume establishment recommendations. A high priority is to demonstrate the benefit of fallows on legume establishment.
3. Better legume varieties. A review by Bell *et al.* (2016) identified the Brigalow Belt as being the highest priority for developing better legume varieties in northern Australia. Research by this and other projects has identified limitation in the adaptation of current commercially available varieties, especially for southerly latitudes. Current research has identified promising experimental legume accessions for release as new varieties in southerly latitudes.
4. Research the impact of fertiliser on productivity and economic returns from pasture legumes. A review of the role of phosphorus fertiliser in the Brigalow Belt found that fertiliser use by graziers is very uncommon, but that production and economic returns

are likely to be good if fertiliser is applied appropriately (Peck *et al.* 2015). Research and development is required to better define the production and economics responses to fertiliser to realise this opportunity.

5. Improved reliability of establishing rhizobia of summer growing legumes when sown onto hot soils. Alternative rhizobia inoculant delivery methods that protect the bacteria from the hot and dry soil surface that are typical when sowing summer growing legumes need to be developed and adopted for legumes with specific rhizobia requirements to be highly productive.
6. Reliable seed quality. The quality and reliability of supply of tropical pasture seed is variable with poor quality seed often being sold. The seed industry needs to address seed quality and labelling issues if legumes are to be more reliable and successful when sown into commercial paddocks with competitive sown grass pastures. Research and extension organisations need to provide information and tools to graziers and their advisors to calculate suitable sowing rates and compare the value of seed lots.

Acknowledgements

This project involved the efforts of many people. The project team changed over the years, and the authors would like to acknowledge and thank the team for all their contribution: Stuart Buck, Bradley Taylor, Andrew McLean, Tiago Silva, Justin Macor, Brian Johnson, Joseph O'Reagain, Graham Kedzlie.

The completion of the research trials would not have been possible without the participation, cooperation and input of the grazing families who have hosted them. Their support is acknowledged and greatly appreciated, especially during very dry years and challenges:

- 'Goorewan', Wandoan
- 'Myall Plains', Nindigully
- 'Kioma', Goondiwindi
- 'Glen Rock', Allora
- 'Malanga', Nindigully

The effort and cooperation from the graziers who have hosted field days and workshops, and those who have participated in the on-farm trials and case studies is greatly appreciated. Without their willingness to be involved and try new things, the project would not be able to facilitate industry adoption through peer-to-peer learning or assist industry to evaluate the benefits of legume adoption.

The project was a team effort which required input from multiple disciplines across multiple locations and organisations. The authors would like to thank colleagues within DAF and other organisations who have supported the project by organising and supporting workshops and field days, as well as encouraging participants to trial activities on-farm. Technical input for the research trials was provided by multiple colleagues. Statistical analysis was conducted by David Mayer. Mike Bell (UQ), Christopher Guppy (UNE) and Richard Flavel (UNE) provided advice on phosphorus trials. Agrimix, Barenbrug and Queensland Agricultural Seeds provided seed for the legume persistence trials.

The project was funded by the Queensland Government and Meat and Livestock Australia.

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1 Background

The Brigalow Belt is an important bioregion for beef production in northern Australia as it carries a high proportion (>30%) of the cattle herd, supports high stocking rates and high animal performance (i.e. reproduction and growth rates) (ABS 2016). This high productivity is due to sown grass pastures growing on relatively fertile soils in a moderate rainfall climate. The region also supports a large percentage of Queensland's grain production with many 'mixed farms' that have both cropping and grazing enterprises.

The productivity of native and sown pastures in northern Australia has been widely observed to have declined over time (Tothill and Gillies 1992; Peck *et al.* 2011). This decline results from changes in land condition that can affect both native and sown pastures, and changes in available soil nitrogen (N) that mainly affects sown grasses and leads to "pasture rundown" (Pressland and Graham 1989; Myers and Robbins 1991; Tothill and Gillies 1992). Although sown grass pastures growing on Brigalow soils are highly productive compared to most of northern Australia, their productivity has declined dramatically since they were first established primarily due to 'pasture rundown' (Graham *et al.* 1981; Myers and Robbins 1991). 'Pasture rundown' is the decline in grass growth due to a reduction in available nitrogen in the soil with increasing age of the pasture stand.

Pasture legumes have been identified as the best long-term option to increase the productivity and returns from both rundown sown grass pastures and native pastures through their ability to biologically fix atmospheric nitrogen (Peck *et al.* 2011; Ash *et al.* 2015; Bowen and Chudleigh 2018). Nitrogen fixation by legumes results in higher quality forage for a longer period of the year than grass-only pastures; and additional nitrogen cycling to companion grasses leads to better grass growth and quality (Quirk and McIvor 2005; Peck *et al.* 2017a).

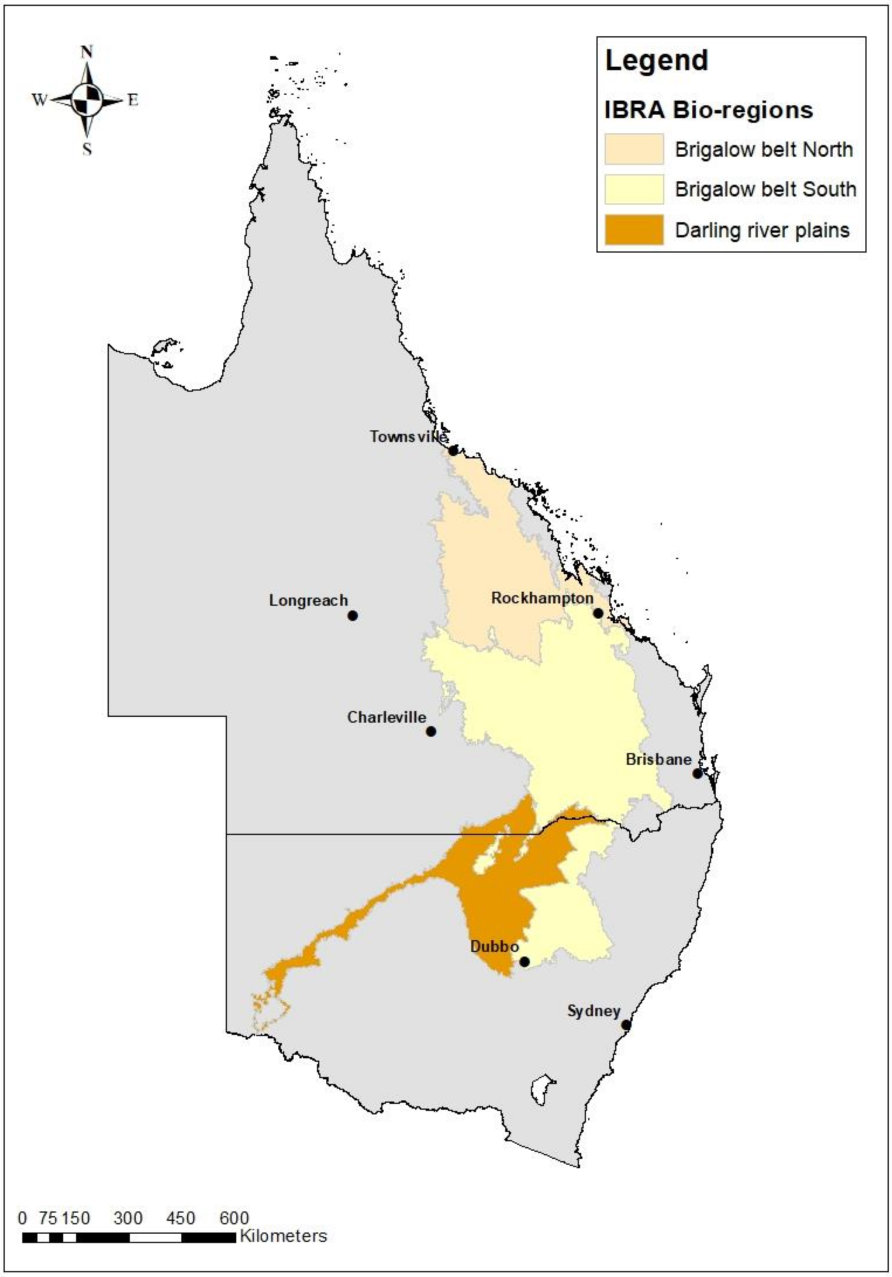
Despite impressive results from legumes in trials and some commercial pastures, adoption levels remain very low in the Brigalow Belt (Peck *et al.* 2011). For example, leucaena is one of the most widely grown pasture legumes, however it has been adopted on only about 3% of the area of pasture land to which it is adapted (Peck *et al.* 2011; Beutel *et al.* 2018). These low adoption rates mean there is a huge opportunity to increase beef production by increasing adoption of pasture legumes in the Brigalow Belt, providing significantly higher economic returns for decades to come.

This project endeavoured to increase the productivity of grass pastures in the Brigalow Belt (primarily in southern and central Queensland but also extending into north Queensland) through more <u>*reliable*</u> and <u>*successful*</u> adoption of legumes. The coordinated extension program supported landholders to assess their options, develop a plan and implement on-farm management practices to successfully adopt legumes. The linked coordinated research and development program helped to develop and demonstrate management practices to improve establishment reliability and long-term performance of legumes in grass pastures.

1.1 Brigalow Belt bioregion

The Brigalow Belt bioregion occupies approximately 36 million hectares of Queensland and New South Wales, stretching from Dubbo in the south to Townsville in the north (Thackway and Cresswell 1995). Approximately 80% of the bioregion is in Queensland (Figure 1).

Figure 1: Geographic extent of the Brigalow Belt and Darling River Plains bioregions (Thackway and Cresswell 1995). Queensland Government bioregion mapping includes the Queensland portion of the Darling River Plains as part of the Brigalow Belt.



The Brigalow Belt bioregion includes a range of land types (including eucalypt woodlands and open grasslands) but is characterised by clay soils where the native vegetation was originally dominated or associated with Brigalow (*Acacia harpophylla*). The soils were initially very fertile for agriculture which led to large areas being cleared for grain cropping and sown pastures. Tree clearing, combined with the inherent soil fertility and moderate rainfall environment, contribute to it being a highly productive region of northern Australia.

1.2 Pasture and livestock productivity

The Brigalow belt is a critically important region for beef production in northern Australia. Queensland accounts for 47% of Australia's cattle herd (ABS 2016). The Brigalow Belt bioregion carries 47% of Queensland's beef cattle herd and accounts for 44% of the gross value of agricultural production (GVAP) from grazing (Table 1) (ABS 2016; Anonymous 2022). The Brigalow belt also produces 92% of Queensland's feedlot revenue (Anonymous 2022). The Brigalow belt bioregion produces more than four times the beef herd and GVAP from grazing than the next most productive bioregion. The high productivity of the Brigalow Belt bioregion is due to extensive areas of sown pastures growing on relatively fertile soils with moderate rainfall. The large areas of sown pasture in the Brigalow belt are important to the northern Australia beef industry because of the large numbers of highly productive and valued livestock, and the production flexibility of either breeding, backgrounding (before entering a feedlot) or finishing.

Table 1: Gross value of agricultural production for grazing in Queensland by bioregion. Presented data is from a spatial analysis of Agricultural Census data (Anonymous 2022). Bioregions are ordered from highest to lowest number of cattle.

	Grazing Businesses		**Grazing beef herd**		**Grazing production**	
Bioregion[A]	**Number of grazing businesses**	**% of Qld grazing businesses**	**Number of cattle**	**% of Qld herd**	**GVAP[B] ($M)**	**% of Qld GVAP[B]**
Brigalow Belt	4,426	42.9%	4,989,067	47.3%	2,305.95	44.2%
Gulf Plains	252	2.4%	1,041,851	9.9%	467.95	9.0%
Mitchell Grass Downs	454	4.4%	844,842	8.0%	411.88	7.9%
Southeast Queensland	2,791	27.0%	820,921	7.8%	489.85	9.4%
Einasleigh Uplands	345	3.3%	597,051	5.7%	279.19	5.4%
Mulga Lands	467	4.5%	591,136	5.6%	321.33	6.2%
Desert Uplands	240	2.3%	482,485	4.6%	226.59	4.3%
Northwest Highlands	57	0.6%	345,959	3.3%	150.73	2.9%
Channel Country	157	1.5%	345,670	3.3%	151.34	2.9%
Central Queensland Coast	423	4.1%	185,843	1.8%	73.52	1.4%
Wet Tropics	425	4.1%	126,885	1.2%	69.48	1.3%
Cape York Peninsula	43	0.4%	91,635	0.9%	40.09	0.8%
New England Tablelands	240	2.3%	80,468	0.8%	226.59	4.3%
Queensland	**10,320**	**100.0%**	**10,543,812**	**100%**	**5,214.49**	**100.0%**

A: Bioregions described by Queensland regional ecosystem descriptions (Department of Environment and Science) which includes the Queensland portion of the Darling River Plains bioregion which is recognised as a separate bioregion nationally (Thackway and Cresswell 1995).
B: Gross value of agricultural production.

Although these sown grass pastures are highly productive compared to most of northern Australia, their productivity has declined dramatically since first established due to 'pasture rundown' (Graham *et al.* 1981; Peck *et al.* 2011). 'Sown pasture rundown' is the decline in grass growth due to a decline in available N in the soil with increasing age of the pasture stand as N is 'tied-up' in soil organic matter. Productivity decline in sown grass is widespread in the Brigalow belt and has reduced production by approximately 50% (Graham *et al.* 1981; Robbins *et al.* 1987; Peck *et al.* 2011). This production loss will continue in the decades to come and the on-going impact has been estimated to cost beef producers in northern Australia >$17 billion at the farm gate in foregone income over a 30 year period (Peck *et al.* 2011). Buffel grass is the dominant sown grass pasture across northern Australia (>75% area of sown pasture) and is widely affected by rundown (Walker and Weston 1990; Walker *et al.* 1997; Peck *et al.* 2011). In Queensland, Buffel is "dominant" on 5.8M ha and "common" on a further 25.9M ha (Peck *et al.* 2011). Similarly, the productivity of native pastures is constrained by low N availability for grass growth in most situations.

1.3 Pasture legumes in the Brigalow Belt bioregion

Pasture legumes have been identified as the best long-term option to increase the productivity and returns from 'rundown' sown grass pastures and native pastures through their ability to biologically fix atmospheric nitrogen (Peck *et al.* 2011; Ash *et al.* 2015). Nitrogen fixation by legumes results in higher quality forage for a longer period of the year than grass-only pastures, and additional nitrogen cycling to companion grasses leads to better grass growth and quality. Studies comparing 'rundown' grass-only sown or native pastures to grass-legume pastures demonstrate that productivity increases from legumes are significant, for example:

- On-farm research studies in central QLD (Wandoan to Capella) reported a 60-160% increase in live weight gain per hectare and a doubling of gross margins with legumes compared to grass only pastures (Bowen *et al.* 2015).
- On-farm research sites in buffel grass pastures recorded a 40-100% increase in annual pasture production (Dry Matter (DM) per hectare) with legumes (Caatinga stylo near Moura; desmanthus near Wandoan) compared to grass only pastures approximately 15 years after establishment on low P soils (Peck *et al.* 2013). These grass-legume pastures also responded strongly to applied P fertiliser with an additional 50% increase in DM/ha (Peck *et al.* 2017a).
- 10-30% increases in pasture production have been reported with native pastures augmented with legumes (McIvor and Gardener 1995). Stylo in native pastures have recorded 30-60 kg/head/year live-weight gain benefits (Hall *et al.* 2004).

Despite impressive results from legumes in trials and some commercial pastures, adoption levels remain very low in the Brigalow Belt. For example, leucaena is one of the most widely grown pasture legumes in the Brigalow belt, however it has been adopted on only about 3% of the area of pasture land that it is adapted to (Peck *et al.* 2011; Beutel *et al.* 2018). These low adoption rates mean there is a huge opportunity to increase beef production through more widespread adoption of pasture legumes in the Brigalow Belt and provide significantly higher economic returns for decades to come.

1.3.1 Legume persistence

Achieving high production gains from legumes requires well adapted varieties with good management. Assessments at old pasture evaluation or demonstrations trials have demonstrated that there are a range of legumes that have persisted at multiple locations covering a large percentage of the soils and climates of the Brigalow Belt bioregion, however there remains important gaps in trial sites in southern Queensland (Peck *et al.* 2017a). Specifically, commercially available legume varieties of Caatinga stylo, desmanthus and leucaena have been demonstrated to be persistent and productive across central Queensland (i.e. at old trial sites located from Roma north), but there are no trial sites in cooler southern districts. This project established new trial sites to test the adaptation of these legumes in important districts that don't have existing trials.

1.3.2 Legume establishment

Despite impressive results in trials and some commercial sowings, graziers often report poor performance from legumes. Focus group discussions with grazier groups across southern and central Queensland identified poor establishment as the most common reason for failure of legume augmentation of grass pastures in the Brigalow Belt bioregion, however, graziers continue to routinely use low cost, low reliability establishment techniques (Peck *et al.* 2011).

Research trials on establishing small seeded legumes (e.g. desmanthus) into existing buffel grass pastures demonstrated that methods and recommendations developed in other climatic zones are not reliably in the Brigalow Belt bioregion(Peck *et al.* 2017b). For example stylo establishment in the seasonally dry tropics (i.e. monsoonal areas) or inland Burnett (higher rainfall) has been considered adequate with little or no disturbance to the existing pasture (e.g. heavy grazing, fire) or one-pass cultivation and seeding operations (e.g. band seeders, crocodiles, blade ploughs, discs, chisel ploughs) (Partridge *et al.* 1996). Clovers have often been flown on with fertiliser in more temperate regions. Minimal disturbance or one pass cultivation methods have been recommended as a generally applicable approach to establishing small seeded legumes across Queensland irrespective of climatic zone (for example in DAF publications, seed companies marketing materials, web sites and sales advice).

Greater use of legumes by graziers is constrained by the perception that establishment is too risky or uncertain, especially in those regions with higher rainfall variability and where the existing pasture is very competitive, such as sown grass pastures of central and southern Queensland. In the same environment, farmers use dramatically different agronomic approaches to grow grain crops to mitigate the impacts of seasonal variability. Similarly, graziers sowing leucaena now routinely use better agronomy which has taken leucaena from being considered the riskiest pasture legume to establish to being considered the most reliable by industry.

The most commonly used and recommended establishment techniques are to broadcast seed into existing grass pasture with either no or minimal (e.g. a fire) preparation; or one pass cultivation and spreading of seed (e.g. with a chisel plough or deep ripper) (Peck *et al.* 2011). These establishment techniques result in failure in most years and have failed in all six legume establishment trials initiated as part of the "Improving productivity of rundown sown grass pastures project" (B.NBP. 0639) (3 districts, 2 soil types, with different districts being sown in 2 different years) (Peck *et al.* 2017b). These experiments were measured as part of this project and identified agronomic practices that dramatically improve the reliability of legume establishment; thereby improving legume productivity and economic returns.

An additional four field trials were conducted to test the impact of phosphorus fertiliser on legume establishment and growth in the initial years after sowing. Fertiliser has been shown to improve legume establishment in some species of legumes. These trials were designed to test the impact of phosphorus fertiliser on the early growth of Caatinga stylo, desmanthus and medics on Brigalow clay soils.

1.4 Project activities

This project assisted industry to increase the productivity of grass pastures through coordinated research and extension activities to facilitate the wider ***successful*** adoption of legumes (high legume yield and persistence). Four project activities addressed key knowledge gaps or constraints to successful adoption of legumes in the Brigalow Belt:

- Extension program to support adoption of improved legume establishment and management practices. Workshops, field days, on-farm trials and demonstrations were conducted to improve industry knowledge and skills (graziers and their advisors) and support successful adoption of legumes.
- Legume persistence research trials were established to determine whether existing tropical legume cultivars are adapted to the frosty southern districts of the Brigalow Belt bioregion. These trials fill a gap in trial sites on the Darling Downs and Border Rivers (near Goondiwindi and St George) to test the adaptation (persistence and productivity) of available legume varieties.
- Legume establishment research trials developed better legume establishment recommendations for the Brigalow belt climate zone.
- Fertiliser research trials tested the impact of fertiliser on legume establishment.

2 Objectives

The objectives of the project are listed in bold below. A statement on whether the objective was met is provided in plain font. The aim was to meet the objectives of the project by November 2022.

Develop agronomic management recommendations from trial and on-farm demonstration results and package them into new extension products to assist graziers and their advisors to:

- **More reliably and effectively establish legumes into existing grass pastures. This will be achieved by identifying and testing practical means of optimising soil moisture and nutrient availability, and minimising competition from existing grass pasture and weeds.**
- **Maintain productivity in the longer term.**

Improved management recommendations specifically adapted for the Brigalow Belt bioregion have been developed. This project reviewed previous research, conducted research and collated technical information to develop legume management recommendations for the Brigalow Belt bioregion. It was essential to develop better management recommendations specifically for the Brigalow Belt bioregion because research results have shown that commonly used establishment practices developed in other climate zones failed to produce adequate legume populations in most years. The main extension product that documented these management practices is a full-day workshop.

Improve available web information with updated legume establishment and management recommendations.

Four case studies, two fact sheets and five web pages have been published on the FutureBeef website. Twelve conference papers have also been presented which are available on-line.

Develop legume management plans with 20 groups of producers.

Legume management action plans were developed with 23 groups of producers.

Facilitate groups of producers and/or individuals to increase successful legume adoption by testing legumes and management practices on their own farms. The project aims for 40-60 producers to trial legume management practices on their farm with an additional 10 detailed demonstrations. From these group or individual experiences, develop 5 case studies that describe the value propositions for other producers to adopt.

One hundred and five on-farm trials and 13 detailed on-farm trials were initiated during the project. Four case studies have been developed.

Test the persistence and productivity of commercially available varieties of legumes in districts where they have not been adequately tested. Specifically, this activity will test the persistence of commercially available varieties of desmanthus and Caatinga stylo on the Darling Downs and Border Rivers regions where there are no historical or current trial sites.

Six desmanthus and stylo persistence trials were established. Five leucaena persistence trials were established. Four species of desmanthus and three species of stylo were included in the trials. Results so far suggest that varieties from one species of desmanthus (*D. virgatus*) and one species of stylo (Caatinga stylo) are likely to be persistent in the long-term. Commercial varieties of shrubby stylo and other species of desmanthus have maintained an adequate legume density at one or more trial sites, however some varieties have declined at all sites. These trials need to continue for several more years to test long-term persistence.

Test the impact of phosphorus fertiliser on the establishment and early growth (up to 3 years growth) of desmanthus, Caatinga stylo and medics.

Trials were sown in the Goondiwindi and Wandoan districts. The Goondiwindi trials were discontinued due to unexplained patchy poor growth. The Wandoan desmanthus/Caatinga stylo trial produced inconclusive results. The medic trial showed a clear response to fertiliser.

Increase the number of producers that are successfully establishing legumes into existing grass pastures. This project aims to work directly with 160 producers to improve the reliability and successful adoption of legumes, thereby improving productivity. Based on property information these producers are likely to have approximately 400,000ha of sown pasture, 450,000ha of native pasture and 180,000 cattle.

Four hundred and twelve people representing 317 businesses, of which 226 were grazing businesses attended workshops on legume management. These businesses manage 1,456,000ha of land (1.2% of Queensland's grazed lands) with 588,000ha of sown pastures. The grazing businesses run 279,000 head of cattle which is 2.7% of Queensland's beef herd. Graziers who have attended the workshop have sown 42,000ha (average of 258ha per business that sowed legumes) of legumes and intend to sow an additional 111,200ha over the next 5 years (average of 617ha per business).

3 Methodology

The project aims were to increase the productivity of grass pastures in the Brigalow Belt bioregion (primarily in southern and central Queensland but also extending into north Queensland) through supporting more reliable and successful adoption of legumes. A coordinated extension program supported landholders to assess and implement on-farm practices to adopt legumes more successfully, and a coordinated research program developed management practices and recommendations to improve establishment reliability and long term (20+yrs) performance of legumes in grass pastures.

There were four main components to the project, with the main outputs for these components described below:

1: Extension activities:

- Industry engagement in learning-based extension activities (workshops and field days). (Project target: 20 workshops/field days).
- On-farm demonstrations conducted by workshop or field day participants. (Project target: 40-60 grazier initiated and managed).
- Detailed on-farm trials (Project target: 10 detailed on-farm trials completed).
- Extension materials developed on legume management (Project target: 3 factsheets and/or web pages).
- Five case studies developed on graziers' experiences with establishing and/or managing legumes in the Brigalow Belt bioregion.

2: Six legume persistence trial sites on the Darling Downs, Goondiwindi and St George districts (Project target: 6 legume persistence trials).

3: Four phosphorus fertiliser impact on legume establishment trials (Project target: two temperate and two tropical legumes trials).

4: Five legume establishment trials testing different approaches to establishing legumes into existing grass pastures were assessed (Project target: five trials assessed).

3.1 Extension activities

Understanding of legumes and best management practices varies across industry (graziers and advisors), but generally, *successful* adoption of legumes (i.e. high production and persistence) by graziers is very low in the Brigalow Belt bioregion. There are significant opportunities for industry to increase productivity and returns from sown grass pastures and native pastures using pasture legumes.

A key output from this project has been to develop agronomic management recommendations to more reliably and effectively establish legumes and to maintain productivity in the long-term in the Brigalow Belt bioregion. Research results have shown that some commonly used and recommended legume establishment practices fail to produce adequate legume populations in most years in the Brigalow Belt climate zone. The main extension product that has documented these management practices is a full-day workshop. Some topics have been developed into factsheets, media stories, web pages and conference papers.

3.1.1 Industry engagement

The project used a learning-based approach to work with industry (graziers, advisors, seed industry) to better understand the drivers of successful legume establishment and high legume-pasture production in the long term, and to identify, develop and test improved management practices on-farm. Industry engagement followed the process of:

- Develop a better understanding on how to successfully and reliably use pasture legumes in the Brigalow Belt bioregion. Workshop materials presented research results and commercial experience.
- Assess own on-farm situation and develop an action plan. Graziers applied the technical knowledge presented during the workshop to their own situation to develop an action plan for their own property during the workshop.
- On-farm testing. Graziers were encouraged to test aspects of the legume best management practices presented during the workshop on their own farm as on-farm trials or paddock sowings.
- Observe results of trials and commercial sowings in the field to inform recommendation for legume management practices in the future.

3.1.1.1 Legume best management practices workshop

A full day "Productive and persistent legume pastures: Best management practice for legumes" workshop was developed and delivered with groups of graziers and farm advisors. The workshop content is based on research results in the Brigalow Belt bioregion which contradicts some results in other climate zones. Some of the management recommendations presented in the workshop are different to what has been provided to graziers for decades, for example the most commonly used and recommended establishment techniques are to broadcast seed into existing grass pasture with either no or minimal (e.g. a fire) preparation; or one pass cultivation and spreading of seed (e.g. with a chisel plough or deep ripper) (Peck *et al.* 2011). These establishment techniques result in failure in most years and have failed in six legume establishment trials conducted in the Brigalow Belt where fallows resulted in high legume density in the year of sowing (Peck *et al.* 2017b).

The workshop process and content was structured to facilitate co-learning from grazier experience (grazier to presenter, and grazier to grazier), present research results, discuss best management practices and to develop a legume management action plan for individual graziers. Graziers were encouraged to implement or test practices from their action plan on their own property.

3.1.1.2 On-farm trials

Workshop participants were encouraged to trial legume management practices on their own properties with the on-farm trials (OFT) being grouped into two categories:

- On-farm trials (OFT). Most OFT involved a simple comparison of participant's own preferred legume establishment or management strategies on their own farm using their own equipment, predominantly taking their own measurements with project team support for trial design and interpretation.
- Detailed OFTs. The detailed OFT involved a higher level of complexity and effort than the OFT described above. The increased complexity and effort came from either a greater number of treatments being tested, replication, larger trial area or more detailed measurement. The project team offered more support to graziers hosting detailed OFT due to the higher level of complexity and cost.

The OFTs and commercial sowings provided real farm data and practical experiences that can be extended to the wider grazing community. Field days shared the results of on-farm trials, research trials and commercial paddocks of legumes. Case studies were developed to show case the experiences of graziers with legumes and on-farm trials.

3.1.2 Project evaluation

Evaluation activities were imbedded through the life of the project.

Information on improving delivery methods and measuring impact of extension activities was collected through:

- Workshop event debriefs. Workshop delivery was evaluated through a debrief with participants and presenters at the end of each workshop by asking "what went well" and "what could be improved". The questions related to the running of the event on the day and allowed the project team to improve delivery at future events.
- Workshop content evaluation survey. Changes in knowledge, skills, understanding and intended practice change was evaluated through a written questionnaire at the end of each workshop. The questions provided feedback about how content was received, as well as highlighting the type of practice change and area of land they intended to implement management change.
- Legume management action plans. More detailed intended practice change described in the Action Plans developed during the workshop were copied from participants who were willing to share their plans. The practices described in participants' action plans were categorised to provide summaries of how graziers intend to manage the next paddock they intend to sow with legumes.
- Project impact evaluation. An impact evaluation was conducted with workshop participants (between January and March 2022). The survey focussed on adoption and practice change, which targeted only grazier businesses (i.e. not agri-businesses), and only one person representing each grazing business.
    - The survey was conducted over the phone. Grazing businesses that did not provide contact details were unable to be included.
    - Questions covered area of land sown with pasture legumes since attending the workshop, practices and species used, changes in management of existing pastures and identifying the main barriers to adoption of legumes into pastures.

  - 176 grazier businesses were approached, and 104 participated in the survey (out of the 226 grazier businesses that attended the workshops).

Evaluation of research trials was undertaken annually through milestone reporting to DAF management and MLA. Progress reporting included processing, collation and interpretation of data from research trials and extension activities. Annual reports were used to adaptively manage delivery of the project.

3.2 Legume persistence trials

3.2.1 Background

Commercially available varieties of Caatinga stylo, desmanthus and leucaena have been demonstrated to be persistent and productive for many, but not all, regions of the Brigalow Belt. There is a good network of trial sites across central Queensland and south to a latitude in line with the towns of Roma and Chinchilla, but no legume evaluation or comparative productivity trials for desmanthus and Caatinga stylo have been conducted on the Darling Downs or Border Rivers (Bell *et al.* 2016; Peck *et al.* 2017a).

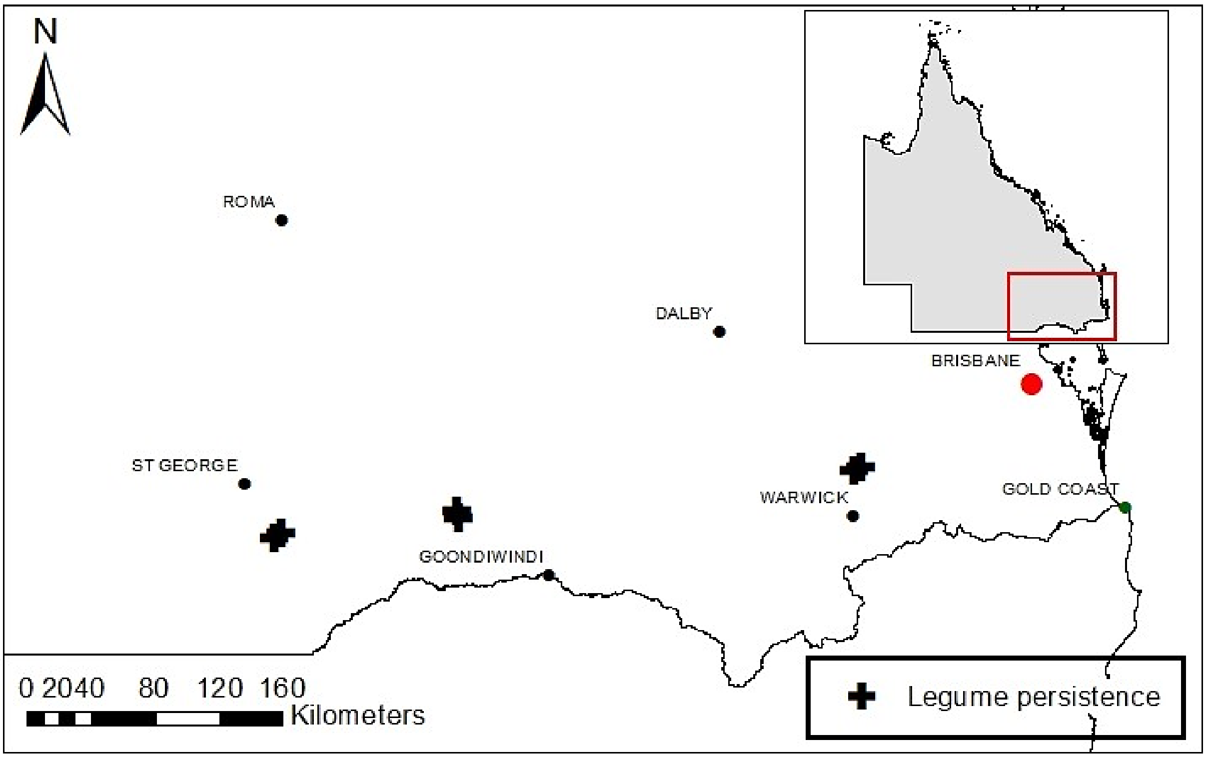
This activity established trials on the Darling Downs and Border Rivers districts to test the persistence and productivity of current legume varieties for clay soils. The aim of this activity was to determine whether the commercially available legume varieties are well enough adapted to these districts to form persistent and productive pastures in this environment, or whether new varieties are required.

3.2.2 Location of persistence trials

Trial sites have been established at the following locations (Figure 2):

- Two trial sites on “Glen Rock” near Allora on the southern Darling Downs. One of the trials is located on the valley floor to expose the plants to a high frost incidence. The other trial site is located mid-slope and is likely to have less severe frost effects. Both sites have basalt clay soils (Vertosol).
- Two trials on “Kioma” north-west of Goondiwindi. One trial is on a poplar box loam textured soil (Kandosol) while the other is on a Brigalow/Belah clay soil (Vertosol).
- Two trial sites on “Myall Plains” south of St George. One trial is on a poplar box loam textured soil (Kandosol) while the other is on a Mitchell grass downs clay soil (Vertosol).

Figure 2: Legume persistence trial site locations in relation to major towns in southern Queensland.



3.2.3 Persistence trial treatments

The legumes included in the trials are shown in Table 2 and Table 3.

Table 2: Legume varieties planted at the persistence trial sites on clay soils (which includes both sites at Allora).

Species	Varieties
Stylosanthes seabrana	Primar
Stylosanthes seabrana	Unica
Desmanthus virgatus	Marc
Desmanthus virgatus	Cowpower
Desmanthus virgatus	JCU2
Desmanthus virgatus	JCU5
Desmanthus virgatus	JCU8
Desmanthus leptophyllus	JCU7
Desmanthus leptophyllus	Ray[A]
Desmanthus leptophyllus	TQ90[A]
Desmanthus bicornutus	JCU4
Desmanthus bicornutus	JCU6[B]
Desmanthus pernambucanus	JCU9
Leucaena leucocephala	Wondergraze
Leucaena leucocephala	Redlands

A: Only sown at St George clay. B: JCU6 was replaced with TQ90 in 2020 at St George.

Table 3: Legume varieties planted at the persistence trial sites on loam soils (Goondiwindi and St George sites).

Species	Varieties
Stylosanthes seabrana	Primar
Stylosanthes seabrana	Unica
Stylosanthes scabra	Seca
Stylosanthes scabra	Siran
Stylosanthes guianensis var. *intermedia*	Oxley
Desmanthus virgatus	JCU2
Desmanthus virgatus	Cowpower
Desmanthus leptophyllus	JCU7
Desmanthus bicornutus	JCU4
Desmanthus bicornutus	JCU6
Desmanthus pernambucanus	JCU9
Leucaena leucocephala	Wondergraze
Leucaena leucocephala	Redlands

These planting lists have additional species and varieties than those outlined in the project contract. These additions allowed the project team to include new varieties that were in the process of being released commercially or short-listed by other research (JCU6, JCU8, JCU9, TQ90 and Ray) and to include shrubby (*Stylosanthes scabra*) and fine-stem (*S. guianensis* var. *intermedia*) stylos on the loamy soils.

The project used 200m^2 plots at Goondiwindi and St George trial sites based on the results from a previous legume persistence study (Peck *et al.* 2017a). The previous study concluded that larger plot sizes allowed study of legume persistence up to 20 years post sowing. Plot size had to be reduced to approximately 60 m^2 plots at Allora due to constraints on available space within paddocks and variable soils at the hill trial site.

3.2.4 Fallowing and sowing

The legume persistence trials were located in paddocks with long term grass pastures prior to the establishment of the legume persistence trials. The pasture was killed using a combination of cultivation and herbicides for a fallow period to store soil moisture, reduce the amount of weed seed in the ground and prepare a suitable seedbed. The fallow period and sowing dates are described in Table 4.

Table 4: Dates for the start of fallowing (i.e. first treatment to kill the existing pasture) and sowing for the legume persistence trials.

Trial	Fallow start	Sowing	Re-sow
Allora: Hill	13/04/2017	18-19/12/2017	Leucaena failed, not resown
Allora: Creek flat	02/08/2017	20/12/2017	17/11/2020 – Leucaena
Goondiwindi: Loam	25/07/2017	09/02/2018	27/02/2020 – Leucaena
Goondiwindi: Clay	25/07/2017	12/02/2018	28/02/2020 More seed was added to the following plots: Rep 1: Unica, JCU5, Marc, Primar; Rep 2: Marc, Primar, Unica; Rep 3: Marc.
St George: Loam	31/07/2017	15/02/2018	27/02/2020 – Leucaena
St George: Clay	31/07/2017	14/02/2018	20/02/2020 – all varieties

3.2.5 Soil analysis and fertiliser applications

Comprehensive soil analyses were conducted at all legume persistence trial site locations prior to site preparation and sowing. Table 5 summarises the results of the soil surface (0 – 10 cm depth) samples which were bulked together for analysis. Further soil analysis results are shown in Appendix 8.3. Five of the six sites were considered to be deficient in one or more nutrients with fertiliser being applied before sowing (triple superphosphate, zinc sulphate or gypsum). The trials objective was to test legume variety suitability to the soil type and climate rather than tolerance to low nutrient levels, therefore fertiliser was applied to limit the impact of nutrient deficiency on legume persistence.

Table 5: Soil nutrients measured at 0 - 10 cm depth at the legume persistence trial sites and fertiliser rates applied

Trial site	Soil nutrient levels			Fertiliser application		
	Colwell P mg/kg	K meq/100g	S mg/kg	Date	Product	Rate of product kg/ha
Goondiwindi Loam	9.0	0.86	1.0	Jan-2018	Triple superphosphate	81
Goondiwindi Clay	9.9	1.2	5.1	Jan-2018	Triple superphosphate	80
					Zinc sulphate	10
St George Clay	9.8	1.07	4.3	Jan-2018	Triple superphosphate	70
					Zinc sulphate	10
St George Loam	35.0	0.84	7.4	No fertiliser applied		
Allora Flat	75.0	1.13	3.9	Dec-17	Gypsum	30
Allora Hillside	87.0	1.23	5.7	Dec-17	Gypsum	30

3.2.6 Insecticide use

Insecticide was applied as an ant bait at sowing to limit seed loss. The insecticide fipronil was mixed with a bait (calf pellets) and broadcast over the trial site immediately after sowing.

At the St George clay site in 2020, it was noticed that a leafhopper insect was causing damage to the new desmanthus plants, and a dimethoate insecticide was applied. Details of both products, rates and dates are listed in Table 6Table 12.

Table 6: Insecticides used at the legume persistence trial sites.

Trial	Insecticide product	Date applied	Rate applied
Goondiwindi Loam	Vista 200 SC (200 g/L fipronil)	At planting	2 mL/ha
Goondiwindi Clay	Vista 200 SC (200 g/L fipronil)	At planting	2 mL/ha
St George Clay	Vista 200 SC (200 g/L fipronil)	At planting	2 mL/ha
	Danadim (400 g/L dimethoate)	14/05/2020	800 ml/ha
	Danadim (400 g/L dimethoate)	17/06/2020	800 ml/ha
St George Loam	Vista 200 SC (200 g/L fipronil)	At planting	2 mL/ha
Allora Flat	Vista 200 SC (200 g/L fipronil)	At planting	2 mL/ha
Allora Hillside	Vista 200 SC (200 g/L fipronil)	At planting	2 mL/ha

3.2.7 Measurements: legume density

The key measurement to describe legume persistence at these trial sites was plant density over time. Different methods have been used for describing plant density at different recording periods. The methods used were:

- Year of sowing (autumn 2018): legume density rating. Rating scale is described in Table 7.
- Autumn 2019: legume density measured. Plant number counted in 15 x 0.5m^2 quadrats.
- Autumn 2020: legume coverage of plots rating. The legume coverage rating is described in Table 8.
- Autumn 2021: legume density measured. Plant number counted in 15 x 0.5m^2 quadrats.

Table 7: Legume density rating scale.

Rating	80% of Row	50% of Row
10	<5cm apart	
9	<10cm	
8	10-20cm	<5cm apart
7	20-30cm	<10cm
6	30-40cm	10-20cm
5	40-50cm	20-30cm
4	50-100cm	30-40cm
3	>100cm	40-50
2		50-100cm
1		>100cm
0	<10 plants/plot	<10 plants/plot

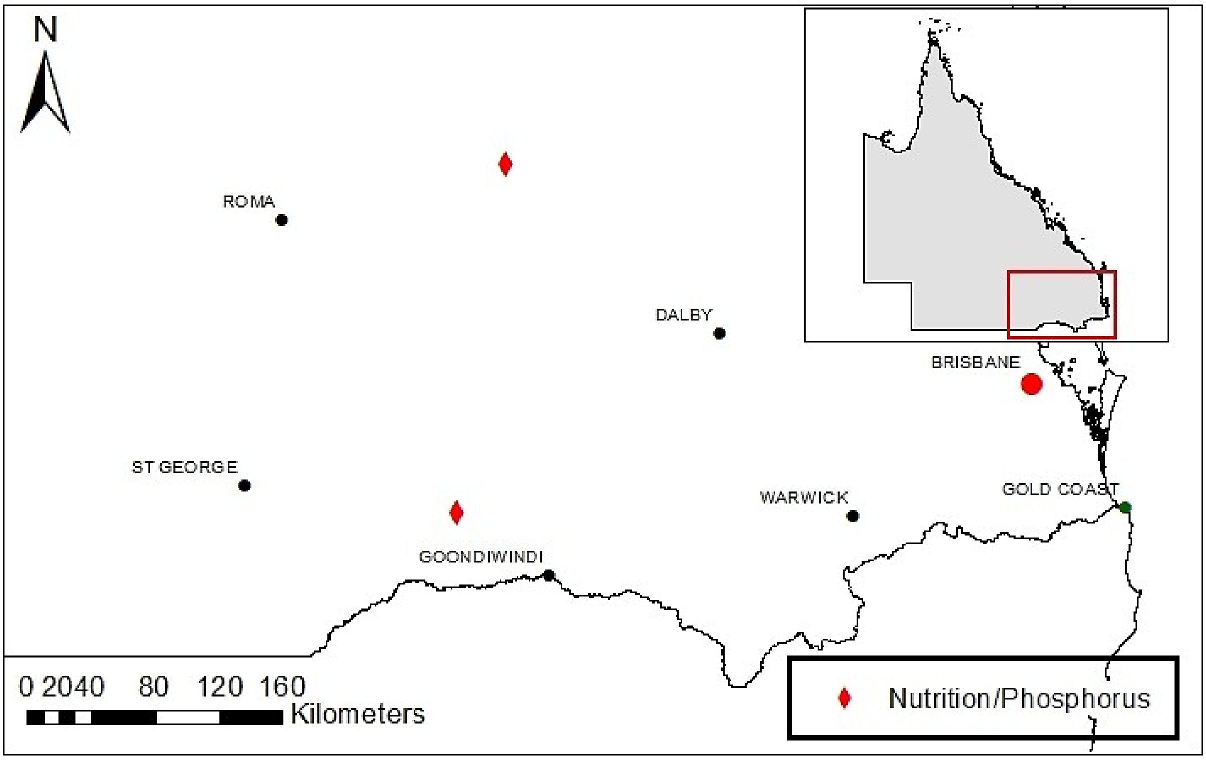
Table 8: Adult legume coverage of plots rating scale.

Rating	Rating	Description
7	VH	Adult plants over >80% of plot area
6	H	Adult plants over 50-80% of plot area
5	MH	Adult plants over 30-50% of plot area
4	MH	Adult plants over 10-30% of plot area
3	ML	Adult plants over 5-10% of plot area
2	L	A few scattered plants <5% of plot area
1	0	<10 individual plants

3.3 Phosphorus fertiliser impacts on legume establishment trials

Four trials tested the impact of phosphorus (P) fertiliser when establishing legumes on low P soils. This activity consisted of temperate and a tropical legume trials at two locations (Figure 3), that is four individual trials. The trials were located near Wandoan and Goondiwindi. The Goondiwindi experiments were abandoned during the project due to unexplained poor growth.

Figure 3: Phosphorus fertiliser nutrition trial site locations in relation to major towns in southern Queensland.



3.3.1 Trial sites

The two locations are Wandoan and Goondiwindi. The initial soil test results for P BSES, P Colwell, phosphorus binding index (PBI) and zinc (Zn) are shown in Table 9**Error! Reference source not found.**. Soil samples were collected in July 2017 prior to any soil cultivation or fertiliser application. Further soil analysis results are listed in Appendix 8.3.

Table 9: Initial soil test for P BSES, P Colwell and PBI at experimental sites at Wandoan and Goondiwindi (collected July 2017) (n.d. denotes no data).

Location	Depth cm	PBI	P Colwell mg/kg	P BSES mg/kg	Zn mg/kg
Wandoan	0 – 10	66	5.9	6.4	0.17
	10 – 30	93	<5.0	6.2	0.22
	30 – 60	72	<5.0	7.1	*n.d.*
	60 – 90	37	<5.0	11.0	*n.d.*
Goondiwindi	0 – 10	59	13.0	12.0	0.2
	10 – 30	72	<5.0	<5.0	0.2
	30 – 60	55	<5.0	<5.0	*n.d.*
	60 – 90	49	<5.0	<5.0	*n.d.*

3.3.2 Fertiliser treatments

All four trials have similar treatments of three legume cultivars representing three species with five rates of phosphorus (P) fertilizer (0, 5, 10, 25 and 100 kg of P/ha) applied with an additional two treatments where zinc (Zn) was applied to the lowest and highest rate of P (i.e. 0 and 100kg of P/ha) (Table 10). Each trial has three replicates in a randomised block design with 5 x 10 m plots as experimental units. The temperate legume cultivars are: *Medicago truncatula* cv. Jester, *Medicago orbicularis* cv. Bindaroo Gold and *Medicago polymorpha* cv. Scimitar. Tropical legume cultivars are: *Desmanthus leptophyllus* cv. JCU7, *Desmanthus virgatus* cv. JCU2 and *Stylosanthes seabrana* cv. Unica.

Triple superphosphate was used as the P source to minimise other nutrients being applied. The fertiliser treatments were applied at an approximate depth of 7cm using a research planter with three tool bars of cultivating tynes producing a 25cm row spacing with following harrows to provide mixing of fertiliser with the surface soil. Zinc was applied to plots using a boom spray at the rate of 10 kg of zinc sulphate and a water volume of 100 L/ha. All P and Zn treatments were applied in January 2018 during the fallow period.

Table 10: Fertiliser rates applied at the phosphorus nutrition trials.

Trial site	Fertiliser application		
	Date	Product	Rate (kg P/ha)
Wandoan	Jan-2018	Triple superphosphate	0, 25, 50, 100, 500
		Zinc sulphate	10
Goondiwindi	Jan-2018	Triple superphosphate	0, 25, 50, 100, 500
		Zinc sulphate	10

3.3.3 Fallowing and sowing dates

A fallowing period was used to kill the existing pasture, store soil moisture, reduce the amount of weed seed in the ground, incorporate the fertiliser treatments and prepare a suitable seed-bed. A combination of cultivation and herbicide was used during the fallow period. The fallow period and sowing dates are described in Table 11.

Table 11: Dates for the start of fallowing (i.e. first treatment to kill the existing pasture) and sowing for the phosphorus fertiliser trials.

P trial	Fallow start	Sowing
Wandoan: Tropicals	29/10/2017	17/01/2019
Wandoan: Temperates	29/10/2017	22/05/2018
Goondiwindi: Tropicals	25/07/2017	27/02/2018
Goondiwindi: Temperates	25/07/2017	10/05/2018 Resown 27/05/2020 Rehabilitated 20/01/2021

3.3.4 Insecticide and fungicide use

At certain times during the trial growing seasons, it was observed that insects or powdery mildew were becoming an issue, threatening the growth of the plants independent of the trial treatments applied. At planting, the insecticide fipronil was used to mix with a bait (calf pellets) to discourage ants from 'stealing' seed from the small trial plots. A leaf hopper insect was causing damage to the desmanthus plants, and a powdery mildew infected the temperate medic trial at Wandoan. Details of products, rates and dates are listed in Table 12.

Table 12: Insecticide and fungicide usage, rates and dates at the phosphorus nutrition trials

Trial site	Chemical type	Product	Date applied	Rate applied
Wandoan tropical	Insecticide	Vista 200 SC (200 g/L fipronil)	At planting (Jan-2019)	2 mL/ha
	Insecticide	Danadim (400 g/L dimethoate)	Jan-2021	800 ml/ha
Wandoan temperate	Insecticide	Vista 200 SC (200 g/L fipronil)	At planting (May-2018)	2 mL/ha
	Fungicide	Microthiol 800F (800 g/kg sulphur)	May-2021	400 g/ha
			11-Jun-2021	400 g/ha
			26-Jun-2021	800 g/ha
			8-Jul-2021	800 g/ha
			15-Jul-2021	800 g/ha
			22-Jul-2021	800 g/ha
Goondiwindi tropical	Insecticide	Vista 200 SC (200 g/L fipronil)	At planting (Feb-2018)	2 mL/ha
	Insecticide	Danadim (400 g/L dimethoate)	May-2018	800 ml/ha
			Jun-2018	800 ml/ha
Goondiwindi temperate	Insecticide	Vista 200 SC (200 g/L fipronil)	At planting (May 2018, May-2020, Jan-2021)	2 mL/ha

3.3.5 Measurements

3.3.5.1 Groundcover

Ground cover has been used as a non-destructive way of measuring growth rates for both tropical and temperate legumes. Additionally, plant height has been used as an estimate of growth rate for tropical legumes.

Ground cover assessment was conducted by imaging a standardised quadrat (0.75m x 0.75m) at a fixed and marked location in the plot for spatial repeatability from a fixed height of 1.35m using a digital SLR camera. Images were cropped to the area of the quadrat prior to analysis in ImageJ (FIJI version 2.0.0-rc-69/1.52i) (Schindelin *et al.* 2012). These cropped images were then used to train a classifier in the 'trainable Weka segmentation' machine learning toolkit (v3.2.29) available in ImageJ (Eibe *et al.* 2016). This classification algorithm determined from three samples was assessed for accuracy, if adequate it was applied to the remainder of the dataset, if it provided a poor fit more classification of images was conducted. The 'threshold' tool was then used to isolate pixels representing leaves for three samples randomly selected across the dataset. These pixels were then used to create a mask of leaf and non-leaf pixels and any misclassification was manually removed. Records of the classified pixels were kept, and leaf pixels were counted to determine the proportion of the ground that was covered by legume leaves.

3.3.5.2 Tropical legume height

Legume height was used as a non-destructive measure of growth rate for tropical legumes due to their ascending growth habit. Twenty plants were measured in a grid pattern in each plot.

3.3.5.3 *Temperate legume yield*

The temperate legume biomass was measured in September 2018 and August 2021. The harvested samples were collected from the same 0.75m x 0.75m quadrats used to measure groundcover change using hand sheers (Figure 4). These samples were then dried in a fan forced oven at 60°C for determination of dry matter content. Plant and soil samples from the temperate legume trial were analysed for nutrient content.

Figure 4: Harvesting biomass at the Wandoan temperate legume phosphorus trial in August 2021. Plots harvested by hand.

3.3.5.4 *Tropical legume yield*

Tropical legume biomass was harvested on 4 - 6 March 2020, 1 - 4 February 2021 and 20 April 2021.

In February 2021, tropical legume biomass was harvested within four 0.5m^2 quadrats due to the potential of continuing dry weather causing leaf drop. Further rain resulted in more legume growth. The March 2020 and April 2021 harvests were cut with a tractor mounted forage harvester for the length of the plot. Fresh weight was measured in the field. Moisture content was measured from sub-samples taken from each plot. Photos of the harvesting method are shown in Figure 5.

Figure 5: Harvesting at the Wandoan tropical legume, phosphorus fertiliser trial in March 2020.

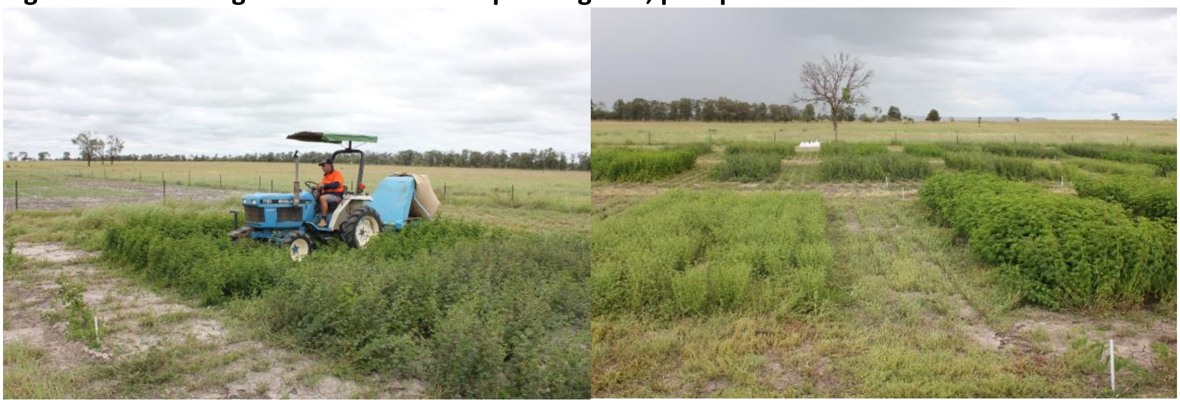
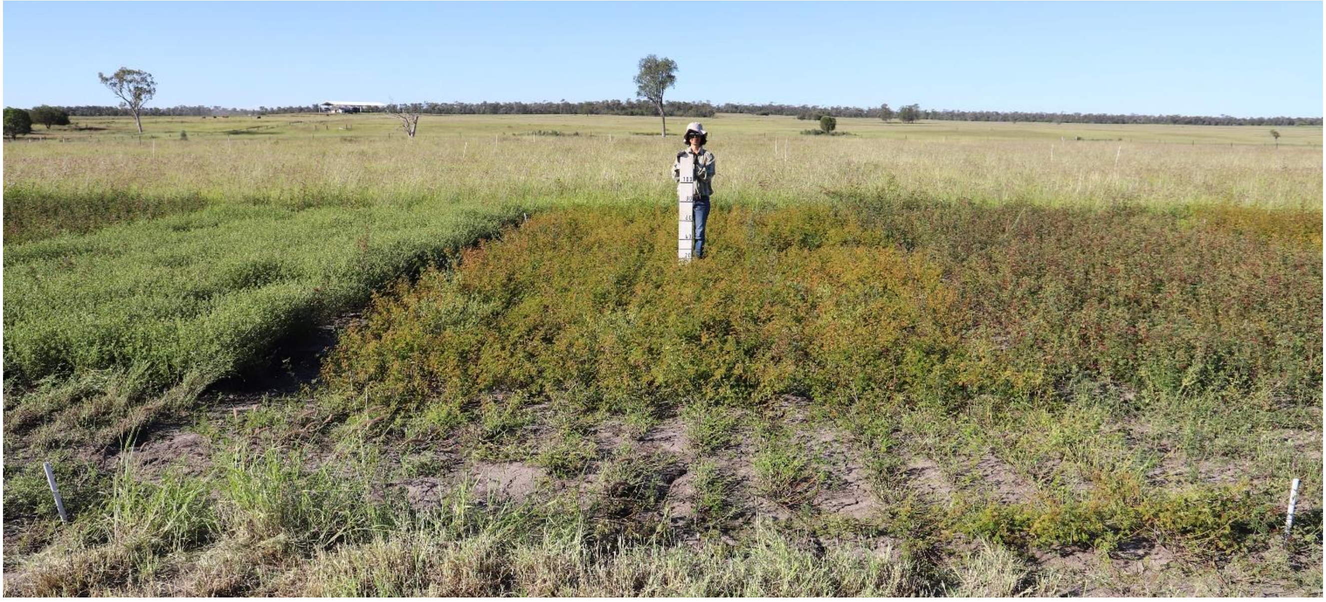


Figure 6 shows the height and growth stage of a few of the plots side-by-side ready for harvest on the 20th April 2021.

Figure 6: Day of harvest at the Wandoan tropical legume phosphorus fertiliser trial in April 2021: pre-harvest height for one of the JCU7 treatments.



3.3.6 Goondiwindi trials discontinued

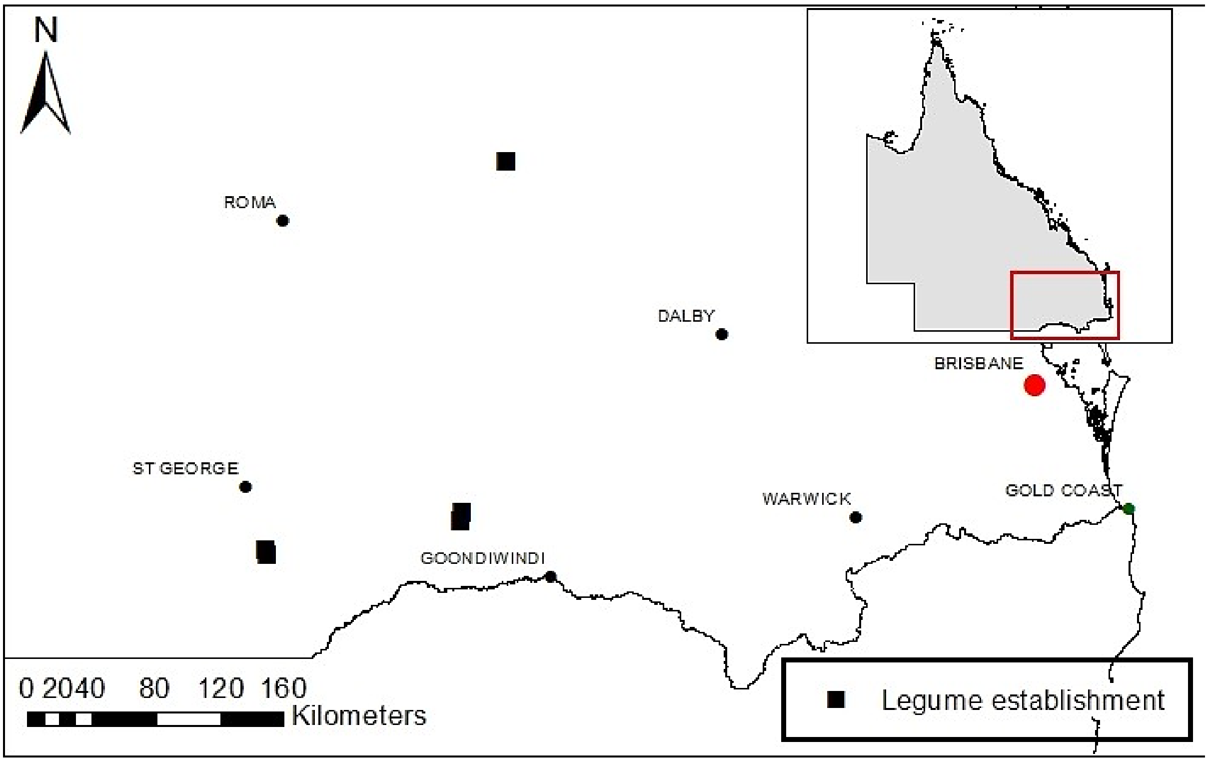
The Goondiwindi trial sites were discontinued due to unexplained patchy poor growth of legumes. MLA and DAF agreed to discontinue these trials in 2020. The temperate legume trial site area was sown with tropical grasses and legumes in January 2021 to rehabilitate the site.

3.4 Impact of agronomic practices on legume establishment trials

These trials were established in the previous project B.NBP.0639 “Improving productivity of rundown sown grass pastures” with sowing dates between 2013 and 2015. The trials are investigating the impact of better agronomic practices that are commonly used for grain cropping in the Brigalow Belt bioregion on establishing small seeded pasture legumes into existing grass pastures. Treatments were a combination of fallow period, seedbed preparation (zero tillage or cultivation), post-emergent weed control and sowing method.

Six trials across three districts (Wandoan, Goondiwindi and St George) and two soil types (grey cracking clays and loamy surfaced soils) were conducted over four years to test the impact of better agronomy on establishing small seeded legumes into existing grass pastures. This array of districts (trial locations shown in Figure 7) and soil types was selected in order to capture a broad insight into the effectiveness of the treatments applied across a range of geo-climatic environments within the Queensland portion of the Brigalow Belt bioregion. For instance, it was anticipated that loam and clay soil types would vary in their capacity to store moisture during fallows, form soil crusts after rain and have different weed pressures. It was also expected that localities with lower average annual rainfalls would pose more challenges in achieving fallow moisture storage and plant survival.

Figure 7: Legume establishment trial site locations relative to major towns in southern Queensland.



3.4.1 Trial design and treatment

The trials were designed with 5.5 m wide by 20 m long plots with grass strips (either 4.5 m or 2.5 m) left between each plot with two replicates of each treatment. Clay soil trial sites were sown with Progardes desmanthus (a blend of five varieties from three *Desmanthus spp.*). The Wandoan loam soil site was sown with fine-stem stylo (*Stylosanthes guianensis var. intermedia*); Goondiwindi and St George loam sites were sown with Caatinga stylo (*Stylosanthes seabrana cv. Primar* and *Unica*).

A full description of treatments is provided in Table 13. There were 30 treatments in total, with most treatments also having split plots in which seed was either drilled with a single disc opener planter or broadcast. The one-pass cultivation treatments described below did not have split plots, that is seed was broadcast over the whole plot, as graziers would most likely spread seed at the same time as cultivation in a one-pass operation as opposed to drilling seed as part of a second operation. Not all treatments were included at each trial site.

Treatments were a combination of fallow period (i.e. period from first treatment to control the grass until sowing); seedbed preparation (zero tillage or cultivated); and post-emergent weed control as follows:

- No disturbance of the grass pasture.
- Grass pasture disturbed at sowing through slashing; cultivation with a deep ripper, tynes or off-set discs; herbicide spray (glyphosate) with no-post emergence herbicides.
- Short fallows of 2 - 4 months using herbicide (i.e. zero tillage [ZT]), cultivation or both.
- Medium fallow of about 4 - 6 months using either ZT or cultivation.
- Long fallow of about 9 - 12 months using either ZT or cultivation.

Table 13: Description of establishment trial treatments and the districts where they were applied.

Treatment count	Fallow period	Seedbed treatment	Post plant weed control	Sowing (split plots)	District †
1	No disturbance	None	Nil	Drill and broadcast	W,G,S
2	Disturb at plant	Slash	Nil	Drill and broadcast	W,G,S
3		Deep rip	Nil	Broadcast only	W,G,S
4		Cultivate (tynes)	Nil	Broadcast only	W,G,S
5		Cultivate (discs)	Nil	Broadcast only	G,S
6		Spray	Nil	Drill and broadcast	W,G,S
7	Short (2 - 4 months)	Zero-till (ZT)	Nil	Drill and broadcast	W,S
8			PEH*	Drill and broadcast	W,S
9		Cultivate	Nil	Drill and broadcast	W,S
10			Spinnaker	Drill and broadcast	W,S
11		Cultivate then spray	Nil	Drill and broadcast	S
12			PEH*	Drill and broadcast	S
13		Spray then cultivate	Nil	Drill and broadcast	W
14	Medium (4 - 6 months)	Zero-till	Nil	Drill and broadcast	W,G,S
15			PEH*	Drill and broadcast	W,G,S
16		ZT + grass seed	Nil	Drill and broadcast	W
17		Cultivate	Nil	Drill and broadcast	W,G,S
18			Spinnaker	Drill and broadcast	W,G,S
19		Cult. + grass seed	Nil	Drill and broadcast	W
20	Long (9 - 18 months)	Zero-till	Nil	Drill and broadcast	G,S
21			PEH*	Drill and broadcast	G,S
22			PEH* 2nd summer	Drill and broadcast	G,S
23		Cultivate	Nil	Drill and broadcast	G,S
24			Spinnaker	Drill and broadcast	G,S
25			2 Spinnaker applications	Drill and broadcast	G,S
26		Cult. + grass seed	Nil	Drill and broadcast	G
27	Long + medic	ZT Medic	PEH*	Drill and broadcast	G
28		Cultivate + medic	Spinnaker	Drill and broadcast	G
29		Cultivate + medic + P fert.	Nil	Drill and broadcast	G
30		Cultivate + medic + P fert.	Post emergence herbicide	Drill and broadcast	G

* PEH: post-emergence herbicide; † District: W is Wandoan, G is Goondiwindi, S is St George.

3.4.2 Measurements

Measurement methodologies are described in Peck *et al.* (2017b). Visual observations were conducted at all trial sites over the period of this project to decide what measurements to conduct.

Severe drought conditions from 2016 – 2019 severely impacted these trials and limited what measurements were able to be conducted.

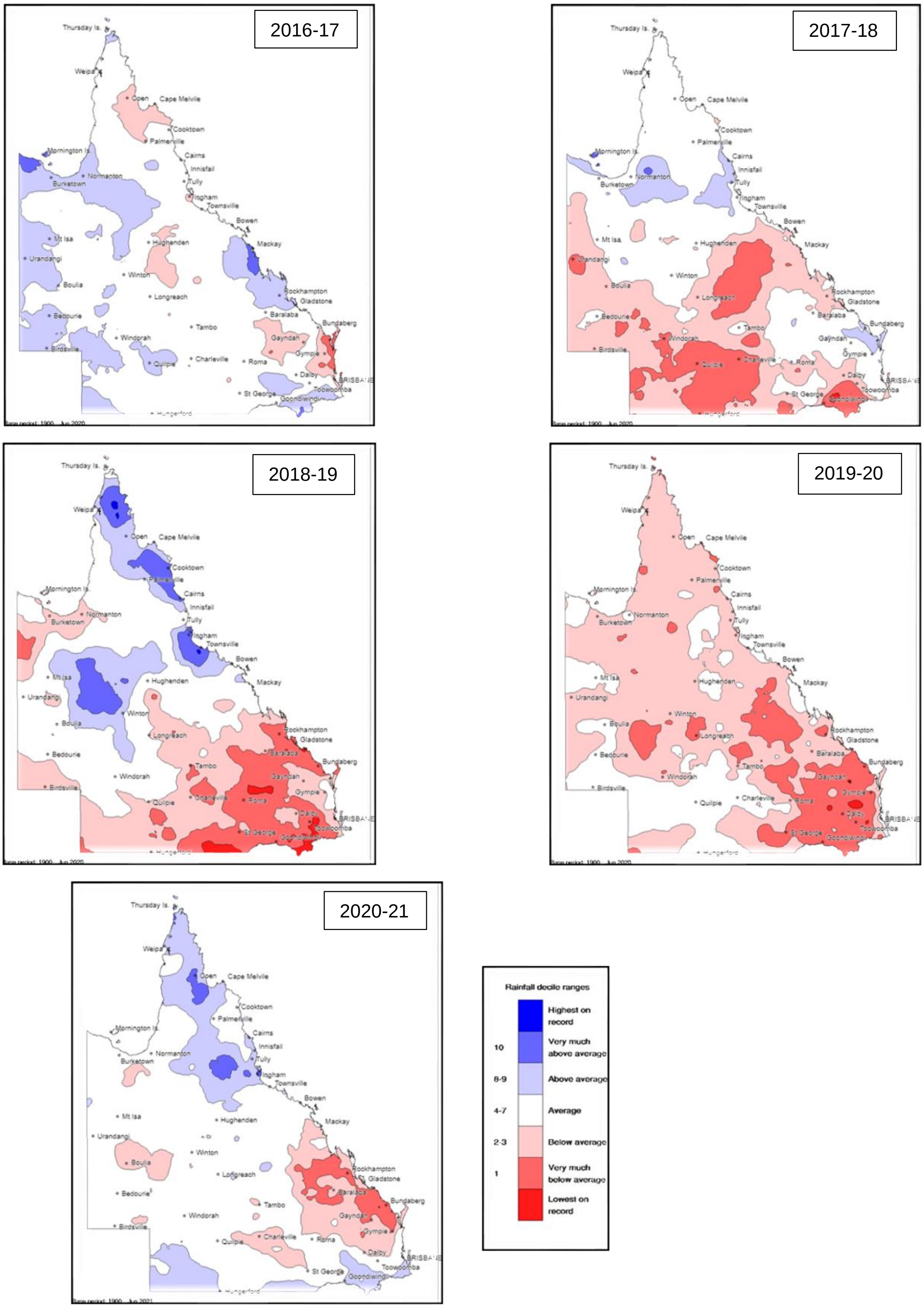
Biomass was measured at the Goondiwindi trial sites in the 2017/18 growing season but was not possible at other sites due to drought and preferential grazing by wildlife. Legume plant density was recorded at all sites in 2021, however these results reflect severe drought and heavy preferential grazing by wildlife rather than the effects of the trial treatments. The intense grazing pressure that occurs on small plots in trials from wildlife does not reflect the results from sowing commercial paddocks.

4 Results

4.1 Seasonal conditions during the trial

The project was conducted during a period of severe drought over most of the Brigalow Belt bioregion. Annual rainfall deciles experienced during the project are shown in Figure 8. Annual rainfall during consecutive years was well below average with many districts recording their lowest rainfall on record during 2019.

Figure 8: Yearly rainfall deciles for Queensland experienced during the project from 1 July 2016 to 30 June 2021 (BOM. 2022).



The severe drought experienced during the project affected all project activities. All research trials required longer periods of fallowing and weed control than what is required in average or higher rainfall years. Several research trials failed to establish adequately and required re-sowing. On-farm trials were similarly affected with graziers reporting failures due to dry weather. The on-going drought reduced graziers' capital and enthusiasm to be involved in pastures RD&E.

4.2 Extension outputs

This section describes the extension outputs that this project produced. The project delivered 23 workshops, six field days, 118 on-farm trials and demonstrations, four case studies, two fact sheets, 12 conference papers or presentations and five media stories.

4.2.1 Industry engagement: Workshops

A major extension product for this project was the development of the 'Productive and Persistent Pastures' legume workshop content and process. These workshops were delivered across the region during the project.

A key output from this project was to review research results and commercial experience to develop agronomic management recommendations specifically for the Brigalow Belt bioregion to more reliably and effectively establish legumes and to maintain productivity in the long-term. Research results have shown that many commonly used and recommended legume establishment practices fail to produce adequate legume populations in most years, in this climate zone, when sown into competitive grass pastures. Improving the recommendations about legume establishment and management was essential to improve the reliability and success of pasture legumes in the Brigalow Belt bioregion. These recommendations have been packaged into a full-day workshop that facilitated graziers through a process to review research results and apply the management recommendations to their own property and situation.

There were two soil testing workshops held in addition to the legume workshops. Legume workshop participants expressed an interest in undertaking soil testing in paddocks that they intended to sow to legumes. Soil testing was conducted in collaboration with Incitec Pivot on graziers' properties. Participants attended a workshop to learn how to understand and interpret their own soil test results.

4.2.1.1 Legume workshop

Twenty-three legume management workshops were delivered by the project. The workshops were attended by 412 people (some people attending multiple events), representing 317 businesses including 226 grazier businesses (Figure 9). The spatial distribution of workshops and field days across the Brigalow Belt bioregion is shown in Figure 10, and a description of how many people attended is in Table 14.

Figure 9: Team member, Stuart Buck presents the legume workshop at Barfield Station near Banana in September 2019.

The workshop participants manage 1,456,000 ha of land, which is 1.2% of Queensland's grazed lands (improved and native pastures) (ABS 2019-20 Agricultural Commodities data) with 588,000ha of sown pastures. Workshop participants run 279,000 head of cattle, which is approximately 5.2% of the herd in the Brigalow Belt bioregion and 2.7% of Queensland's beef herd (ABS 2019-20 Agricultural Commodities data); and 22,000 head of other livestock.

Figure 10: Location of extension events in the Brigalow Belt bioregion of southern and central Queensland delivered during the project.

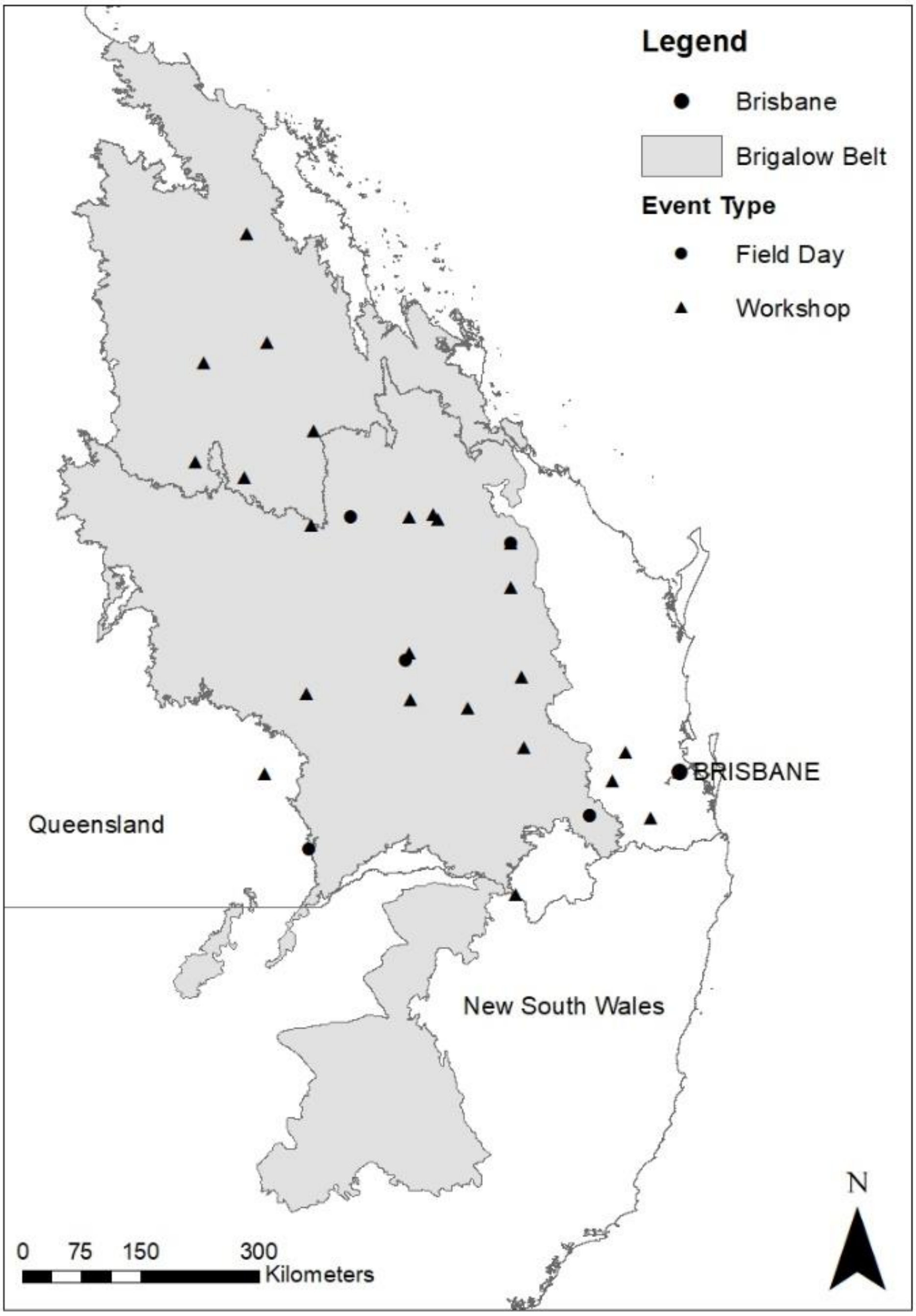


Table 14: Summary of workshop date, location, attendees, evaluation survey responses, legume management action plans and evaluation surveys.

Workshop Date	Workshop Location	Participants Attended				Businesses Attended [A]	Evaluation Survey Responses	Legume MAPs Captured	End-of-project Phone Survey Responses
		Total	Agribusiness	Grazier	Landcare/ Govt				
31-Oct-17	Moura	18	2	14	2	14	13	8	6
1-Nov-17	Springsure	10	2	8	0	8	9	7	4
2-Nov-17	Blackwater	9	4	3	2	7	4	2	2
8-Nov-17	Roma	12	2	10	0	10	9	5	4
9-Nov-17	Wandoan	23	1	21	1	20	17	12	5
14-Nov-17	Dalby	16	2	11	3	13	12	7	6
15-Nov-17	Durong	25	2	20	3	16	19	11	7
16-Nov-17	Eidsvold	14	0	14	0	11	10	9	7
6-Mar-18	Drillham	25	0	25	0	23	19	9	9
21-Jun-18	Monto	16	3	13	0	15	16	8	4
11-Sep-18	Dysart	8	1	5	2	7	8	6	2
12-Sep-18	Glenden	17	0	15	2	16	14	5	5
18-Sep-18	Texas	19	1	16	2	17	12	3	4
15-Nov-18	Chinchilla	24	1	21	2	22	22	9	7
1-Apr-19	Arcadia Valley	21	0	21	0	10	16	9	5
3-Apr-19	Clermont	20	0	20	0	15	16	4	6
4-Apr-19	Lochington	16	0	15	1	10	10	4	3
25-Jul-19	Banana-Gibson	19	1	17	1	15	16	11	9
3-Sep-19	Banana-Barfield	23	3	20	0	17	16	7	6
14-Nov-19	Begonia	11	0	11	0	7	9	7	3
18-May-21	Esk	28	1	24	3	20	16	4	0
19-May-21	Gatton	21	0	16	5	15	15	7	0
20-May-21	Boonah	17	0	13	4	9	13	1	0
TOTALS	**23**	**412**	**25**	**355**	**32**	**317** [B]	**311**	**155**	**104** [C]

A: Some businesses, especially agribusinesses, attended multiple workshops.
B: 226 grazier businesses in total.
C: Grazier business survey responses during end-of-project adoption evaluation phone surveys (completed March 2022).

4.2.1.2 Soil test meetings

Following the legume workshops held in Monto and Texas in 2018, the project team supported the collection and testing of soil samples from paddocks of 13 graziers who were interested in sowing pasture legumes. Soil samples were collected in November 2018. When the laboratory results were returned, the project team gathered the producers together again in two workshop groups to discuss the results and provide recommendations for each individual. This activity was conducted with the support of a Toowoomba Incitec Pivot agronomist, and the Nutrient Advantage laboratory in Victoria.

In Texas, seven grazier businesses participated in the soil tests. The follow-up meeting was held in December 2018, with seven producers (from five businesses). Key learnings for this group were:

- ‘How saline our soils are’
- ‘How many similarities there are across the paddocks sampled (in the region)’
- ‘Importance of soil testing, and complexities’
- ‘Importance of professional interpretation’
- ‘Great starting point for planning’.

Out of the Monto workshop, six grazier businesses participated in soil testing. The follow-up meeting was held in June 2019 with four of the producers. The group reported that their key learnings were:

- ‘Information about optimal ranges for the soil results’
- ‘Talking through the results’
- ‘Going through all the results together’ (to get an idea about what other paddocks are like)
- ‘An appreciation for the range of soil types tested and discussed’.

4.2.2 Industry engagement: Field days

Six field days with 164 participants were held during this project focussing on visiting recently sown or well-established examples of pasture legumes. The number of participants at each event and event description are described in Table 15 below. The first field day held at the legume persistence trial at Spring Creek in May 2018 is shown in Figure 11.

Figure 11: A field day at the legume persistence trial at Spring Creek on the Darling Downs in May 2018 with local graziers.

Table 15: Field Day locations and attendees during the project.

Field Day Date	Field Day Location	Field day purpose	No. Attendees
24-Apr-18	Bauhinia	Results from grass and legume varieties and establishment trials in the district.	52
17-May-18	Spring Creek #1	Results from the Legume BMP Legume Persistence trial after 1 year	24
30-May-18	Monto	Visits to a number of commercially sown legume-grass paddocks	20
20-Sep-18	Nindigully	Demonstration of pasture establishment techniques and options in SW Qld	20
3-May-19	Spring Creek #2	Results from the Legume BMP Legume Persistence trial after 2 years	28
14-Jun-19	Wandoan	Results from a Legume BMP detailed OFR fallow trial and visits to commercial paddocks of leucaena, stylos and desmanthus, in partnership with the Leucaena Network	40
TOTALS	**6 Field Days**		**164**

4.2.3 On-farm trials

During this project 118 on-farm trials were initiated, including 105 on-farm trials and 13 detailed on-farm trials.

4.2.3.1 Description of on-farm trials initiated

During the course of this project, 105 on-farm trials (OFTs) were initiated, predominantly with graziers who attended the legume workshops or field days. The OFTs varied in progress, success and type of trial or demonstration. Table 16 outlines the type of OFTs that were initiated and how many, over the project.

Table 16: On-farm trial types initiated as a result of this project

OFT type	No. Initiated
Legume varieties (including seed supplied at workshops)	61
Plant and soil nutrition	22
Establishment method	8
Fallowing	3
Rhizobia	2
Undetermined at the time	9
Total number of sites	**105**

4.2.3.2 On-farm trial results

Provision of technical support, small amounts of seed and soil testing encouraged graziers to conduct trials on their property. Significant contributions towards successful OFT activities initiated include:

1. Soil testing with 13 producers. The project team partnered with Incitec Pivot in 2018 to test nutrient levels in soil samples, present results and develop recommendations for preparing to sow pasture legume pastures.
2. Legume (or grass) seed samples. Small bags (200 – 500g) of legume or grass seed samples were supplied to 53 producers to trial in their paddocks, at the end of 7 workshops (Chinchilla, Lochington, Arcadia Valley, Clermont, Begonia and both Banana workshops).

During the end-of-project survey in early 2022, 104 workshop participants were asked about OFT activities undertaken and any results observed, including asking participants involved in the two activities mentioned above. From these respondents, 50 OFTs were recorded as having been completed and were located across the project area. The majority of respondents did a legume variety trial (60%) – most of them sowing the legume seed provided at the workshops. A further 16% tested different legume establishment methods, and 20% tested or added soil nutrients (Table 17).

Table 17: On-farm trial types reported by respondents in the end-of-project survey.

Trial type	Responses
Legume varieties	60%
Soil and plant nutrition	20%
Establishment method	16%
Unspecified	4%
Total OFTs	**50**

Results varied as there were many different types of trials, varying degrees of precision, undertaken at different times of the year and seasonal conditions (e.g. drought). A quarter of respondents (24%)

reported that their on-farm trial provided information, and a further 6% said that the trial supported decisions such as which variety to sow in commercial-scale paddocks. Some (14%) reported that their trial established well, some (22%) reported that selected species (or treatments) worked well while others were poor, and others (16%) reported that they had a failed establishment (Table 18).

Table 18: On-farm trial results summarised from the end-of-project survey.

Results	Reponses
Trial provided information	24%
Some treatments good; others poor	22%
Failed establishment	16%
Legumes established well	14%
Trial supported decisions	6%
Seasonal limitations affected trial	2%
No progress	2%
Unspecified	14%
Total OFTs	**50**

4.2.4 Detailed on-farm trials

Thirteen detailed on-farm trials were initiated during the project, but some were discontinued resulting in nine progressing. Measured and/or observational data was collected during the project period. All trials will continue as legacy activities for the cooperating producers.

A summary of the trials underway is listed below (Table 19). Further details including photos and results about each trial are found in Appendix 2.

Table 19: Summary of detailed on-farm trials

ID	Progress	Location	Trial Type	Trial overview	Progress / What happened…
D1	Measurements + Progressing	Wandoan	Fertiliser	Impact of legume compared to nitrogen fertiliser on grass growth. Treatments: with and without N, with and without P, with and without Caatinga stylo. All treatments sown with Gatton panic (responsive to N fertiliser).	Initiated August 2017, sown February 2018. Data collected over three seasons. Caatinga stylo has established with sufficient plant density in the two treatments it was sown. Gatton panic did not establish adequately. Strong weed competition and drought contributed to the background grasses (buffel and Queensland bluegrass) re-establishing instead of the sown Gatton panic.
D2	Measurements + Progressing	Moura	Establishment method, varieties, fertiliser	Seed-bed preparation, fallow, legume variety and nutrition trial. Desmanthus and Caatinga stylo with and without fertiliser (N, P, S and Zn fertiliser blend).	Initiated September 2017, sown February 2018. Data collected in three seasons. Caatinga stylo has established well, especially in the treatments where a spray or spray then cultivate fallow was used. Desmanthus has not established well. The fertiliser blend treatment appears to have been detrimental to legume production.
D3	Measurements + Progressing	Wandoan	Establishment method, varieties, fertiliser	Planting legumes into grass pastures using long, medium and short fallow times.	Initiated February 2018, sown December 2018. Data collected in two seasons. The Caatinga stylo has had a very poor establishment, regardless of treatment, however the desmanthus has established – some treatments with good plant numbers. The difference between treatments were inconclusive as the first year of establishment was very dry.
D5	Measurements + Progressing	Wandoan	Establishment method	Establishing desmanthus into an existing pasture by feeding seed to stock through lick.	Initiated in August 2018. Data was collected over four seasons. Desmanthus has established across the paddock, but in low numbers and mainly in bare areas owing to the competitive existing grass (buffel grass).

ID	Progress	Location	Trial Type	Trial overview	Progress / What happened…
D6	Progressing	Bauhinia	Fertiliser	Fertiliser applied to existing legume-grass pasture. 7 different treatments including P rates of 0 kg/ha, 20 kg/ha and 40 kg/ha (one treatment with added K & S), each drilled and broadcast.	Initiated in early summer 2018 into an existing legume-grass pasture. Observations were made over three seasons. There was no visual difference between the treatments due to drought and moderate soil P levels.
D9	Measurements + Progressing	Durong	Establishment method, varieties, fertiliser	Grass-only pasture planted with legumes in strips, fertilisers applied across both grass and legume strips	Initiated in March 2018. Data was collected over one season. No visible difference between the fertiliser treatments. No lucerne plants were found, but a small population of Caatinga stylo and desmanthus were measure across the paddock.
D10	Progressing	Wandoan	Fertiliser	Testing either fertiliser blends or application methods on existing grass-legume pastures on low phosphorus soils.	Initiated in August 2018. Site data was collected in 2018 and 2021, but no treatments have been put in place. Drought and obligations elsewhere have resulted in this trial not getting underway during the project timeframe. The landholder is still interested, and it is expected the trial will go ahead.
D11	Progressing	Alpha	Legume varieties	Tropical legume variety trial sown into prepared paddock with a long fallow. This trial is at the western (drier) extremity of the Brigalow belt.	Initiated in April 2019. Observations have been made over three seasons. All five varieties established and went to seed. In the third summer, Progardes desmanthus and Caatinga stylo have persisted, while the others have disappeared.
D12	Measurements + Progressing	Theodore	Establishment method	Rate of spread trial testing the rate at which legumes established in strips spreads into the surrounding, buffel grass pasture. 3 legume varieties sown.	Sown in January 2015. Data has been collected over five seasons. All three legume varieties continue to spread in low numbers beyond the strips up to 3 m from where they were sown.

4.2.5 Extension products

Case studies, factsheets, web pages and media have all been produced during this project to promote recommended practices for successful and reliable legume establishment. A summary of the extension products delivered during this project is described in this section.

Four case studies have been produced with producers from across the Brigalow Belt, covering the topics in Table 20. The case studies have been published online on the FutureBeef website.

Table 20: Case studies produced - topics, locations and online access

Title	Summary of content	Online access
'Pasture legumes form the basis for beef production'	Decades of experience with pasture improvement, including leucaena, desmanthus, stylos and more. Theodore, Queensland	Available online via FutureBeef: https://futurebeef.com.au/resources/pasture-legumes-form-the-basis-for-beef-production/
'Desmanthus and leucaena strips: spread and persistence at Dulacca'	Long-term persistence of two legume species and natural spread of desmanthus sown at Dulacca, Queensland.	Available online via FutureBeef: https://futurebeef.com.au/resources/desmanthus-and-leucaena-strips-spread-and-persistence-at-dulacca/
'Challenges of establishing legumes into buffel grass using faecal seeding'	An overview of a faecal seeding on-farm trial (detailed on-farm trial D5). Wandoan, Queensland.	Available online via FutureBeef: https://futurebeef.com.au/resources/faecal-seeding-legumes/
'Production benefits of legumes: Desmanthus in a grazing trial at Wandoan'	Grazing productivity on a long-term desmanthus and grass pasture compared to a grass only pasture north of Wandoan, Queensland.	Available online via FutureBeef: https://futurebeef.com.au/resources/beef-production-benefits-of-legumes-at-wandoan/

Two factsheets have been produced and published on the subjects of: 1. '*How to identify and manage stylos',* and 2. '*How to conduct and interpret tissue testing in leucaena to make fertiliser decisions*' (Table 21). The publications were written by the project team and are published online on the FutureBeef website.

Table 21: Factsheets produced during the project - topic, overview and online access

Title	Summary of content	Online access
'Stylos in Queensland: an identification and suitability guide for graziers and advisers'	An identification and management guide on the stylo species in Queensland	Available in print for distribution through DAF, and online via FutureBeef: https://futurebeef.com.au/resources/stylos-in-queensland-an-identification-and-suitability-guide-for-graziers-and-advisers/
'Plant nutrient analysis in established leucaena'	A how-to guide to sampling and testing leaf tissue in leucaena to guide fertiliser decisions	Available in print for distribution through DAF, and online via FutureBeef: https://futurebeef.com.au/resources/plant-nutrient-analysis-in-established-leucaena/

Additional online content was published early in the project, with stories on the FutureBeef website and one story in the Nutrient Advantage newsletter. The content was mostly project updates and news, but also included a 'how-to' webinar. Details shown in Table 22.

Table 22: Additional web content developed during the project

Title	Summary of content	Online access
'Phosphorus deficient in Brigalow soils'	Web story posted to Nutrient Advantage newsletter	Published 27 August 2018 https://www.nutrientadvantage.com.au/about/latest-news/phosphorus-deficient-in-brigalow-soils
'Moisture storage vital for reliable pasture establishment during a dry year'	Web story posted to FutureBeef	Published 29 March 2019 https://futurebeef.com.au/moisture-storage-pasture-establishment/
'Ideal conditions to test tropical legumes at Allora'	Web story posted to FutureBeef	Published 29 May 2019 https://futurebeef.com.au/ideal-conditions-to-test-tropical-legume-varieties-at-allora/
'Pasture legume establishment information in high demand'	Web story posted to FutureBeef	Published 31 July 2019 https://futurebeef.com.au/pasture-legume-establishment-information-in-high-demand/
'How to reliably establish leucaena'	Webinar held 11 September 2019, with more than 50 attendees	Published online on 17 September 2019 https://futurebeef.com.au/knowledge-centre/how-to-reliably-establish-leucaena/

Research results have been shared with beef and pastures research peers at five conferences and further research material will be presented at a conference postponed and planned for late 2022 (Table 23).

Table 23: Conferences papers by project team members during 2017 - 2022

Conference	Date	Title
International Leucaena Conference, Brisbane	October 2018	1. 'Establishment of leucaena in Australia' 2. 'Adoption, profitability and future of leucaena feeding systems in Australia'
Australian Grassland Association Conference, Launceston	February 2019	1. 'Legumes and phosphorus fertiliser could dramatically improve productivity and returns from sown pastures in the Brigalow Belt bio-region of Queensland'
North Australian Beef Research Update Conference, Brisbane	August 2019	1. 'Legumes preferred by graziers in the Brigalow Belt' 2. 'Grazier practice change on legume pasture establishment and management' 3. 'Phosphorus and zinc fertilisation on the first season growth of three annual medic cultivars'
Australian Fertiliser Industry Conference, Gold Coast	September 2019	1. 'Fertilized legumes significantly improve productivity and returns from pastures in the Brigalow Belt'
International Tropical Agriculture 'TropAg' Conference, Brisbane	November 2019	1. 'Phosphorus in northern Australian soils supporting pastures or grain cropping'
Australian Agronomy Conference, Toowoomba	September 2022 *(postponed from 2021)*	1. 'Field tolerance to pasture dieback of 26 tropical grass varieties sown into an affected paddock' 2. 'Experimental stylo accessions produce higher yields than commercial pasture legume varieties on light textured soils in southern Queensland' 3. 'Adoption of better agronomic practices for improving establishment of pasture legumes in the sub-tropics' 4. 'Impact of phosphorus fertiliser on tropical pasture legume production'

4.3 Extension outcomes (knowledge, skills, adoption)

Changes in knowledge, attitudes, skills, aspirations and practice change were evaluated from the 23 legume workshops held during this project.

4.3.1 Knowledge and skills

Improvement in knowledge and skills was quantified in an end-of-workshop evaluation survey. Overall, participants from all 23 legume workshops reported that knowledge and skills of the participants was increased after participating in the workshop, with a score of 4.2 out of 5 – a 'Good' improvement (Table 24).

Table 24: Workshop participant ratings for how well the workshop helped to improve their knowledge, skills and ability to establish and manage legumes in sown pastures (1 = very poor, 5 = very good) (n = 311).

	Question asked	Average response
Improvement in knowledge	The cause of pasture rundown	4.1
	The importance of N supply to pasture productivity	4.5
	How legumes supply N to the pasture	4.5
	Benefits of legumes to my production system	4.5
	Which legumes are best adapted to my property	4.0
	Which grasses are best adapted for my property (SEQ only)	3.6
	How much legume is needed to improve productivity	4.3
	Why it's critical to store soil moisture prior to planting	4.6
	The benefit of applying phosphorous to legumes	4.5
	Which techniques improve reliability of legume establishment	4.4
	The costs/benefits of different legume establishment techniques	4.0
Improvement in skills and ability	Assess the need for legumes in my sown pastures	4.2
	Ability to assess the amount of legume in my pastures	4.0
	Develop an overall strategy to reliably establish legumes	4.3
	Identify the options that are best suited to my situation	4.0
	Increase the productivity of my pastures	4.3
	Increase the sustainability of my pastures	4.3
	Increase the profitability of my pastures	4.2
Overall participant rating		**4.2**

Participants described a range of key learnings from the workshop. Participants' key learnings from the workshop was an open-ended question with responses grouped by the project team. The most common key learning was 'Improved legume establishment techniques', other key learnings are described in Table 25.

Table 25: Workshop participants' key learnings (n=311).

Key learning	No. responses
Improved legume establishment techniques	23.5%
Legume selection	10.9%
Legume management	10.6%
Importance of nitrogen to pasture	9.6%
Importance of soil nutrients include P	7.7%
Importance of soil moisture	6.4%
Grass: Legume balance	6.1%
Need for rhizobium/difficulties with rhizobium	4.5%
Value of seedbed prep	2.3%
Difficulties/benefits of legume-pastures	1.9%
Coated seed/uncoated seed	1.6%
Importance of grazing management	1.6%
Spreading legumes through lick	0.3%
No answer	12.9%
Total no. responses	**311**

4.3.2 Adoption and practice change

From the evaluation surveys completed at the end of each workshop, most (85%, n=255) workshop participants indicated they intended to make a practice change of some description to their business or property. Two thirds of workshop participants (n = 210) specifically indicated they intend to make changes to how they establish legume pastures, described in detail in Table 26.

Table 26: Participants' intended practice change when establishing legumes (n=189).

Intended practice change in establishing legumes	No. responses
Seedbed preparation, weed control, fallowing	29.1%
Improved planting techniques	14.3%
Improved general practices	14.3%
Use strips	11.6%
Change species / varieties	9.0%
No change	5.8%
Soil testing / nutrient application	5.3%
Use rhizobium more effectively	3.7%
Improved grazing management	1.6%
Distribute legume through lick	0.5%
No answer	4.8%
Total no. responses	**189**

At the end of the 23 workshops held between 2017 – 2021, participants indicated they intend to sow a total of 17,083 ha to legumes within the next 12 months (of attending their workshop) and 106,100 ha within the next 5 years (Table 27). Compared to the total area of pastures managed by participants (sown plus native pastures 1,456,000 ha) this represents 1.2% of their land in 12 months and 7.3% over 5 years. The intended area to be sown to legumes represents approximately 2.9% of their existing sown pastures area (588,000 ha) in 12 months and 18% over 5 years. These intentions have been hindered by the extended drought across the project area.

The project impact evaluation survey was conducted at the end of the project in early 2022. The project team contacted 176 of the 226 grazier businesses with 104 responding (59% response rate), providing an insight into on-ground adoption of pasture legumes since attending the workshops. Seventy-six (73% of survey respondents) reported that they had sown legumes since attending the workshop.

The 'adoption' data from the 2022 survey was compared to 'intended change' from the end-of-workshop evaluation surveys and presented in Table 27. The data shows the number of hectares sown as at 2022 (19,682 ha) was more than what was expected for the 12-month period (17,083 ha) from the workshop. Only half as many people provided information in the 2022 survey compared to the end-of-workshop surveys, and one of the driest years on record fell during that timeframe, which reportedly delayed many people from sowing paddocks.

At the workshop, the average area of land intended to be sown in the next 12 months was 83 ha per person, and 533 ha per person in 5 years. In the 2022 end-of-project survey, participants reported 258 ha per business has been sown and a further 617 ha per business is intended to be sown over the following 5 years. It has been estimated that the total number of hectares sown to date and influenced by this project was 42,600 ha (based on 19,600 ha sown by 76 businesses representing 226 grazier businesses who attended, and a 73% adoption rate). The intended area of land to be sown in the next 5 years is predicted to be 111,200 ha (based on 51,200 ha to be sown by 83 businesses representing 226 grazier businesses who attended, and an 80% intended adoption rate). Combining those estimated areas, a total of more than 153,800ha is assumed to have been sown or will be sown between 2017 and 2026 (5 years from now, 9 years in total). These figures are summarised in Table 27.

Table 27: Practice change intentions compared to adoption and future intentions.

Detail	Intended Change [A]		Adoption [B]		Future Intended Change [B]	
Hectares of legumes	17,083 ha	Next 12 mths	19,682 ha	Between 2017 - 2022	51,209 ha	Next 5 years
	106,100 ha	Next 5 years				
	83 ha	Avg. per person 12 mths	258 ha	Avg. per business	617 ha	Avg. per business 5 years
	533 ha	Avg. per person 5 years				
		N/A	42,600 ha	Estimated [C]	111,200 ha	Estimated next 5 years [C]
Most common legume species [D]	40%	Desmanthus	30%	Desmanthus	39%	Desmanthus
	26%	Caatinga stylo	20%	Shrubby stylo	16%	Leucaena
	9%	Leucaena	9%	Caatinga stylo	14%	Shrubby stylo
	4%	Butterfly pea, lucerne and medics (each 4%)	8%	Butterfly pea	8%	Caatinga stylo
			7%	Wynn cassia	7%	Butterfly pea
Soil type selection	69%	Clay	50%	Clay	51%	Clay
	24%	Loam	38%	Loam	35%	Loam
	7%	Sand	12%	Sand	14%	Sand
Fallowing practices [E]	41%	Long (9-12m)	24%	Long (9-12m)	22%	Long (9-12m)
	41%	Medium (4-8mth)	11%	Medium (4-8mth)	17%	Medium (4-8mth)
	17%	Short/none	20%	Short	22%	Short
		N/A	45%	No fallow	39%	No fallow
Fertiliser practices [E]	94% [F]	Use fertiliser	26%	Used fertiliser	24%	Use fertiliser
Rhizobia practices [E]	69% [F]	Add rhizobia	12%	Added rhizobia	14%	Add rhizobia
Sowing methods [E]	51%	Drilled	41%	Drilled	54%	Drilled
	49%	Broadcast	59%	Broadcast	46%	Broadcast
Management of existing legume-grass pastures	46%	Change management	43%	Changed management		N/A

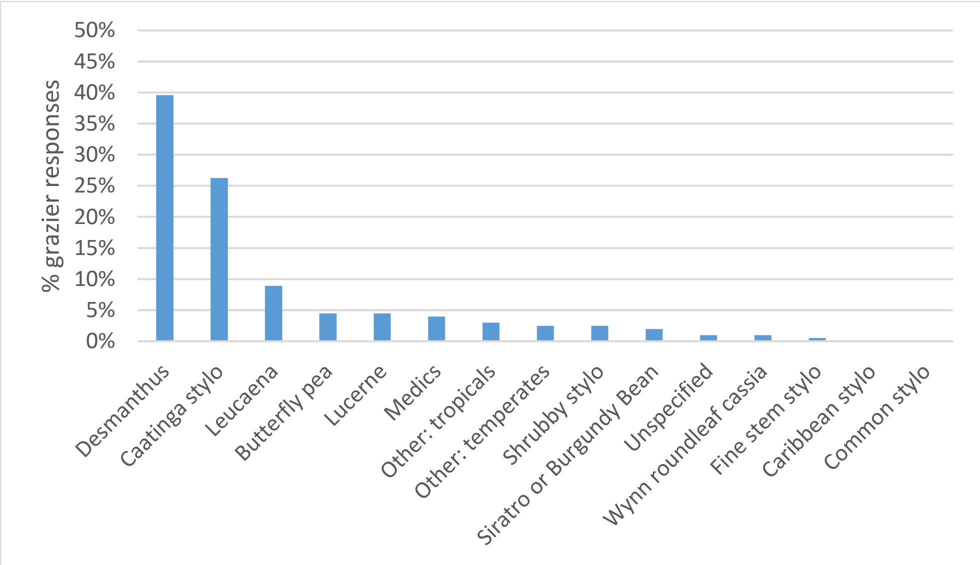
A: Data collected from 311 end-of-workshop evaluation surveys (from 412 workshop participants), and 155 legume management action plans from the workshops (2017 – 2021)
B: Data collected from end-of-project evaluation surveys (2022). 226 grazier businesses, 104 survey responses.
C: Data from the end-of-project survey. 'Adoption' based on area sown by respondents representing 226 grazier businesses with a 73% adoption rate. 'Future Intended Change' based on area to be sown by respondents with an 80% intended adoption rate.
D: Legumes were described as being either sown alone or as part of a blend. The % figure describes number of paddocks sown with the legume listed.
E: Data from surveys who described 'How'.
F: Any consideration given to either rate, type or how to apply, counted as an intention to use fertiliser or rhizobia.

4.3.2.1 Legume species sown by graziers

Information was collected about which legume species graziers preferred during the workshop and in the end of project survey (some species highlighted in Table 27). The Legume Management Action Plans developed during the workshop indicated what legume graziers intended to use in the next paddock they sow with legumes. The end of project survey asked what legume species they had sown since attending the workshop and what they intend to sow over the next five years.

Figure 12 shows the most common to least common legumes preferred by workshop participants as reported on their Legume Action Plan during the workshop. Desmanthus was the most popular species that graziers intended to sow, followed by Caatinga stylo. Many graziers intended to sow desmanthus and Caatinga stylo together. Leucaena and butterfly pea were less popular preferences, with less than 10% of participants planning to sow either of those two legumes. Most of the research trials discussed during the workshop were about desmanthus and Caatinga stylo or had used these species as the example legume, which would have contributed to the interest at the end of the workshop.

Figure 12: Intended species to be sown, as recorded on workshop participant's Action Plans during the workshops (n=202).



The end-of-project evaluation survey conducted between January – March 2022 asked graziers which legume varieties were sown in paddocks since attending the workshop (Figure 13) and what they intend to sow in the next five years (Figure 14).

Figure 13: Legume species sown into paddocks by the workshop participants since attending the workshop, as reported during the end-of-project evaluation survey (n=161).

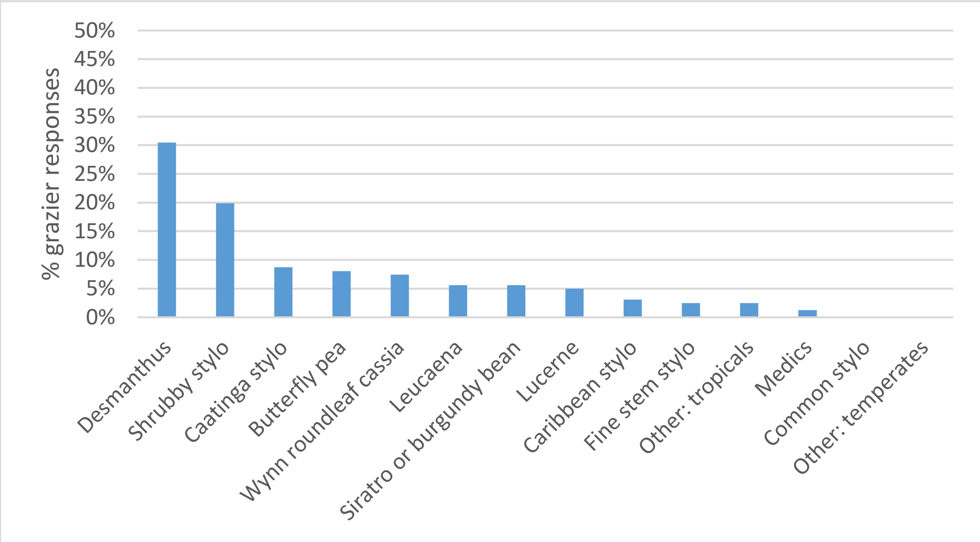
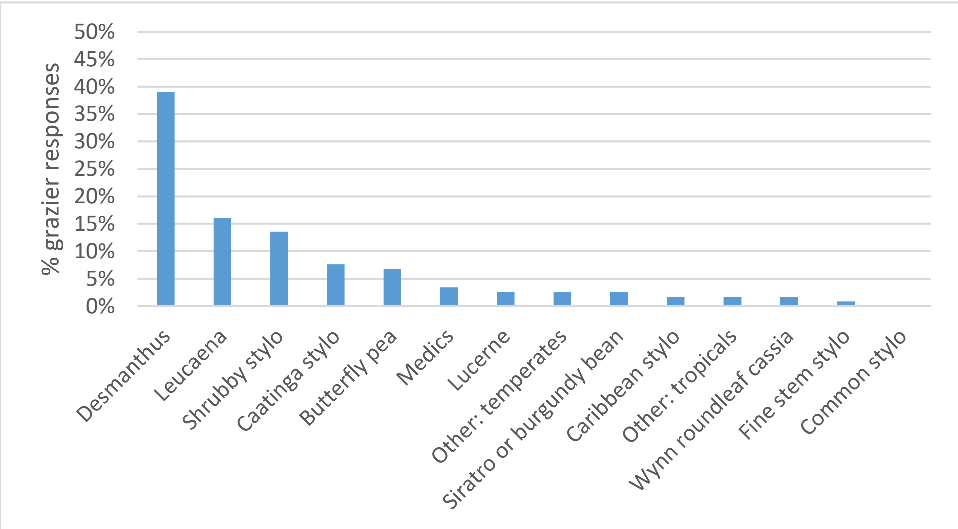


Figure 14: Legume species intended to be sown in paddocks in the next 5 years by the workshop participants, as reported in the end-of-project evaluation survey (n=118).



Desmanthus was the most popular species during the workshop (40%), in sowings since the workshop (30%) and intentions to sow over the next five years (39%). The current interest in desmanthus is a dramatic change in grazier interest over the last decade. Six focus group meetings with 41 graziers in 2010 demonstrated a different attitude to desmanthus (Peck *et al.* 2011). Graziers in only two of the six focus groups mentioned desmanthus. Of the graziers who had used desmanthus, the comments were that they had sown small paddocks or trial plantings with mixed results, and cv. Marc was persisting, but cvv. Bayamo and Uman were not persisting. The release of new varieties (Progardes) and rigorous marketing effort has had a dramatic impact on grazier interest. A representative of the seed company that sells Progardes was present at eight of the legume workshops during in this project, promoting their product during breaks which may also have contributed to graziers sowing desmanthus.

Caatinga stylo was the second most popular legume choice during workshops with 26% of graziers intending to sow it, but only 9% sowed it since the workshop and 8% intend to sow it in the future. Caatinga stylo is the other persistent legume species (along with desmanthus) that was released in the 1990s for the Brigalow Belt bioregion. Despite impressive results from Caatinga stylo in research trials (Peck *et al.* 2017a) few graziers had positive experiences with it in 2010 focus groups (Peck *et al.* 2011). Historically, the widespread adoption of Caatinga stylo has been hindered from a lack of concerted marketing effort, poor quality seed and unreliable seed supply. Caatinga stylo is widely adapted, persistent and productive; therefore the grazing industry would benefit from a committed extension and marketing effort to promote more widespread use of this promising legume species.

Shrubby stylo was the second most commonly sown legume since attending the workshop with 20% of graziers sowing it. Shrubby stylo has been commercially available since the 1970s and has been widely used by graziers in central and northern Queensland. Commercially available varieties of shrubby stylo are well adapted to light soils in the central Queensland part of the Brigalow Belt where 10 workshops were held.

Leucaena is the second most popular choice for future sowings of legumes with 16% of graziers intending to sow it, but only 6% of graziers had sown it since attending the workshop. Graziers routinely use good agronomy including long fallows to store soil moisture when sowing leucaena, the severe drought experienced during the Brigalow Belt bioregion in recent years would have contributed to less sowings since attending the workshop. Leucaena has been commercially available since the 1960s and there is lots of information about it, including a dedicated industry group (i.e. The Leucaena Network).

Other legume species were sown or intended to be sown by a lower percentage of graziers. **Butterfly pea** is adapted to clay soils in central Queensland and has been commonly sown in a limited geographic region. **Medics** are a useful legume in southern inland Queensland, but the climate is unsuitable in central Queensland. Adoption was low for some of the other legume species which are adapted to lighter soils; the workshop content encouraged participants to start with their paddocks with higher production potential which is generally higher clay content soils.

4.3.2.1.1 Intentions compared to adoption: species selection

There are similarities and differences between what species graziers intended to sow during the workshop and what they actually sowed. Desmanthus has consistently been the most preferred legume when planning and when sowing paddocks (Table 27). The other species fluctuate.

The DAF project team delivered information about legume selection and productivity during the workshops but are not the only source of information for graziers. It is likely that graziers' decisions on which legume to sow have been influenced by peers, seed companies and resellers. A survey of seed company employees conducted in 2010 provided examples where legume species were described poorly by seed company and farm supplies employees, especially if it was their competitor's product (Peck *et al.* 2011). For example, both desmanthus and Caatinga stylo were described as not being persistent, and Caatinga stylo was described as being a "dead duck" by companies that were not selling these species. The negative commentary from competing seed companies in preference to species they sell can result in poorly guided legume recommendations to graziers regardless of their suitability to the grazier's needs. Graziers need un-biased information to select the legume species and variety best suited to their paddock and grazing situation.

Seasonal conditions, soil types and other priorities also impact on the number of paddocks sown and the species selected. The preference for shrubby stylo suitable to lighter soils over leucaena suited to heavy soils is an indication of this.

4.3.2.2 Soils and paddock selection

The data suggests that people planned to and adopted the practice of sowing onto their 'better country' first to improve their returns. The soil type data in Table 27 suggests that participants are focussing on their clay and loam soil paddocks which are generally higher in nutrients and water-holding capacity and therefore able to grow more pasture.

4.3.2.3 Fallow adoption

Workshop participants indicated that they intended to use longer fallow periods than short or none, for a higher chance of storing moisture and having successful legume establishment. Medium (4-8 months) or long (9-12 months) fallows were planned by 82% of participants during the workshop. The adoption survey in 2022 indicated that most participants didn't follow through with their intention to use longer fallows and instead most (65%) opted for short or no fallow and plan to do the same in the future (Table 27). Research results have shown that short or no fallows result in establishment failure in most years when sown into existing buffel grass pastures in the Brigalow Belt climate zone (Peck *et al.* 2017b). Industry continues to use and recommend one-pass cultivation or no pasture disturbance despite decades of establishment failure in the Brigalow Belt. Continued extension effort including demonstration of improved practices is required to change this practice.

4.3.2.4 Rhizobia and Fertiliser adoption

The use of fertiliser and rhizobia when establishing new pastures dropped from good intentions (94% considered using fertiliser, and 69% considered adding rhizobia) to a quarter or less of participants using them in their paddocks (Table 27).

4.3.2.5 Sowing method

Methods of sowing were consistent between early intentions and on-ground adoption, with half intending to drill seed and half intending to broadcast (Table 27). The trend in the 2022 survey swayed more towards broadcasting (59%), but participants still seem interested in drilling seed again in future sowings (54%).

4.3.2.6 Management of existing legume pastures

From the workshop evaluation survey, less than half of all workshop participants (46%, n=144) indicated they intend to make changes to how they manage their existing legume-based pastures (Table 27). These changes include:

- Change grazing management
- Soil test and use fertiliser
- Add more legume
- Add rhizobium
- Use chemical.

When participants were asked in the 2022 end of project survey about managing existing pastures, 43% of respondents reported that they had made changes (Table 27). Most change was in grazing management practices, but a small number of respondents reported that they either applied fertiliser, some did soil tests or made other management changes. Most participants in the 2022 end-of-project evaluation survey who reported making no changes to pasture-legume management stated that they were already using sustainable management practices, and therefore did not see a need to make a change.

4.3.3 Barriers to adoption

4.3.3.1 Workshop participants

The 2022 end-of-project evaluation survey with 104 workshop participants reported 27% (n=28) had not sown legume pastures since attending the legume workshop. Drought and seasonal conditions were given as the most common reason for not sowing legume pastures for 35% (n=8). An additional 30% (n=7) explained that their focus had been elsewhere during the time since the workshop. Other reasons for not sowing included - already having sufficient legume pastures (22%, n=5); concern over finding a suitable species for their paddock; having access to suitable equipment; and lacking information (all 4% each, n=1).

In the end-of-project survey, only 16% of respondents (n=17) reported that they had no intention to sow more paddocks with legumes in the next five years. They reported that they were focussing elsewhere on their business; already had enough legumes; or were wanting to see results before sowing.

4.3.3.2 Broader grazing industry

All survey participants in 2022 were asked their opinions about why the broader grazing industry in Queensland has not widely adopted legumes. The responses varied but many suggested that having spare funds available to justify the cost involved would be the biggest (34%) barrier to adoption. Many suggested that climate, seasonal conditions and drought were considered a barrier to adoption with 31% of survey participants. There was also the perception that people who have tried establishing pasture legumes in the past may be discouraged to trying again (25%), especially if they have caused land degradation issues with establishment in the past (e.g. erosion) or had previous poor results. Information, knowledge and advice was the fourth most common barrier identified (22% of respondents) which suggests there is an on-going need for extension effort on legumes in the Brigalow Belt bioregion. A summary of the barriers to adoption is listed in Table 28.

Table 28: Barriers to adoption for the broader grazing industry in Queensland, reported from the 2022 end-of-project evaluation survey.

Barriers to adoption	% Survey Responses
Cost / money availability	34%
Climate / seasons / drought	31%
Establishment issues, or previous poor results	25%
Information / knowledge / advice	22%
Suitable legumes	18%
Lack of equipment or skilled contractors	15%
Mindset or attitude towards change	14%
Seed availability or quality	11%
Available land to spell or sow	8%
Time commitment required	7%
Advancing age of graziers	4%
Lack of registered herbicides & weed competition	4%
Grazing management of legume paddocks	3%
Lack of education on the benefits of legumes	2%
Focus elsewhere	2%
Need for more evidence (of successful paddocks etc)	2%
No barriers	2%
Pests	1%
Suitable grasses	1%
Total No. Survey Responses	**104**

4.3.4 Information required by graziers

Participants in the 2022 end-of-project survey were asked what information they thought would be relevant to the broader grazing industry in Queensland. This question was asked immediately after the ‘what are the barriers to adoption’ question in Section 4.3.3.

Practical information about establishment practices came up as the information most needed (37%) for pasture legume adoption. This includes information on planning, fertiliser, rhizobia and herbicide use. Legume selection or identification was the second most common information need with 30% of respondents identifying this as a need. Other information needs are shown in (Table 29). Conversely, 12% of survey respondents (n=12) believed that there was no need to create more information, and that there was sufficient information already available. Some commented that the information just needed to be adopted.

Table 29: Information content needed for the broader grazing industry in Queensland, reported from the 2022 end-of-project evaluation survey

Information needed	% Survey Responses
Establishment practices	37%
Legume selection, mixes or identification	30%
Independent information / advice	18%
Machinery options (and contractors)	16%
Information is already available	12%
Paddock selection	12%
Grass selection / mixes	11%
Demo sites or field days	5%
Soil test interpretation	5%
Economics	3%
Research results	3%
Benefits of legumes	1%
Ecology	1%
More research into legume establishment	1%
Total No. Survey Responses	**104**

4.3.5 Preferred delivery methods for information

As the survey respondents were asked about what information was needed, they were then asked which methods should be used to deliver that information to the grazing industry (Table 30). A review of extension in Australia identified five "methods" of extension that categorised the approaches across industries and programs (Coutts *et al.* 2005; Coutts *et al.* 2017). The five models of extension are: facilitated groups, technology development, training and group presentations, information provision and access, and one-on-one individual farm advisory. The preferred method of providing information described by graziers is grouped and discussed within the extension method groupings described by Coutts *et al.* (2017).

Table 30: Preferred methods for providing information on sown pastures to the grazing industry. Responses are grouped by extension method (Coutts *et al.* 2005).

Method of Extension	Requested methods for information	No. Responses	No. Responses (Grouped)	% Survey Respondents
One-on-one advice & coaching	Coaching / advisors / one-on-one	59	62	60%
	Seed companies	3		
Information provision and access	Web sites / online info	27	59	57%
	Factsheets	12		
	Books / booklets	11		
	Popular media	9		
Facilitated groups	Social media	5	10	10%
	Networks	5		
Technology Development	Field days	4	8	8%
	Demonstration sites	3		
	Apps	1		
Training and group presentation	Workshops	6	6	6%
Other programs^	Other	3	3	3%
^ = not one of Coutts' Methods		**148**	**responses**	
		104	**survey respondents**	

The preferred methods for providing information provided by graziers were "one-on-one advise and coaching" (60%) and "information access" (combined 57%).

Graziers preference for "**one-on-one individual farm advice**" extension method (Coutts *et al.* 2017) needs to be balanced against the cost and impact at the industry scale compared to other extension methods. Public sector investment in one-on-one extension support has reduced dramatically since the 1980s/1990s with few district agronomists and extension staff working on pastures remaining in the Brigalow Belt bioregion. Some of the individual advice role that had previously been provided by the public sector is provided by the private sector but for pastures has been largely sales oriented. Only 3% of respondents suggested seed companies as their preferred method for information delivery which probably reflects a lack of confidence in their advice. There are few independent consultants that are active in the Brigalow Belt that provide advice on sown pastures. Graziers have been reluctant to pay full costs for consultants to provide services and advice, for example the costs of soil sampling to depth and analysing for nutrient levels was discussed during workshops but many participants expressed opinions that it was too expensive to use a consultant. Another constraint to individual coaching is the large number of beef businesses in the Brigalow Belt bioregion. The Brigalow Belt has 4426 grazier businesses which is 44% of Queensland's beef businesses, therefore other extension approaches need to be used to engage a large enough percentage of graziers to have an impact on the broader beef industry. Follow up contact with workshop participants as part of a "training and group presentation" approach may meet some of the grazier's preference for individualised information without overwhelming extension staff.

A high percentage of graziers (57%) had a preference for "**information provision and access**" method of extension. The information provision and access methods listed by graziers included online/web-based material (26%), factsheets (12%), booklets (11%) and popular media (9%) (). An extension review conducted by this project reported that there is a need to update extension materials and improve public access for sown pastures in the Brigalow Belt bioregion. Improving access to information on legume management in the Brigalow Belt would help provide a balance to sales driven advise and recommendations from other climatic regions.

The workshops delivered by this project are an example of "**training and group presentations**" extension method (Coutts *et al.* 2017). Although 6% of graziers responding to the survey said they preferred workshops, 100% of respondents had attended a workshop on pasture legumes. Follow up contact with workshop participants as part of the overall training program to adapt, reinforce and support adoption of recommended practices to a grazier's individual circumstances as well as access to updated extension materials for further reading could enhance the outcomes from future training programs (Coutts *et al.* 2017).

Demonstration sites (4%) and field days (6%) are examples of a "**technology development**" approach to engaging with graziers (Coutts *et al.* 2017). The technology adoption method is mainly about testing or adapting research and practices that are used elsewhere into a local context or developing new technological solutions in a local, on-farm context that is visible and easily accessed (Coutts *et al.* 2017). A technology development approach is likely to be the most effective in improving adoption of some of the legume establishment recommendations from research trials (such as fallowing or establishing in strips) to paddock scale adoption using commercial scale equipment and methods.

"**Facilitated groups**" were discussed by a small number of graziers during the workshops. The preference for networks (4%) and social media (5%) from the end of project survey is likely to be an example of a facilitated group. Facilitated groups could have a role in future extension effort especially if linked to a "technology development" approach on topics such as improving adoption rates of better agronomic practices when establishing legumes.

4.4 Legume persistence in southern inland Queensland

The legume persistence trials sowed different legume varieties on loam soils and clay soils. Results are presented by soil type to reflect the different sowing lists and adaptation to different soils.

4.4.1 Desmanthus and stylo persistence on loam soils

Plant density of the legume varieties at the loam soil trials located near St George and Goondiwindi after three years post sowing is shown in Figure 15. Plant density over time is shown in Appendix 8.3.

Caatinga stylo and shrubby stylo have maintained high plant densities at the loam trial sites relative to the other species sown. Caatinga stylo (cvv. Primar and Unica) had the highest plant densities of the species sown. Shrubby stylo cv. Seca has high population density at both sites, however Siran has a low plant density at the St George trial. Oxley fine-stem stylo did not persist at either site.

Desmanthus has not maintained high plant densities at the loam trial sites. *Desmanthus virgatus* cvv. Cowpower and JCU2 have higher populations than other desmanthus species, however their plant density is low with small plants compared to Caatinga stylo. *D. pernambucanus* cv. JCU9 has a low plant density but with larger plants. *D. bicornutus* and *D. leptophyllus* have low plant densities. Early results indicate that *D. bicornutus* and *D. leptophyllus* are unlikely to persist on these soil types in this climate zone. The trial has not continued long enough to determine whether *D. virgatus and D. pernambucanus* varieties will persist in the long-term at these sites.

Figure 15: Legume plant density three years after sowing at loam soil trial sites in autumn 2021. A: Goondiwindi and B: St George trials. (*D.virg: D.virgatus; D.bico: D.bicornutus; D.lept: D.leptophyllus; D.pern: D.pernambucanus; S. seab: S. seabrana; S.scab: S.scabra; S. guia: S. guianensis var. intermedia; Cowp: Cowpower*).

4.4.2 Desmanthus and stylo persistence on clay soils

Plant density of the legume varieties at the clay soil trials located near Allora, St George and Goondiwindi is shown in Figure 16. Plant density over time is shown in Appendix 8.2.

All clay trial sites were on cracking clay soils (vertosols), however they all had individual characteristics that affected the legume persistence results. Allora Flat has had high death rates of adult plants during winter due to it being the coldest site with regular frosts. The Allora Hill site had very high grass competition which has reduced the population of all legume species. Goondiwindi has had limited grazing opportunities due to the surrounding paddock being converted to fodder cropping. The St George trial site was resown due to it being the driest location and most severely affected by the drought. The St George legumes were also affected by spray drift damage during establishment.

Results were also affected by seed quality impacts. Cultivars JCU2 and JCU4 were contaminated with other desmanthus varieties. A calculation error resulted in Marc being sown at a lower pure live seed sowing rate than other cultivars in the 2017/18 sowing. Marc had lower seeds per kilogram due to seed coating which was not adequately accounted for in seeding rate calculations. The resowing at St George for Marc (and all other varieties) was based on germinable seeds per kilogram of "product" in the bag. Marc has had seedling recruitment at all trial sites.

Caatinga stylo (*S. seabrana*) and *D. virgatus* varieties generally have the highest plant densities at the clay soil legume persistence trials (Figure 16).

Caatinga stylo cvv. Primar and Unica had higher populations compared to other varieties at all sites except for Allora Hill presumably due to grass competition. Unica had very high death rates during winter at the Allora Flat site. Primar and Unica had a low initial population at the Goondiwindi trial but it has subsequently had seedling recruitment which resulted in >13 plants/m^2 three years after sowing. Caatinga stylo has some of the highest plant densities after one year at St George.

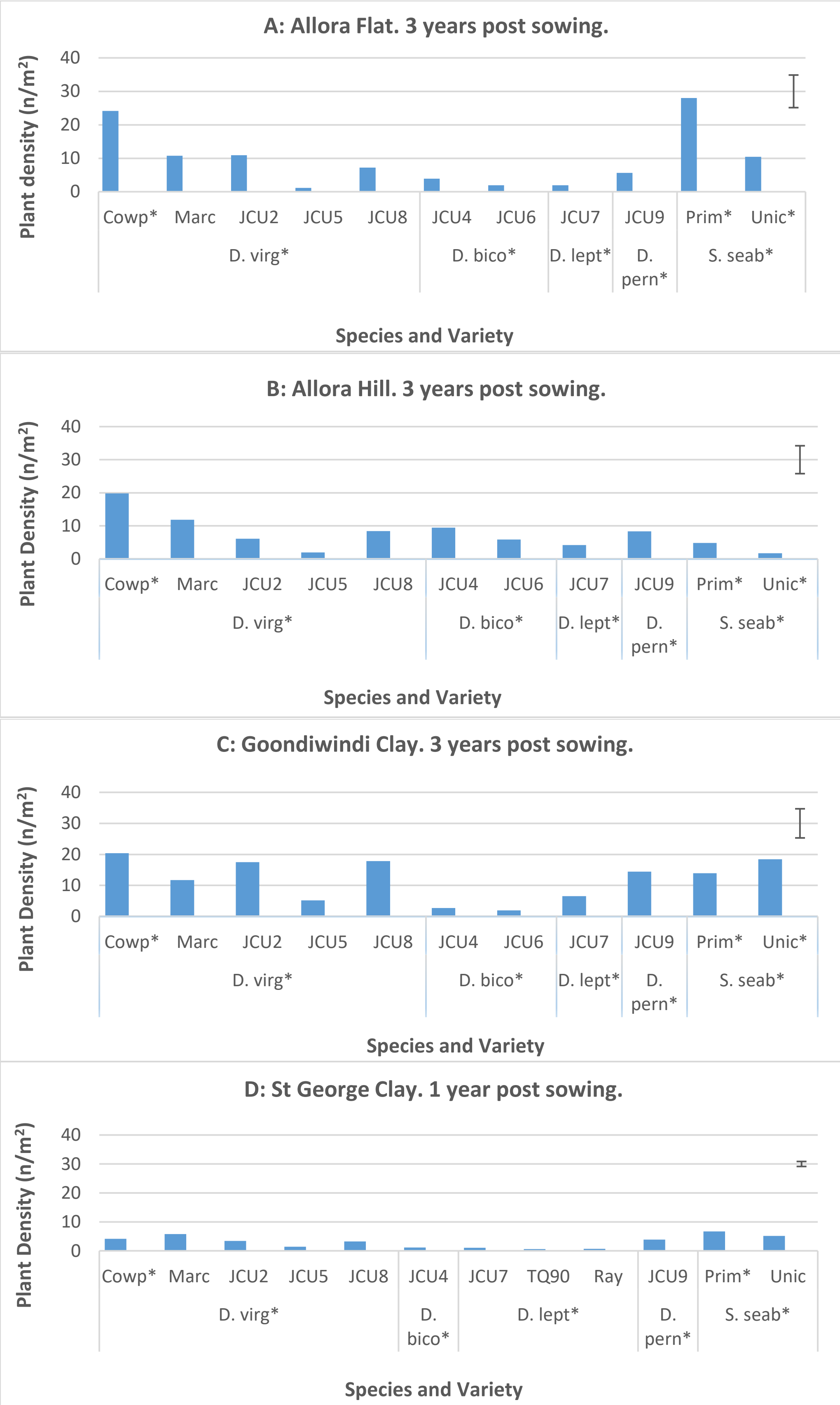
Desmanthus virgatus cvv. Cowpower, Marc, JCU2 and JCU8 have maintained high plant densities relative to other varieties at all trial sites. Cultivar JCU5 has lower plant densities at all trial sites.

The *D. bicornutus* and *D. leptophyllus* cultivars included in these trials have generally lower plant densities than *D. virgatus*. Cultivar JCU6 was observed to produce some flowers but no pods at the trials. Cultivar JCU7 flowered very late and was not observed to produce mature seeds before dry weather or frosts limited seed production. Cultivars JCU6 and JCU7 are unlikely to persist in the long term due to the very low seed production in southern inland districts. JCU4 seed was contaminated with a *D.virgatus* accession which affected the ability to assess its persistence at these trials. JCU4 has produced seed.

Two additional accessions of *D. leptophyllus* were included at the St George site when it was re-sown in 2020. Ray is a newly released variety, TQ90 is a promising accession shortlisted by previous evaluation projects conducted by DAF. There has only been one measurement of legume density at this site, therefore it is too soon to assess persistence of these two accessions.

D. pernambucanus cv. JCU9 grew exceptionally well at all sites in the first growing season after sowing. The population density has subsequently declined during dry years. The trials need to continue for a longer time period to assess the long-term persistence of JCU9.

Figure 16: Legume plant density at clay soil trial sites in autumn 2021. A: Allora Flat; B: Allora Hill; C: Goondiwindi clay; D: St George clay. (D.virg: D.virgatus; D.bico: D.bicornutus; D.lept: D.leptophyllus; D.pern: D.pernambucanus; S. seab: S. seabrana; Cowp: Cowpower; Prim: Primar; Unic: Unica).



4.4.3 Leucaena persistence in southern inland Queensland

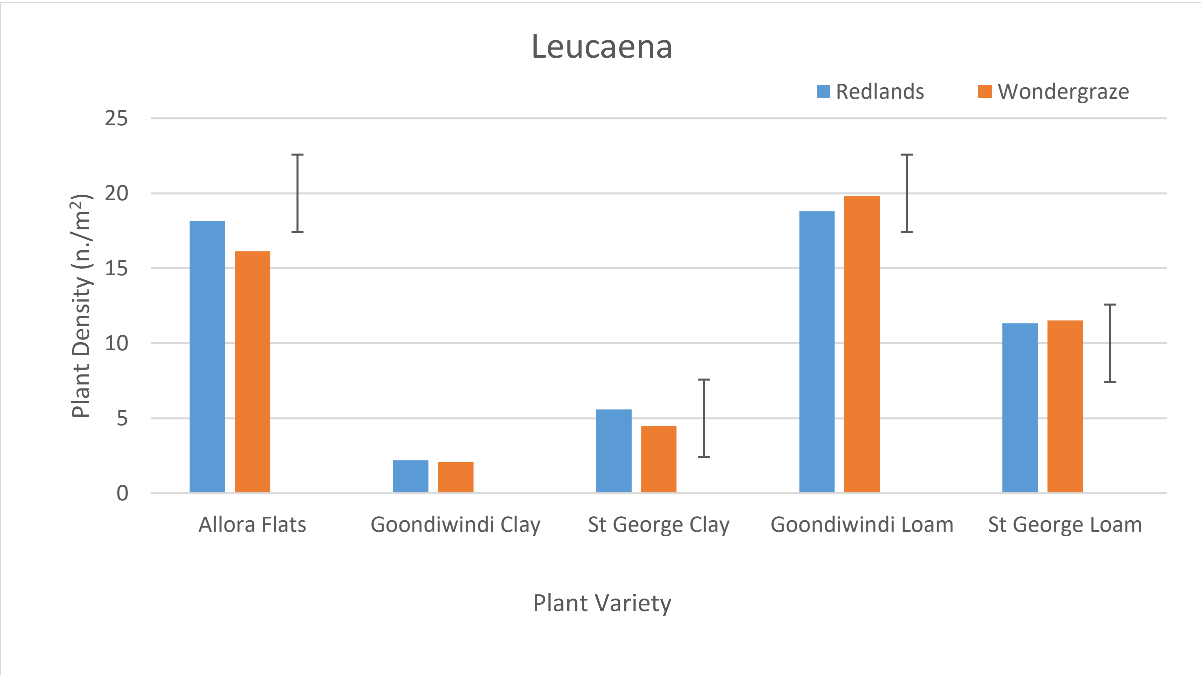
Initial establishment of Leucaena failed in 2017 at five out of six sites sown due to dry weather with inadequate stored moisture and follow up rain. Four of the trials were resown (Table 31). The Allora hill site was not resown because there is a commercial paddock of leucaena next to the trial site. Four out of the five trial sites with leucaena are only one year old, therefore it is too early to assess long-term persistence at these experiments.

Table 31: Leucaena persistence trial sowing and plant density recording dates.

Site	Date Sown	Date Recorded	Establishment Time (Years)
Allora Flat	17/11/2020	3/11/2021	1
Allora Hill	19/11/2020	Not re-sown	NA
Goondiwindi Loam	27/02/2020	08/03/2021	1
Goondiwindi Clay	12/02/2018	21/04/2022	4
St George Loam	27/02/2020	07/04/2021	1
St George Clay	21/02/2020	08/04/2021	1

Leucaena plant densities were similar for cultivars Redlands and Wondergraze at all trial sites (Figure 17). The Goondiwindi clay trial is the only site where leucaena has been established for more than one year. The leucaena plants are small and variable in size at the loam soil and St George clay trials which may inhibit its long-term persistence. Leucaena has produced much bigger plants at the Goondiwindi clay and Allora Flats trial sites. These trials need to continue for several more years before the long-term persistence of leucaena can be assessed.

Figure 17: Leucaena plant populations for cultivars Redlands and Wondergraze at five trials in southern inland Queensland. Goondiwindi clay was measured in April 2022 (4 years post sowing), all other sites were measured in autumn 2021 (1 year post sowing). (LSD bars: p = 0.05).



4.5 Phosphorus fertiliser

4.5.1 Goondiwindi trials discontinued

The Goondiwindi phosphorus trials were discontinued due to un-explained, patchy poor growth (Figure 18). Plants in affected patches were smaller or absent with some of the plants having lesions on the main taproot. Similar poor growing patches were observed in millet grown in 2018 in the adjacent temperate legumes trial.

Figure 18: Bare patches in the Goondiwindi phosphorus trial (plot with bare patch on the left, un-affected plot on right). The cause of these bare patches was not conclusively determined during the project.

The poor growing patches were investigated to try and determine what was causing the poor growth and plant death. These investigations were hampered by severe drought also causing damage to plants. A summary of results from these investigations is shown in Table 32 which suggested the most likely explanation is a pathogen.

Table 32: Results of investigations to determine the cause of poor growing patches of desmanthus.

Potential cause	Results
Herbicide residue	No residues detected.
Gilgai	Soil salinity and pH profiles were tested. No differences between affected and unaffected patches were detected.
Biological agent (pathogen)	No root lesion or root knot nematodes. Potential pathogen isolated, further sampling required when plants actively growing. (There was insufficient rain to produce plant growth for re-sampling before the trial was discontinued).
Drought	Poor patches did not align with micro-relief, they occurred in both shallow depressions where water accumulates during rainfall events and humps.

Both the temperate and tropical legume trials were discontinued due to the unexplained poor growing patches. The temperate trial was subsequently rehabilitated by sowing a tropical grass and legume pasture.

4.5.2 Wandoan tropical legumes

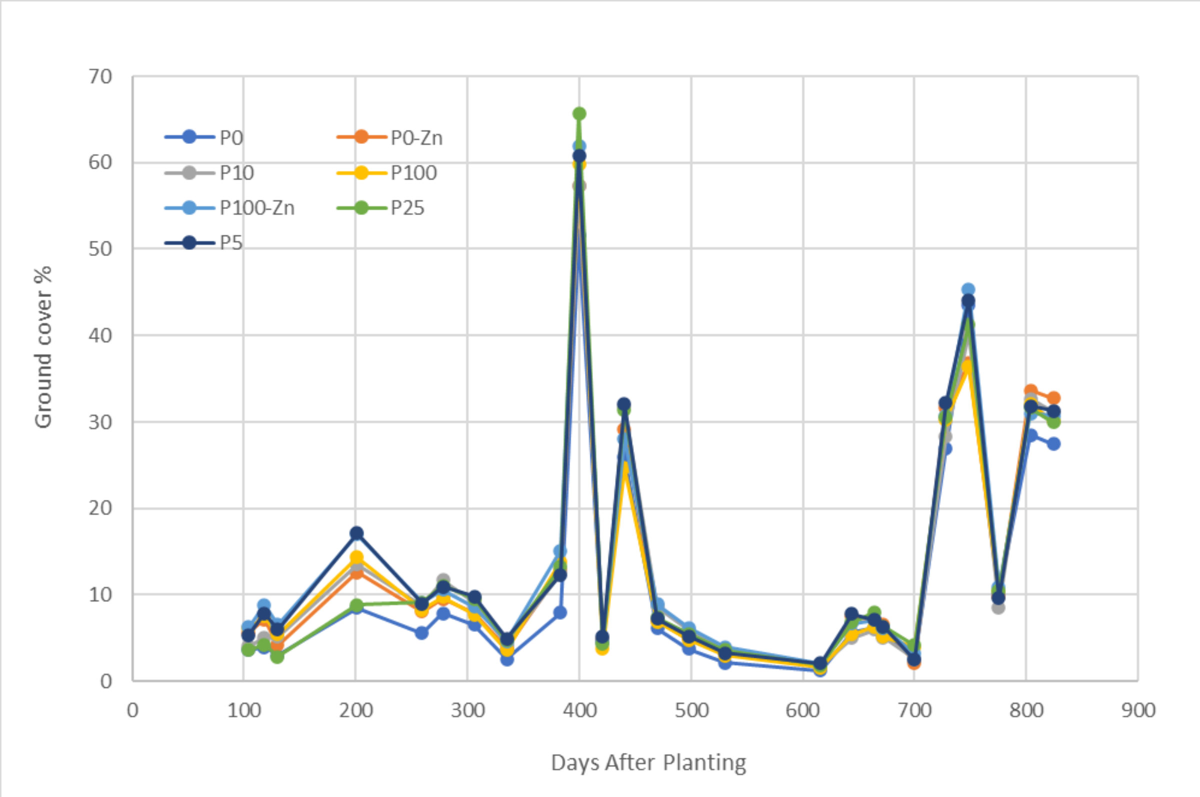
Sowing of this trial was delayed due to dry weather. This trial was not sown in the 2017/18 summer due to insufficient soil moisture being stored during the fallow. A cover crop of wheat (cv. Gregory) was sown in May 2018 and sprayed out in September to provide ground cover and reduce erosion risk. The legume seed was sown into the wheat stubble in mid-January 2019, however germinating rain did not occur until late in March. The late emergence of the legumes and low rainfall resulted in the legumes being too small to harvest in 2019. The tropical legumes were harvested for the first time in March 2020.

4.5.2.1 Ground Cover

Groundcover was used as a non-destructive measure of growth rate over time. Groundcover over time for the fertiliser rates are shown in Figure 19. The trial was sown on the 17th of January 2019, however germinating rain was not received until late March and the first groundcover measurements were taken in early May 2019. The 2019 calendar year was the driest on record for the Wandoan district which resulted in poor legume growth and very low ground cover until January 2020 (i.e. 365 days after sowing).

Groundcover has increased and decreased at similar rates over time regardless of P fertiliser rate Figure 19. These results suggest there was no increase in legume growth in response to applied phosphorus fertiliser.

Figure 19: Tropical legume ground cover at the Wandoan phosphorus trial to April 2021. Legume ground cover was averaged across the three legume species (Legend: -Zn, zinc not applied)

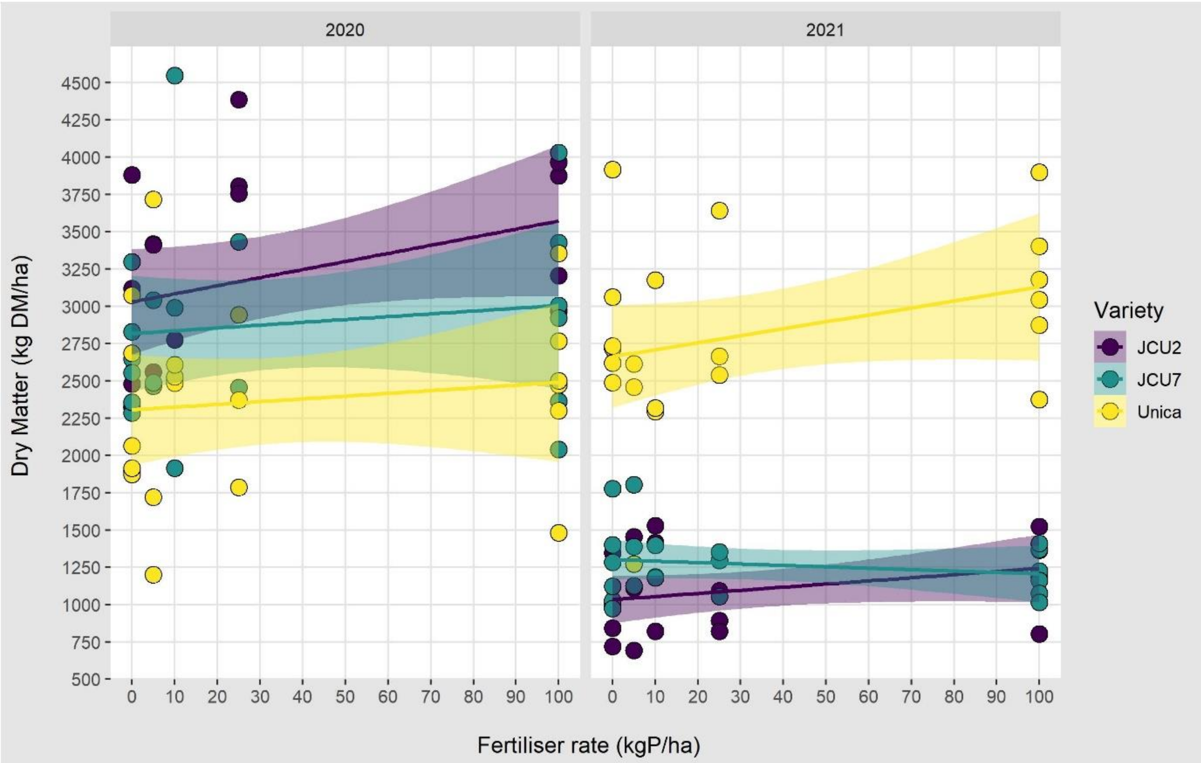


4.5.2.2 Dry matter production response to phosphorus fertiliser

Dry matter response to applied P fertiliser for the 2020 and 2021 harvest is shown in Figure 20. Harvest dates aimed to measure peak yield during the growing season. The trial was harvested for dry matter in March 2020. In 2021 the trial was harvested initially in February due to dry weather threatening to reduce yields and again in April 2021 with the second harvest data being presented in this report. The desmanthus yield reduced between the two harvests in 2021, however the Caatinga stylo increased its yield. The reduction in yield is most likely due to leaf and stem senescing in the desmanthus.

The 2020 data showed there was no significant response to phosphorus application (p=0.10) for any of the treatments. The 2021 data indicates there is no clear response by the desmanthus varieties JCU2, JCU7 to the application of phosphorus fertiliser in the Wandoan trial. The data suggests that the Caatinga stylo cv. Unica did have a slight yield response to applied phosphorus however it was not statistically significant.

Figure 20: Tropical legume dry matter (kg DM/ha) compared with phosphorus application rates at the Wandoan phosphorus trial. Legume dry matter is compared across the 2020 and 2021 harvests with shading indicating Standard Error.



The lack of response to applied P fertiliser suggest that desmanthus (*D. virgatus* and *D. leptophyllus*) and Caatinga stylo have a low phosphorus requirement compared to other pasture legumes. However, other studies have shown large increases of 40-100% higher dry matter in established grass and legume pastures for these species when applying phosphorus fertiliser in similar soils and climate (Peck *et al.* 2017a).

It is likely that the experimental design and site selection affected the results for desmanthus and Caatinga stylo which may not reflect what would occur in commercial paddocks for the following reasons:

- No grass was sown with the legumes. Grasses compete strongly with the legume for available P in the soil. Not sowing grass reduced the likelihood of measuring a response to fertiliser in this trial.

- Long bare fallows. The tropical legume trials were fallowed for >12 months which would have increased P availability during establishment.
- Soil variability. The trial site has a subtle underlying Gilgai pattern that increased variability between plots. Many low P clay soils in the Brigalow Belt have Gilgai.
- Moderate P levels. The Wandoan trial site had a Colwell P of 6 mg/kg and a PBI of 66; the ideal trial site would have a lower Colwell P and/or higher PBI.

For future phosphorus fertiliser experiments on Caatinga stylo and desmanthus it is recommended that trial sites be managed differently to better reflect likely commercial results. Recommendations include sowing grass with the legumes, minimising the fallow period (to reduce mineralisation of P and N in the soil) and selecting soils with lower soil P levels (if possible).

4.5.2.3 Variety differences in dry matter yield

There were significantly different yields between varieties in both years that were harvested (Table 33). The 2020 harvest produced higher yields than 2021. In 2020 the desmanthus varieties produced higher yields than Caatinga stylo. In 2021 Caatinga stylo produced higher yields than the desmanthus varieties. Based on visual observation of the plots in 2021 and 2022, the desmanthus has had a greater reduction in plant population than Caatinga stylo.

Table 33: Mean dry matter yield for each tropical variety (DM kg/ha) for the 2020 and 2021 harvests. Means not sharing superscript differ significantly at α = 0.05 indicated by Fisher's LSD for that harvest year.

		Harvest	
Species	**Variety**	**2020**	**2021**
D. leptophyllus	JCU7	2882^{a}	1268^{b}
D. virgatus	JCU2	3216^{a}	1104^{b}
S. seabrana	Unica	2368^{b}	2823^{a}

4.5.3 Wandoan temperate legumes

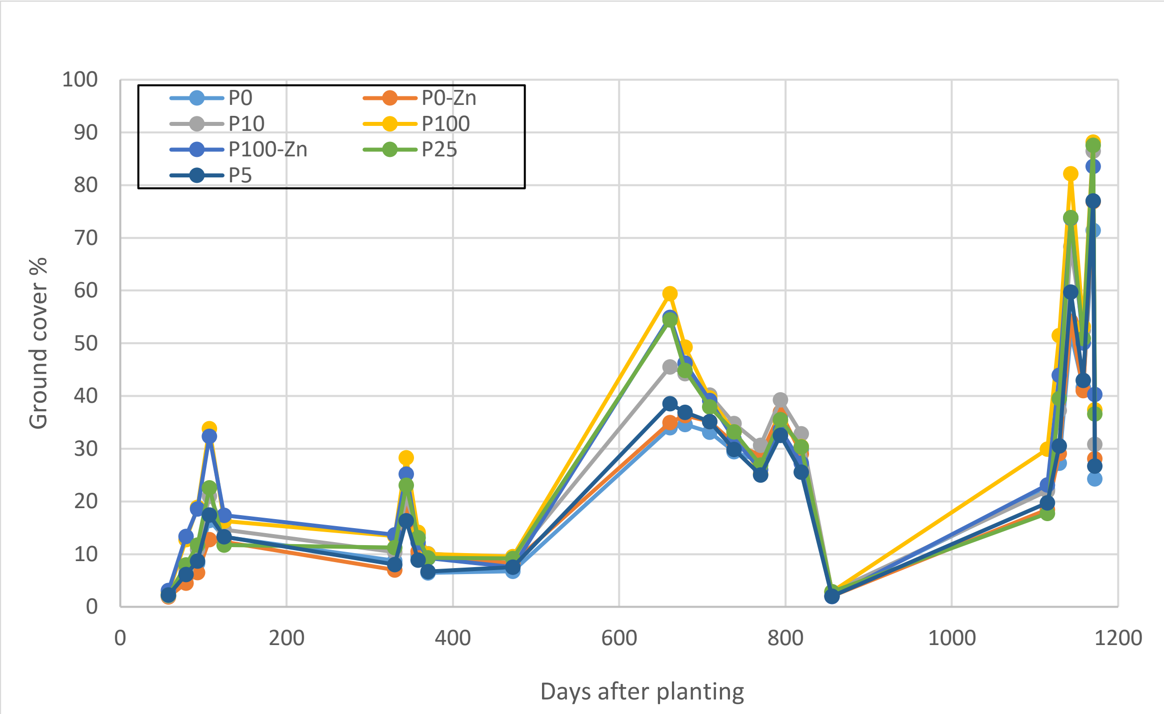
4.5.3.1 Ground Cover

Groundcover was used as a non-destructive measurement of medic growth from sowing in 2018 until the end of the 2021 growing season with the results shown in Figure 21.

The medic growth and resulting ground cover measurements were closely aligned with rainfall. The Wandoan temperate legume trial site was sown in May 2018 with germinating rain in June 2018 producing good plant establishment and early growth showing an increase in groundcover (Figure 21). Dry seasonal conditions restricted recruitment in the 2019 growing season. The medics did not produce harvestable yield in 2019 due to drought and therefore low groundcover for the whole year. Good rain in February 2020 resulted in high ground cover early in the third winter growing season, however subsequent dry weather resulted in high death rates, declining ground cover and declining yields. The medics succumbed to the dry weather and died before they could be harvested in 2020. In 2021 there was good germinating rain in March with follow-up rain recorded until the harvest in August allowing ground cover and plant yields measurements to be obtained.

The groundcover measurements demonstrated increased medic growth rates with higher phosphorus fertiliser rates when moisture was present (Figure 21). When rainfall allowed the medics to grow, the higher fertiliser rates produced faster increases in ground cover (i.e. they grew faster), for example 470 – 660 days after sowing. However, dry weather resulted in the medics dropping leaf and dying resulting in similar groundcover (e.g. the decline from 660 to 770 days after sowing).

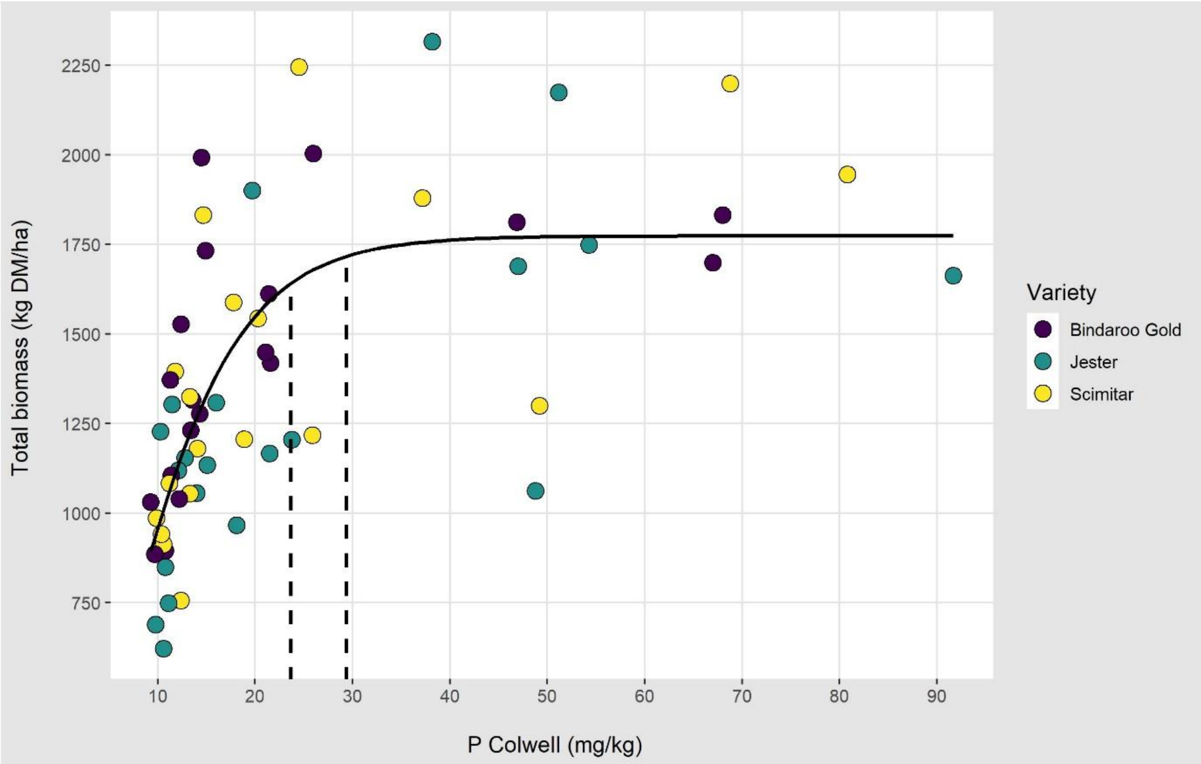
Figure 21: Temperate legume ground cover at the Wandoan phosphorus trial to August 2021. Legume ground cover is averaged across the three legume species (Legend: -Zn, zinc not applied)



4.5.3.2 Dry matter production

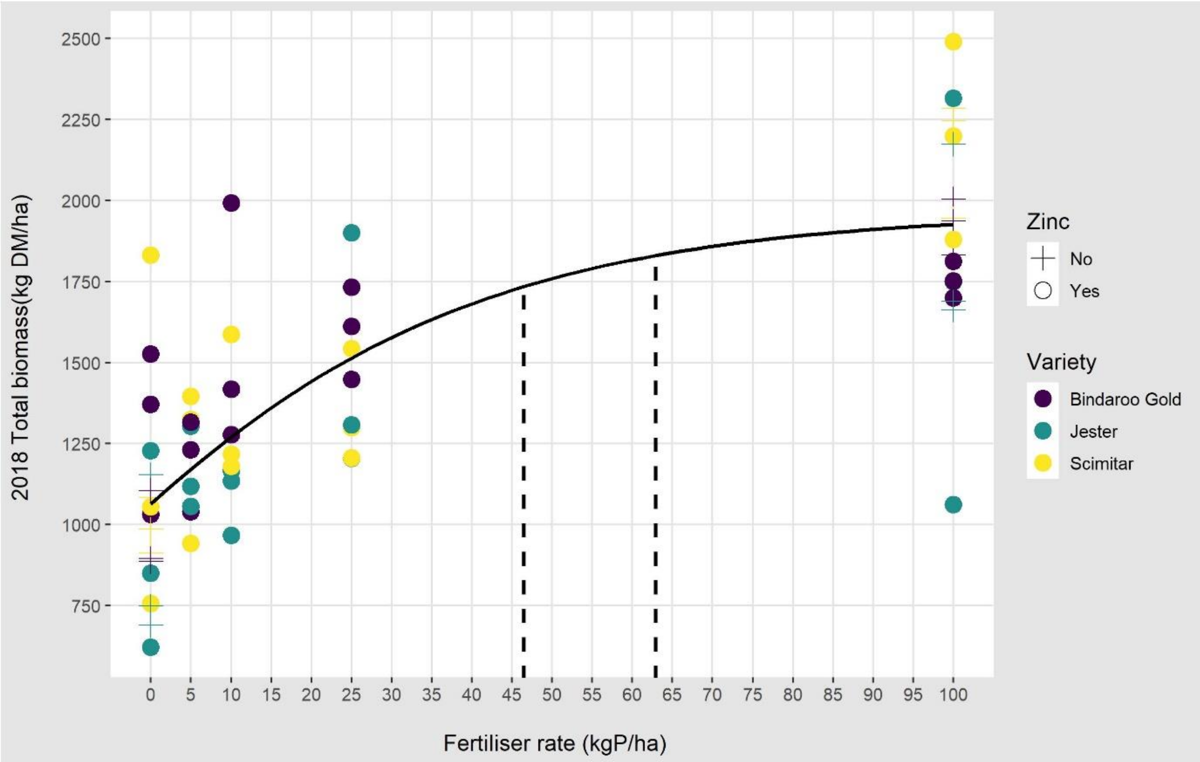
During the 2018 harvest medic biomass was sampled and compared to soil Colwell P for all treatments (Figure 22). There was no significant difference in critical Colwell P level (i.e. 90-95% of max production) between the three cultivars, with critical Colwell P between 24 and 29 mg/kg.

Figure 22: Relationship between total biomass production and the level of phosphorus in the soil for three different legume cultivars. Dashed lines show 90 and 95 % of total biomass production. Data was fitted to the general Gompertz equation. Values of coefficient for the equation are a=1837 (P<0.001), b=2.389 (P<0.05) and c=0.8767 (P<0.001).



The dry matter response of the three medic varieties to phosphorus fertiliser rate was evaluated in 2018, with the results shown in Figure 23. In 2018, a significant increase in dry matter was measured (P<0.001) with increased application of fertiliser rate. The application of zinc did not influence total biomass. A prediction curve was plotted to estimate the response of dry matter yield to phosphorus fertiliser (R^2=0.61), this prediction curve suggests that to reach 95% percent of peak production that an application rate of 63kg P/ha was required.

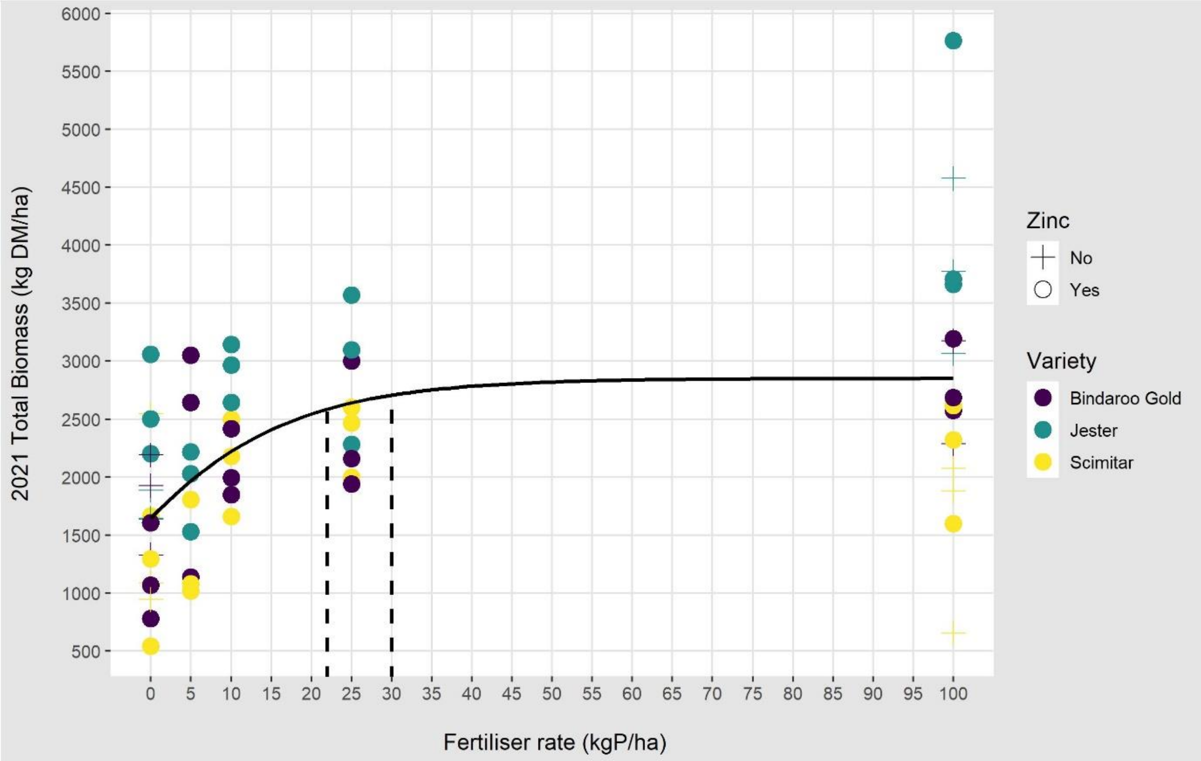
Figure 23: Relationship between 2018 total biomass production and the phosphorus applied to the soil for three different legume cultivars. Dashed lines show 90 and 95 % of total biomass production. Data was fitted to the general Gompertz equation. Values of coefficient for the equation are a=1966 (P<0.001), b=0.615 (P<0.001) and c=0.966 (P<0.001).



The dry matter response of the three medic varieties to phosphorus fertiliser was evaluated again in 2021, with the results shown in Figure 24. In 2021, a significant increase in dry matter was measured (P<0.001) with increased application of fertiliser treatment rates. Therefore, when this and the 2018 are combined it shows that at this site the use of phosphorus fertiliser increases total biomass for Bindaroo gold, Scimitar and Jester medic varieties. Total biomass was not affected by the addition of zinc.

A prediction curve was plotted to estimate the response of dry matter yield to phosphorus fertiliser (R^2=0.27), this small R^2 value is due to high variation within each fertiliser treatment group, although an estimate for the fertiliser rate for 95% of peak production (30kgP/ha) has been shown in Figure 24, it should be noted that the reliability of this estimate is low.

Figure 24: Relationship between 2021 total biomass production and the phosphorus applied to the soil for three different legume cultivars. Dashed lines show 90 and 95 % of total biomass production. Data was fitted to the general Gompertz equation. Values of coefficient for the equation are a=2851 (P<0.001), b=0.5484 (P<0.001) and c=0.9244 (P<0.001).



There was a significant difference between dry matter yields between medic varieties in 2018 ($p=0.03$) and 2021 ($p<0.001$) shown below in Table 34. In 2018 Jester was the lowest yielding variety whereas in 2021 it was the highest yielding variety. The higher yield of Jester relative to the other varieties in 2021 is probably due to the use of a fungicide (microthiol) to control powdery mildew that was not used in 2018. Jester is known to be more susceptible to powdery mildew than other medic varieties.

Table 34: Mean dry matter yield for each medic variety (DM kg/ha) for the 2020 and 2021 harvests. Superscripts denote statistically significant differences (α = 0.05) indicated by Fisher's LSD for that harvest year.

		Harvest	
Species	**Variety**	**2018**	**2021**
M. orbicularis	Bindaroo Gold	1473^{a}	2138^{b}
M. truncatula	Jester	1290^{b}	2903^{a}
M. polymorpha	Scimitar	1493^{a}	1740^{b}

4.6 Establishing legumes into grass pastures

These research trials tested the impact of agronomic practices commonly used in grain cropping (e.g. fallows, post emergent herbicides) on establishing small seeded legumes into existing buffel grass pastures compared to industry standard practices of broadcasting with no disturbance of existing pasture or one-pass cultivation. The trials were initiated under a previous project and continued under this project. A summary of key results from all six trials over both the data collected under the previous and current project is discussed in the following sections of the report. Results and data from the first few years of these research trials have been published in Peck *et al.* (2017b).

4.6.1 Establishment trial results

Dry Matter (DM) production results are shown for Goondiwindi clay for 1, 2 and 3 years after sowing; and loam soil trial sites for the third year after sowing growing seasons (Figure 25 - Figure 28). Data from other trial sites, other measurements (e.g. legume density) and first growing season results are described in the final report for the “Improving productivity of rundown sown grass pastures” project (Peck *et al.* 2017b). Strong trends of better legume growth with increasing fallow length were evident in all sites in the year of sowing. Longer fallows produced more legume DM at 1, 2 and 3 years after sowing at the Goondiwindi trial sites. Similar results were achieved at the Wandoan clay trial site.

The Wandoan loam site was discontinued due to using an unsuitable legume species (fine-stem stylo) that is better suited to higher rainfall districts. Fine-stem stylo was used due to lack of seed supply of other species at the time of sowing. The St George trial sites (clay and loam soil) were discontinued due to legume seedlings dying from severe drought in the second year (these trials are located in the lowest average annual rainfall part of the Brigalow Belt bioregion).

The Goondiwindi trial sites were affected by preferential grazing of plots with higher legume content. The most damaging preferential grazing was by kangaroos, however when livestock grazed the trial, they also preferentially grazed the plots with high legume content. The preferential grazing reduced legume growth, flowering, seed production and recruitment which therefore means the data presented underestimates the legume production benefits in the long fallow treatments that had higher legume density. The preferential grazing of small plots means that the trial treatments were no longer representative of the likely results at the commercial paddock scale.

Figure 25: Grass, legume and weed dry matter at the Goondiwindi clay soil legume establishment site, 14 months after germinating rain (March 2016).Significance notation is for comparison within dry matter fractions(P<0.05). Treatments with significantly higher weed burden than all other treatments are marked with an asterisk. (PEH: post-emergent herbicide, using Verdict for grass control and Basagran for broad-leaf weeds; Spinn.: Spinnaker residual herbicide).

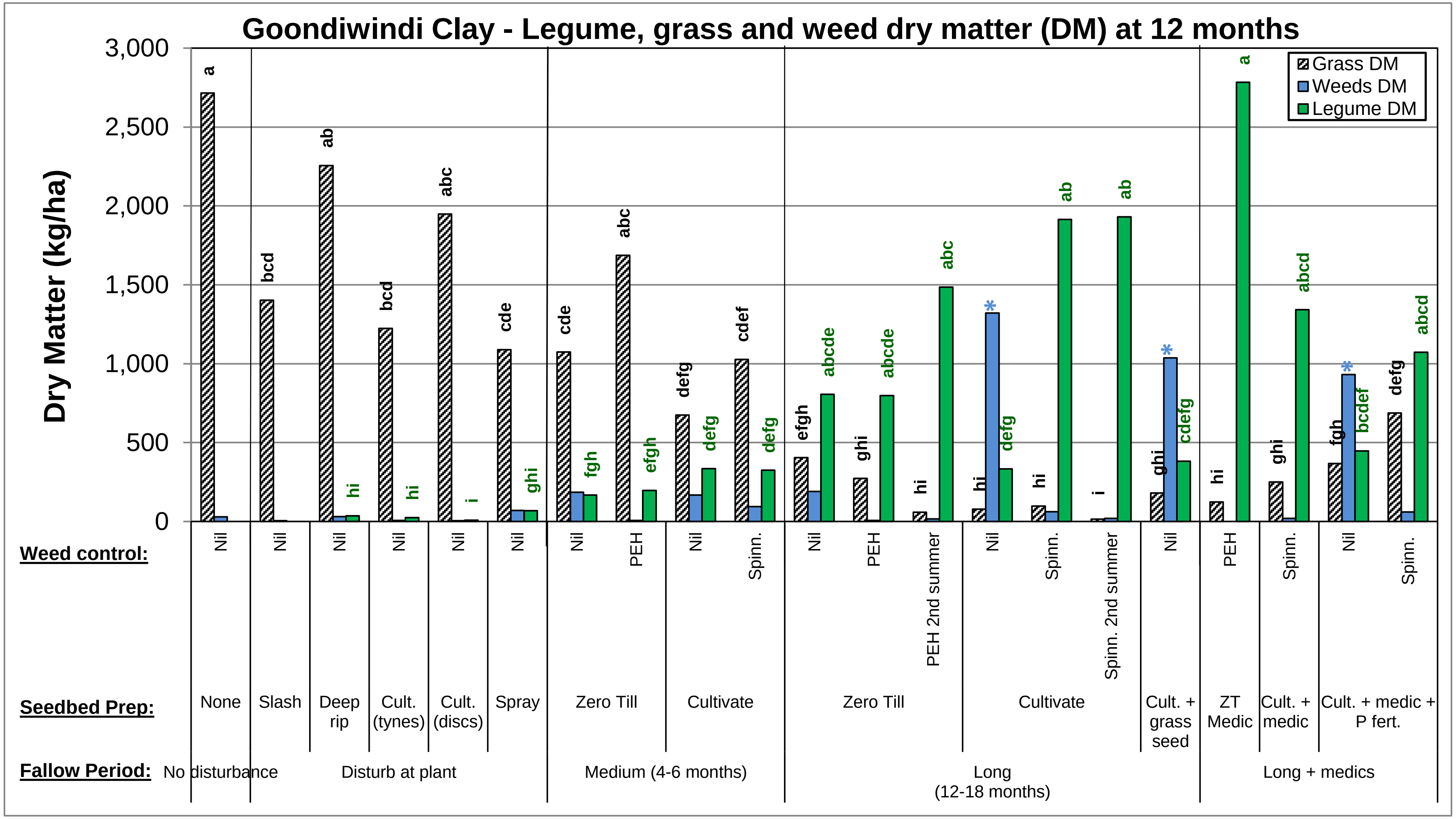


Figure 26: Grass, legume and weed dry matter at the Goondiwindi clay soil, legume establishment trial at 2 years after sowing (January 2017). (ZT: Zero Tillage; Cult.: Cultivation; PEH: post emergent herbicide, using Verdict for grass control and Basagran for broad-leaf weeds; Spinn.: Spinnaker residual herbicide; x2: weed control continued through the second growing season).

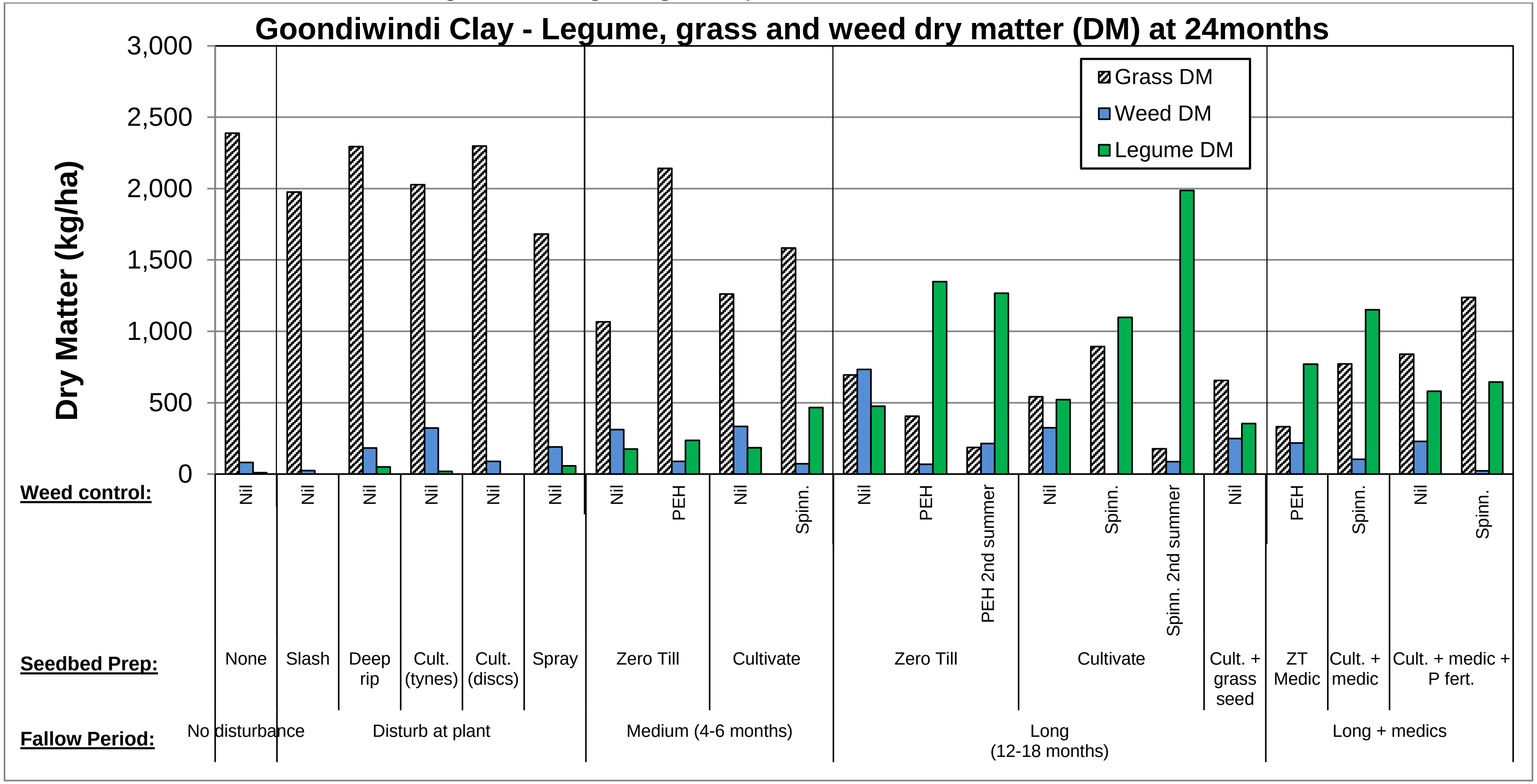


Figure 27: Grass, legume and weed dry matter at the Goondiwindi clay soil, legume establishment trial at 3 years after sowing (April 2018). (ZT: Zero Tillage; Cult.: Cultivation; PEH: post emergent herbicide, using Verdict for grass control and Basagran for broad-leaf weeds; Spinn.: Spinnaker residual herbicide; x2: weed control continued through the second growing season).

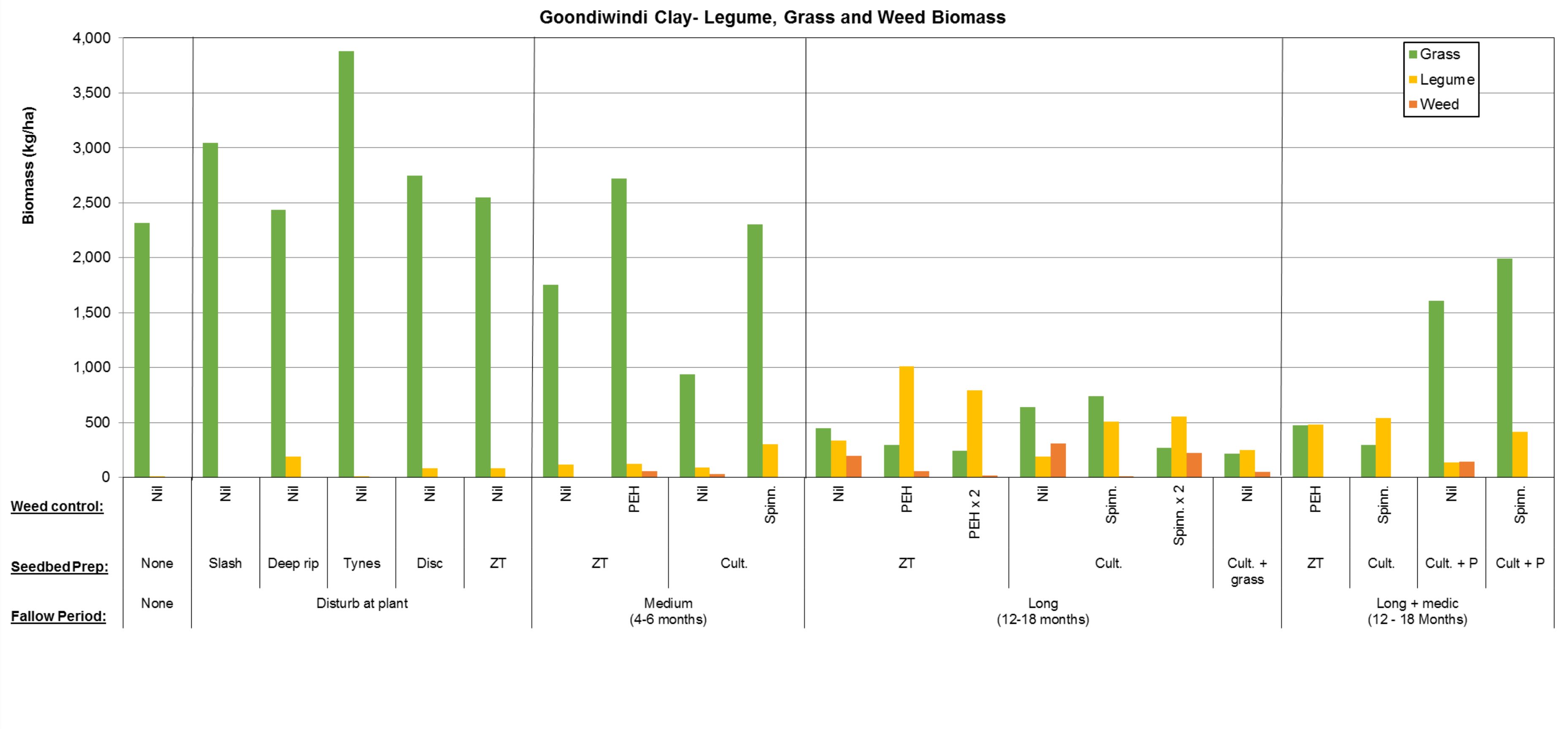
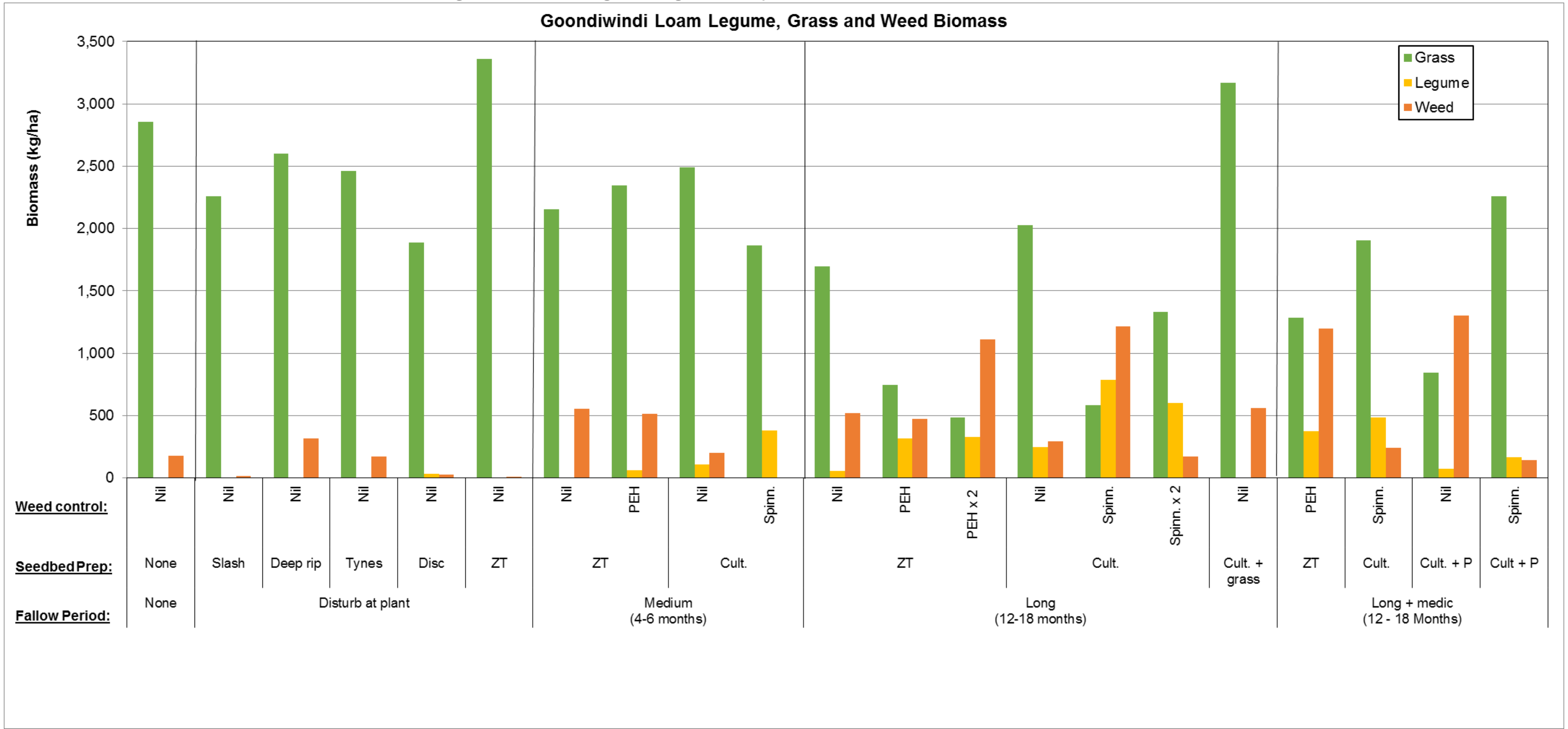


Figure 28: Grass, legume and weed dry matter at the Goondiwindi loam soil, legume establishment trial at 3 years after sowing (April 2018). (ZT: Zero Tillage; Cult.: Cultivation; PEH: post emergent herbicide, using Verdict for grass control and Basagran for broad-leaf weeds; Spinn.: Spinnaker residual herbicide; x2: weed control continued through the second growing season).



4.6.2 Key results and conclusions

Establishment trials conducted as part of this project have shown that establishing small seeded legumes like desmanthus and Caatinga stylo can be a lot more reliable if good agronomic practices are used. Key principles or considerations for reliable legume establishment in existing grass pastures are:

- Legume seedling access to moisture and other nutrients.
- Good seed to soil contact.
- Establishing legumes in strips or across whole paddocks.

4.6.2.1 Legume seedlings need access to moisture (and other nutrients)

Legume seedlings need good moisture supply for rapid early growth to be large enough to cope with the stresses of dry seasonal conditions and winter to limit mortality as well as produce forage for livestock. Seedlings are more prone to these stresses because of their small root systems. In particular, there needs to be enough water when seedlings are very small to survive from the first germinating rain through to when follow up rain is received.

The Brigalow Belt bioregion has a climate with mild winters where plant growth is limited by moisture throughout the year rather than having a distinct wet season or growing season (Hutchinson *et al.* 2005). The climate classification based on a plant growth model of Hutchinson *et al.* (1992) identifies the Brigalow Belt climate zone as being unique in the world. Reliability of grain cropping in the Brigalow Belt climate zone relies on storing moisture in the soil during a fallow rather than in-crop rainfall that is typical of other cropping regions in Australia and around the world (Hutchinson *et al.* 1992). Agronomic practices for establishing legumes into existing pastures therefore needs to be appropriate for this climate zone rather than using practices developed in other climate zones for graziers to improve establishment reliability.

The supply of moisture for legume seedling growth can come from stored soil moisture and/or rainfall. The water that is available can be used either by legume seedlings or by competing plants like the existing grass pasture or other weeds. Reliable legume establishment in the Brigalow Belt relies on more water being available (through stored moisture in the soil rather than relying on rainfall post sowing), more often (higher percentage of years than relying solely on post sowing rain in a variable rainfall climate zone), and more of the available water being used to support legume growth (rather than weeds or existing grass using the water). Irrigation in the Brigalow Belt bioregion is used on high value crops such as horticulture, cotton or hay production but is unavailable for widespread establishment of broadacre pastures. Improving reliability of establishing legumes into existing grass in the Brigalow Belt therefore relies on the use of fallows to store soil moisture and control competition from the existing grass and weeds.

4.6.2.1.1 Fallowing improves legume establishment

Fallowing to kill the existing pasture, reduce the soil seed bank, store soil moisture and therefore reduce competition from both grass and weeds to legume seedlings is critical to minimise the impacts of the episodic rainfall events that are typical of the Brigalow Belt bio-region, thereby reducing seedling mortality rates. Stored soil moisture via fallowing allows seedlings to survive and grow even in dry seasons.

Across all six trial sites conducted, increasing fallow period improved legume establishment. The best legume establishment with the highest plant numbers and dry matter production occurred in long fallow period (9-12 months) treatments. Even in very wet years it is likely that at least some fallowing will improve establishment in this environment due to reduced competition from other plants (i.e. grass and weeds), but it is critical in average to dry years and in drier locations.

By contrast, the low cost, low reliability establishment techniques routinely used by graziers and recommended by farm advisors of broadcasting into existing pastures or one-pass cultivation failed at every trial site. No disturbance, slashing and one-pass cultivation treatments all failed to produce adequate legume density at all sites and should not be recommended as establishment techniques in this environment with competitive grass pastures.

One application of glyphosate at sowing produced better results than one-pass cultivation at two out of six trial sites, at the other four it showed promising early legume density and height but ended up producing similar results as other disturb at plant treatments. These results suggest that one-pass spraying may be better than one-pass cultivation in wetter years, although to successfully establish legumes it is completely reliant on follow up rain and therefore may be better suited to wetter districts closer to the coast or more monsoonal areas. Timing is critical for spraying at plant to work effectively as the grass needs to be actively growing with good leaf area and little dead stalks or leaves to get good control of the grass, followed by good germinating rains to compensate for the lack of stored soil moisture.

4.6.2.1.2 Rainfall

Rainfall patterns in the inland sub-tropics mean there is a low likelihood of germinating rain combined with follow up rain before seedlings die in the absence of stored soil water and in the presence of competition by existing pasture. This contrasts with more monsoonal areas or “Mediterranean climate” areas where the shorter wet season means rainfall events are closer together. Growing grain crops in the sub-tropics relies on storing soil moisture, whereas in Mediterranean climates farmers rely on “in-crop” rain. Trial results in this project and graziers commercial experience suggest that reliable legume establishment in the inland sub-tropics also relies on stored moisture.

Follow-up rainfall is critical for legume seedling survival, however stored soil moisture can dramatically increase the period that legumes can grow before being moisture stressed. Timing of sowing is therefore critical to maximise the chance of follow up rainfall. For most of Queensland’s sub-tropics, the highest rainfall months with higher likelihood of consecutive days of rain are January and February, which often also coincide with decreasing temperatures which reduces water demand by plants and evaporation. In some seasons the rainfall can come earlier but is often followed by hot dry weather with stored soil moisture therefore being critical to seedling survival.

Wetter districts closer to the coast and more monsoonal areas have a higher chance of receiving follow up rainfall and will therefore have a lower requirement for storing moisture during fallows. Wetter years will also have less of a requirement for stored moisture, however predicting seasonal conditions 6-12months prior to summer to allow sufficient fallow periods has low predictive confidence. Given the challenges of predicting seasonal conditions, the recommendations for fallowing therefore remain, but should be adapted as seasonal conditions unfold.

4.6.2.1.3 Grass and weed competition

The soil moisture stored during fallows and follow up rainfall can either be used by the legume seedlings or through competing plants like the existing grass pasture or other weeds. Competition from existing grasses and weeds often has a major influence on high seedling mortality. It is not the competition per se that kills seedlings; rather competition from existing vegetation may restrict growth to such an extent that seedlings subsequently die from moisture stress, temperature stress or acute nutrient deficiency (Cook et al., 1993). Survival depends on plant size when stress is encountered.

Controlling competition from the existing grass is best achieved through fallows. The results from the establishment trials showed that the longer the fallow period, the greater the control of both the existing pasture and also the soil seed bank. Within the same fallow period treatments, there can be a significant improvement in legume growth through controlling competition from re-colonising grasses and weeds via post emergence herbicides. For example, at one of the trials the herbicide treatments with long fallows produced two to five times as much legume dry matter as without the herbicide at 12 months after sowing.

In the trials, the herbicides used were:

- Spinnaker for cultivated fallow treatments applied at plant (pre-emergent) to give residual control of grass and weeds both pre and post legume emergence.
- Verdict was used for grass control and Basagran was used for broad-leaf control for zero-tillage fallows.

The trials also showed that the herbicides can cause damage to legume seedlings in some circumstances in the short-term. Despite the short-term damage, all the affected treatments ended up growing better than the comparison treatment without selective herbicide. These results suggest that the damage from competition from weeds is greater than the herbicide damage and/or the legumes grow out of the damage. Further trial work is required to develop better recommendations for using these herbicides with these legumes.

4.6.2.1.4 Recommendations for moisture availability to seedlings

The general recommendations to balance soil water storage, follow up rainfall and competition for the in-land sub-tropics of Queensland from our trial results (and other trials) therefore are:

- Plant in January/February as this is the time of the year with highest rainfall and the greatest chance of follow up rain. Adjust to planting earlier if there is good stored moisture and/or the seasonal outlook is for a wet summer. If the paddock is in a cold location (e.g. a frost hollow on the Darling Downs) and planting summer growing legumes, earlier planting will allow plants to be larger before frosts occur and therefore survive the winter period better.
- Store sufficient soil water through fallowing.
    - *Establishing in strips*. In most districts on better soils that can store significant amounts of water, this is likely to mean long fallows of 9-12 months duration to maximise legume growth within the strips to maximise seed set and spread in subsequent years. In wetter years or wetter districts or soils with lower water

holding capacity this can be reduced to medium length fallows of 3-6 months (this topic is discussed further in section 4.6.2.3.

- *Planting whole paddocks*. If planting the whole paddock there is a trade-off between grass and legume growth to maintain a balance in pasture composition. Medium length fallows of 3-6 months will allow grass to re-colonise from some remaining tillers or tussocks and from the soil seed bank.

- Control grass and weed competition. The most effective way to reduce competition from existing plants (grass and weeds), as well as reducing the soil seed bank through control of germinating seedlings is via fallowing. During the fallow, cultivation and a wide range of herbicides can be used. By contrast, after legumes have emerged there are relatively few selective herbicides that can be used. Where grass and weed loads are high, spraying with post emergence herbicides should result in significantly more legume growth. If establishing the legumes in strips, maximising the legume production through controlling grass and weeds is critical to facilitating high seed set and spread of the legume into the surrounding pasture. If planting across whole paddocks, there is a balance between allowing the grass to recolonise and controlling competition to the legume.

4.6.2.2 Good seed to soil contact

Seeds need to imbibe water via contact with moist soil to germinate. Practices that increase soil to seed contact when sowing can improve legume germination and growth. In the trials conducted in this project, drilling seed produced better legume density than broadcasting seed where it improved seed to soil contact, for example on firmer surfaced soil. Based on the trials in this project and other trials, drilling is more likely to be beneficial with:

- Soil types where the soil surface is firm. That is, crusting, hard setting or firm soil surfaces.
- Zero tillage compared to cultivated fallows or cultivated planting operations.
- Prior management that has allowed the soil surface to become firm (e.g. the medic treatments at Goondiwindi trial sites).
- Very dense pasture cover which reduces the chance of broadcast seeds contacting the soil surface.

Drilling produced no benefit on the cracking clay soil trial sites that had self-mulching surfaces without excessive pasture cover. Drilling produced negative results where seed was sown too deep. Drilling of small seeded legumes should not be attempted unless planting equipment allows very precise control of sowing depth.

4.6.2.3 Establishing legumes in strips

Pastures require both grass and legumes to be highly productive in the long-term. If a paddock already has good grass pastures, graziers are reluctant to kill them and forego grazing for a period to establish a legume. The dry matter (DM) production from the trials in this project suggest that establishing legumes in strips within existing grass pastures offers the compromise between cost, lost grazing and reliable legume establishment.

At the site where DM production was measured at 12 months, the long fallows produced four to five times more legume DM than the medium fallows. Therefore if 20 – 25% of a paddock (e.g. 5m fallowed strip on 20-25m centres) was established to legumes in long fallow (9-12months) strips, it is capable of producing as much legume per hectare as ploughing or spraying out the whole paddock for a medium length fallow (3-6 months).

Fallowed strips need to be wide enough to allow soil moisture storage for legumes to be reliably established in strips. That is, fallowed strips need to be wide enough that the grass roots do not extract the water by growing in from the edge during the fallow. To maximise moisture storage to depth in the soil requires fallow strips to be >6m wide. Competition from the grass strips is greatest out to approximately 1m into the fallowed strips, therefore even in higher rainfall environments with a high likelihood of follow up rain require strips >2m.

Given the considerations above it is recommended that strips be >3m wide in the wetter parts of the Brigalow belt bio-region (e.g. the inland Burnett catchment, Callide district) as a minimum. In drier districts further inland, fallowed strips would need to be wider to allow for fallow moisture storage and less likelihood of in-crop rainfall after sowing legumes. Strips in inland districts should be >6m wide.

5 Conclusion

5.1 Key findings

5.1.1 Extension

Extension activities during the project have contributed to developing interest and enthusiasm for pasture legumes within the grazing industry. Key findings from the extension activities and project evaluation include:

- Strong interest in pasture legumes. There are a lot of graziers and farm advisors who are interested in improving productivity through adopting legumes.
- Workshops were effective in building knowledge and facilitating adoption of legume management practices.
- Large opportunity to improve the reliability of legume establishment. Research trials have shown that better agronomy dramatically improves the reliability of legume establishment but adoption levels remain low.
- Need more “local” examples of successful legume establishment and long-term production in commercial paddocks in the Brigalow Belt.
- Extension materials need updating and be made more accessible.
- Preferred legume species has changed over the last decade. Desmanthus is now the legume preferred by graziers.

5.1.1.1 Strong interest in pasture legumes

The project has contributed to the grazing industries interest and enthusiasm for pasture legumes. Graziers and farm advisors have shown interest in attending workshops and field days hosted by this project and other organisations. The strong interest shown by the grazing industry reflects the importance of improving productivity from rundown sown grass pastures and native pastures.

Workshops were popular. The team attempted to restrict attendance at workshops to 15 businesses, however 13 out of 23 workshops were oversubscribed and graziers were put on waiting lists to attend. Workshops were effective in engaging with graziers and farm advisors. Participants in the workshops represented 226 grazier businesses and 279,000 head of cattle which is 5.1% of grazing businesses and 5.6% of the herd in the Brigalow Belt (ABS 2016).

Field days were similarly well attended with an average of 27 participants. The attendance at workshops and field days demonstrates that there is an interest and need to conduct similar training events in the future.

5.1.1.2 Workshops were effective

Workshop participants reported improvements in knowledge and skills, with an average score of 4.2 out of 5 (where 5 is a "very good improvement"). The majority of workshop participants made changes on their property. Eighty-five percent reported that they intend to make changes to how they establish or manage legumes on their property. Seventy-three percent of grazing businesses sowed legumes after attending the workshop with 42000 ha being sown. Eighty of businesses intend to sow more legumes over the next 5 years (additional 111,200 ha). Graziers conducted 105 on-farm trials with almost all having been initiated during workshops.

5.1.1.3 Industry can improve the reliability of establishing legumes

Research trials and commercial experience has demonstrated that better agronomy can dramatically improve the reliability of establishing legumes into existing grass pastures in the Brigalow Belt, however adoption rates remain low.

One of the key practices to improve establishment reliability is to have a fallow to store soil moisture and control competition from grass and weeds before sowing. Research results have demonstrated that fallows dramatically increase the reliability of establishing legumes in the Brigalow belt climate zone (Peck *et al.* 2017b). Eighty percent of graziers indicated they would use a medium (4 – 8 months) or long (9-12 month) fallow at the end of the workshop, however when sowing on their own property only 35% used a medium or long length fallow (Table 27). These survey results suggest that most graziers will not start using fallows based purely on information supplied in a workshop, local demonstration is required.

The difference between "intended" and "actual" adoption of fallowing is indicative of the opportunity to improve the reliability of establishing legumes in the Brigalow Belt bioregion.

5.1.1.4 Local examples of legume establishment and long-term productivity

Local examples are needed to provide strong evidence on the benefits of using better agronomy when establishing legumes. Previous poor results and establishment issues were the third most common reason cited as a barrier to adoption of legumes after cost/money availability and seasons/drought which are issues outside of the control of an extension program (Table 28). Graziers across Queensland have been advised for decades to use one-pass legume establishment methods, however these methods do not produce reliable legume establishment when sown into competitive grass pastures and episodic rainfall patterns in the Brigalow Belt (Peck *et al.* 2017b). Local demonstration of the impact of better agronomy should help increase the adoption of practices such as fallowing which mitigate the risk from seasonal variability.

There is also a need to have local demonstration of other practices that impact long-term productivity (e.g. soil testing, rhizobia inoculation and fertiliser use).

5.1.1.5 Extension materials require updating

There is a need to improve public access to independent and reliable information on sown pastures. A review of extension materials conducted by this project found that information on sown pastures in Queensland from independent organisations (e.g. DAF, CSIRO) required updating as it was outdated, required collation of fragmented technical knowledge, was at risk of being lost and in many instances was not accessible to the public. The private sector materials were more recently updated but was sales driven and provided recommendations that are contrary to research results on some topics.

Survey results from graziers suggest that websites, fact sheets and books are popular extension products (Table 30). Updating these extension products would improve information access for graziers and farm advisors.

5.1.1.6 Preferred legume species

Desmanthus is currently the legume preferred by graziers. In the surveys conducted by this project, desmanthus was the legume that the greatest number of graziers sowed and intend to sow in the future (Table 27). During legume management workshops 40% of graziers intended to sow desmanthus, 30% have sown desmanthus since the workshop and 39% intend to sow it in the future.

The current interest in desmanthus is a dramatic change in grazier interest over the last decade. Six focus group meetings with 41 graziers in 2010 demonstrated a different attitude to desmanthus (Peck *et al.* 2011). Graziers in only two of the six focus groups mentioned desmanthus. Of the graziers who had used desmanthus, the comments were that they had mainly only sown small trial plantings with mixed results, and cv. Marc was persisting but Bayamo and Uman were not persisting. The release of new varieties (Progardes) and rigorous marketing effort has had a dramatic impact on grazier interest.

Caatinga stylo is the other persistent legume species that was released in the 1990’s for the Brigalow Belt bioregion. Despite impressive results from Caatinga stylo in research trials (Peck *et al.* 2017a) few graziers had positive experiences with it in 2010 focus groups. During the workshops 26% of graziers intended to sow Caatinga stylo but only 9% of graziers actually sowed Caatinga stylo and 8% intend to sow Caatinga stylo in the future. The widespread adoption of Caatinga stylo has been hindered from a lack of concerted marketing effort, poor quality seed and unreliable seed supply.

Graziers intend to sow a wide range of other pasture legumes (section 4.3.2.1). Desmanthus (40%), leucaena (16%), shrubby stylo (14%) and Caatinga stylo (8%) are the top four legume species that graziers intend to sow in the next five years, however there were another nine species that some graziers intend to sow.

5.1.2 Legume persistence in southern inland Queensland

5.1.2.1 Desmanthus and stylo persistence in southern inland Queensland

Caatinga stylo and *Desmanthus virgatus* generally have the highest plant densities across the trial sites. The early results suggest that these two species will persist at most of the six trial sites where they were sown by this project. These results align with legume persistence studies further north (from approximately Roma and Chinchilla north) where these two species were widely persistent across old pasture evaluation sites (Peck *et al.* 2017a).

Legume density measurements after three years post sowing indicate that *D. virgatus* was likely to persist at most if not all of the trial sites. The *D. virgatus* varieties have maintained higher plant densities at the clay soil trials compared to other species, however they have not maintained the relatively high plant densities on the loam trial sites. Early results from these trials and results from previous trials suggest that *D. virgatus* is well adapted to the clay soils of the Brigalow belt, however Caatinga stylo is better adapted to the lighter textured loamy soils.

The *D. virgatus* cultivars Cowpower, Marc, JCU2 and JCU8 have maintained adequate plant densities across the trial sites, however JCU5 has low plant densities. Results from these trials suggest that cv. JCU5 is not well adapted to southern inland Queensland.

The *D. bicornutus* and *D. leptophyllus* cultivars sown in these trials are not likely to be persistent in southern inland Queensland. Cultivars of these two desmanthus species have low plant densities compared to other species and have flowered very late in the growing season resulting in them producing either no seed or very small amounts of seed. The lack of reliable seed production means that these varieties are not adapted to southerly latitudes and should be recommended further north. New varieties would need to be developed for these two species to be useful in southern latitudes.

Desmanthus pernambucanus cv. JCU9 established well with big plants and high seed production, maintained plant density but has not had high seedling recruitment at five out of six trial sites. These results suggest it may persist in southern inland Queensland, but the trials need to continue to test long-term persistence.

Caatinga stylo has high plant densities indicating that it is widely persistent across both the clay and loam trial sites. These results align with previous studies that show Caatinga stylo persists across a wide range of soils and districts in the Brigalow Belt bioregion (Peck *et al.* 2017a).

Shrubby stylo cvv. Seca and Siran has maintained a high plant density at Goondiwindi but a much lower population at St George loam soil trials. These two varieties have not persisted in the long term at other trial sites in southern inland Queensland but are well adapted to similar soils in more northerly latitudes (Peck *et al.* 2017a). The trials need to continue to test the long-term persistence of these varieties in this climate zone.

Fine-stem stylo did not persist at either loam soil trial sites. Fine-stem stylo should not be recommended in southern inland Queensland.

All varieties tested had high death rates at the Allora trial sites. Legumes had high death rates during winter especially at the Flat site which experiences heavy and frequent frosts during winter. Some of the legumes subsequently recruited well during spring and summer in part due to low grass density in the plots. Questions remain about the long-term persistence and productivity of these legume species in colder, heavily frosted locations of southern Queensland and northern New South Wales.

5.1.2.2 Leucaena persistence in southern inland Queensland

Leucaena failed to establish after the initial sowing at five out of six trial sites compared to desmanthus and stylo which was successfully established at five out of six sites. These establishment results reinforce the message to industry that good agronomy is essential when sowing leucaena.

Leucaena was resown at four of the trial sites with plant density only being measured up to one year post sowing. Early indications are that leucaena is growing poorly at the loam trial sites and St

George clay however the trial sites are too young to conclude whether leucaena will persist in the long-term. The leucaena has grown well at Allora flat and Goondiwindi clay.

The leucaena persistence trials need to continue for several more years to assess the long-term persistence in southern inland Queensland.

5.1.3 Legume establishment research

5.1.3.1 Improving reliability of legume establishment

Poor establishment is the most common reason for failure of pasture legumes in existing commercial grass pastures, however the most commonly used methods by graziers are low cost and low reliability. Fallowing to store soil moisture and control competition from the existing grass pasture improves establishment. Greater control of competition through the use of post-emergence herbicides like Spinnaker, Basagran and Verdict (all not registered for these legumes) can improve seedling survival and therefore establishment success. Establishing legumes in long fallowed strips (9 – 12 month fallows) may be able to achieve equally high legume dry matter production per hectare with higher reliability than medium length fallows (3 – 6 months) over the whole paddock.

Plot trials in this project have shown that dramatically better and more reliable establishment of small-seeded legume into existing sown grass pastures is achievable through using agronomic practices that are commonly used by the grains industry (and graziers when establishing leucaena). Industry needs to adopt more reliable establishment techniques when introducing legumes into existing grass pastures to realise their full potential to improve productivity and economic returns in the sub-tropics. The challenge for future participatory research and extension is to take the principles developed from the plot trial results in this project and adapt and demonstrate them at the paddock scale using commercial equipment.

5.1.3.2 Phosphorus fertiliser impact on legume establishment

Annual medic responded strongly to phosphorus fertiliser during establishment. These results align with previous studies (Rudd 1972; Clarkson *et al.* 1989). The medic trial only produced harvestable yields in two out of four years which demonstrates the impact of drought but also the large variation in medic yield between years in summer dominant rainfall zones that have unreliable winter rainfall patterns.

Desmanthus (*D. virgatus* and *D. leptophyllus*) and Caatinga stylo did not respond to phosphorus fertiliser during establishment. These results suggest that these legumes have a low phosphorus requirement compared to other pasture legumes. Other studies have shown 40-100% increases in dry matter production from applying P fertiliser in established grass and legume pastures for these species in similar soils and climate (Peck *et al.* 2017a).

It is likely that the experimental design and site selection affected the phosphorus fertiliser response from desmanthus and Caatinga stylo for the following reasons:

- No grass was sown with the legumes. Grasses compete strongly with the legume for available P in the soil. Not sowing grass would have in effect increased the supply of P to the legume seedlings through reducing grass competition.
- Long bare fallows. The tropical legume trials were fallowed for >12 months which would have increased P availability during establishment.

- Soil variability. The trial site has a subtle underlying Gilgai pattern that increased variability between plots. Many low P clay soils in the Brigalow Belt have Gilgai.
- Moderate P levels. The Wandoan trial site had a Colwell P of 6 mg/kg and a PBI of 66; the ideal trial site would have a lower Colwell P and/or higher PBI.

It is recommended that future phosphorus fertiliser application experiments on desmanthus and Caatinga stylo be managed differently to better reflect likely commercial results. Recommendations include sowing grass with the legumes, minimising the fallow period and selecting soils with lower soil P levels (if possible).

5.2 Benefits to industry

The Brigalow Belt bioregion is an important production zone for red meat in Australia. Queensland accounts for 47% of Australia's cattle herd (ABS 2016). The Brigalow Belt bioregion carries approximately 50% of Queensland's beef cattle herd and accounts for 44% of the gross value of agricultural production (GVAP) from grazing (Table 1) (ABS 2016; Anonymous 2022). The Brigalow Belt bioregion produces more than four times the GVAP from grazing than the next most productive bioregion in Queensland.

Pasture legumes have been identified as the best long-term option to increase the productivity and returns from both rundown sown grass pastures and native pastures in the Brigalow Belt bioregion through their ability to biologically fix atmospheric nitrogen (Peck *et al.* 2011; Bowen and Chudleigh 2018). Despite impressive results from legumes in trials and some commercial pastures, adoption levels remain very low in the Brigalow Belt (Peck *et al.* 2015; Beutel *et al.* 2018). This project has contributed to sowing additional areas of pasture legumes, adoption of practices that improve the reliability of legume establishment and improved long-term productivity. More widespread and successful adoption of pasture legumes is therefore a large production and economic opportunity for individual beef producers and collectively the broader red meat industry. This project has contributed to the northern Australian beef industry due to working in the bioregion with the greatest gross value of production and working on the best long-term management option to improve productivity in the region.

Research trials on establishing small seeded legumes (e.g. desmanthus) into existing buffel grass pastures demonstrated that methods and recommendations developed in other climatic zones are not reliably in the Brigalow Belt bioregion (Peck *et al.* 2017b). For example, stylo establishment in the seasonally dry tropics (i.e. monsoonal areas) or inland Burnett (higher rainfall) has been considered adequate with little or no disturbance to the existing pasture (e.g. heavy grazing, fire) or one-pass cultivation and seeding operations (e.g. band seeders, crocodiles, blade ploughs, discs, chisel ploughs). Clovers have often been flown on with fertiliser in more temperate regions. One pass cultivation while seeding approaches to establishing legumes into existing competitive grass pastures failed in all six research trials conducted by this project. Commercial experiences over decades demonstrates that these methods fail in most years in the Brigalow Belt (Peck *et al.* 2011). By contrast, fallowing and weed control produced successful and reliable results in the year of sowing at all six trial sites. These trial results were used to develop better recommendations for establishing legumes in the Brigalow Belt bioregion.

A key output from this project was to review research results and commercial experience to develop agronomic management recommendations specifically for the Brigalow Belt bioregion to more reliably and effectively establish legumes and to maintain productivity in the long-term. These recommendations have been packaged into a full-day workshop that facilitated graziers through a process to review research results and apply the management recommendations to their own property and situation. This workshop was delivered to 23 groups of graziers and farm advisors.

The workshop engaged with 355 graziers and 57 farm advisors from both the private and public sector. Two hundred and twenty-six grazier businesses attended the workshops which is 5.1% of Brigalow Belt bioregion and 2.2% of grazing businesses in Queensland. These graziers run 279,000 head of cattle which represents 5.6% of the beef herd in the Brigalow Belt and 2.6% of Queensland's beef herd. It is a major achievement of a small project team to engage with so many producers representing a large percentage of the industry through workshops in a 5 year project that was also conducting research trials.

Graziers who attended the workshop sowed 42,000 ha of legumes since attending the workshop. These graziers intend to sow an additional 111,200 ha with legumes over the next 5 years (i.e. from 2022 – 2027). The project team also conducted field days which likely resulted in additional sowings. One seed company reported that they had increased seed sales in the week after our workshops were held in the district, with the largest single sales week being after one of our field days (N. Kempe *pers. comm.*).

Early results from research trials conducted by this project are indicating that available varieties *Desmanthus virgatus* and Caatinga stylo are likely to persist in the frosty southern parts of the Brigalow Belt. Some of the other species of desmanthus and stylo are unlikely to be persistent in southern districts. It is likely that more productive varieties could be found through an evaluation program. The results from this project will help graziers and farm advisors choose which varieties to sow in the future.

6 Future research and recommendations

Pasture legumes have been identified as the best long-term option to increase the productivity and returns from both rundown sown grass pastures and native pastures through their ability to biologically fix atmospheric nitrogen (Peck *et al.* 2011; Ash *et al.* 2015). Despite impressive results from legumes in trials and some commercial pastures, adoption levels remain very low in the Brigalow Belt (Peck *et al.* 2011). Research, Development and Extension (RD&E) priorities therefore focus on improving commercial results, reliability and long-term productivity from legumes in competitive grass pastures (especially buffel grass). High priorities for future RD&E are described below:

1. Extension to improve commercial reliability and productivity of legumes.
2. Develop improved legume establishment methods.
3. Better legume varieties.
4. Improved nutrition of legumes.
5. Improved reliability of establishing rhizobia of summer growing legumes when sown onto hot soils.
6. Reliable seed quality.

In addition to RD&E to improve the successful adoption of legumes described above, there are also opportunities to improve productivity through the adoption of other strategies to increase productivity from pastures. For example, strategic use of N fertiliser and improved grazing management can have a role to improve productivity and economic returns (Quirk and McIvor 2005; Lawrence *et al.* 2014).

6.1 Extension to improve commercial reliability and productivity of legumes

Understanding of best management practices varies across industry (graziers and advisors). There is a large opportunity to improve returns in the grazing industry through widespread, successful and reliable adoption of pasture legumes. Investment in development and extension is required for widespread improvement in commercial results from legume augmentation in competitive sown and native pastures in the Brigalow Belt. Priorities for future work include:

- Learning based extension program on pasture legumes. Build landholders understanding and skills in establishing and managing pasture legumes through a learning-based extension program. There are clear opportunities for improving reliability of pasture legumes through widespread adoption of better practices. The workshop developed as part of this project should continue to be delivered as it has been well attended and had positive feedback. The workshop presented research results that have direct application to commercial paddocks, packaged information and knowledge accumulated from multiple sources and met a demand from industry. The workshops were also linked to graziers testing practices on-farm. Follow up contact with workshop participants as part of the overall training program to adapt, reinforce and support adoption of recommended practices to a graziers individual circumstances is recommended to enhance the outcomes from future training programs (Coutts *et al.* 2017)
- Improving sown pasture information access. There is a need to update independent information on sown pastures to prevent previous research and commercial experience from being lost, bring together fragmented and inaccessible technical information and provide an avenue for public access to information. Providing independent information would also allow graziers and advisors to assess sales-oriented advice and recommendations developed in other climatic zones.
- Development and demonstration of key practices. Some practices that have been produced positive results in research trials need to be adapted for use in commercial paddocks. This may require development of new methods or machinery as well as field demonstration in commercial paddocks. The results and information generated through developing management recommendations and commercially demonstrating the approach would provide examples for the 'pastures information access' extension method (described in dot point above).
- Development of management packages for key legume species.
- Promotion of decision support tools or information sources to inform establishment and management of legume pastures. Decision support tools that are useful include seasonal forecast, long-term rainfall data analysis, fallow and soil moisture storage, remote sensing of land condition and pasture yield to inform grazing management.
- Bioeconomic modelling is required to underpin the development of management recommendations.

6.2 Develop improved legume establishment methods.

Establishing legumes into buffel grass pastures is widely perceived to be risky and un-reliable in the Brigalow Belt bioregion (Peck *et al.* 2011). Poor establishment is the most common reason for desmanthus, Caatinga stylo, leucaena and other persistent legumes failing when sown into existing sown grass pastures in the sub-tropics (Peck *et al.* 2011). Industry routinely recommends no disturbance and one pass cultivation approached to sowing legumes that have been successful in other climate zones; however these methods fail to produce adequate legume establishment in most years in the Brigalow Belt (Peck *et al.* 2017b). Poor establishment with low initial legume densities have not recruited additional legume plants to produce an adequate legume population over a 15 year time period after sowing with buffel grass in the Brigalow Belt (Peck *et al.* 2017a).

Improving reliability of establishing small-seeded legumes into existing, competitive grass pastures is required to provide industry with the confidence to invest in sowing legumes. Research trials have shown that improved agronomy can dramatically improve the reliability of establishing legumes into existing grass pastures in the Brigalow Belt climate (Peck *et al.* 2017b). RD&E priorities for legume establishment include:

- Development and extension of improved legume establishment methods. Research results from plot scale experiments need to be adapted to paddock scale commercial sowing of legumes. This requires both extension of existing recommendations and development, testing and field demonstration of commercial scale methods and equipment in a "technology development" extension approach (Coutts *et al.* 2017).
- Herbicide registration for important legume species. Herbicides used for selective weed control in legumes are not registered for desmanthus and Caatinga stylo (and other important species). Research trials are required to support applications for off-label registration of herbicides.
- Model the reliability of legume establishment methods in different climatic zones to develop regionalised recommendations. Graziers get legume recommendations from multiple sources, many of the recommendations are relevant to the regions where they were developed but are unsuited to the unreliable seasons experienced and high grass competition in the Brigalow Belt climate zone. A modelling approach would allow regionalisation of legume establishment recommendations across Queensland.
- Demonstration of fallows to improve legume establishment. Research results suggest medium to long fallows (>4 months) dramatically improve reliability of legume establishment. During workshops 82% of graziers indicated they intended to use medium or long fallows, however only 35% of graziers used medium or long fallows when sowing legumes on their own property after attending the workshop. Industry continues to use and recommend one-pass cultivation or no pasture disturbance despite decades of establishment failure in the Brigalow Belt. Continued extension effort including demonstration of improved practices is required to change this practice.

6.3 Better legume varieties

A review by Bell *et al.* (2016) identified clay soils in the Brigalow Belt bioregion as being the highest priority for developing better legume varieties in northern Australia. The highest priority genera for further evaluation were *Desmanthus* and *Stylosanthes*.

Early results from the legume persistence trials conducted by this project suggest that several commercial varieties of desmanthus have not maintained high plant densities or high yields. A recently completed project identified stylo varieties that had 40-70% higher yields than commercial varieties (Peck *et al.* 2022). There is a high probability that there are more productive and persistent lines of both desmanthus, Caatinga stylo and other species in the Australian Pastures Genebank collection. There is a need for on-going investment in pasture evaluation to mitigate the risk from diseases affecting existing pasture varieties (e.g. powdery mildew in medics, anthracnose in stylo, pasture dieback in tropical grasses).

6.4 Improved nutrition of legumes.

The potential of fertilising legume based pastures in the Brigalow Belt with phosphorus and other fertilisers has been reviewed by MLA and DAF (Peck *et al.* 2015). The report concluded that there is likely to be large production and economic benefits but that there is limited trial data and very limited commercial experience in using P fertiliser on sown grass with legumes in the Brigalow Belt. This paucity of information limits the capacity to conduct detailed bio-economic assessments of P fertiliser use. RD&E priorities therefore focus on improving the understanding and quantification of responses to fertiliser application. RD&E priorities identified by Peck *et al.* (2015) include:

1. Demonstrating the animal production response and economic impact of P fertiliser applied to legume-based pastures at the paddock scale in the sub-tropics and developing recommendations for important legume species.
2. Pot trials to rapidly develop comparative response curves for adapted legumes to establish critical P requirements and rate of response to applied P for legumes. These trials will help to define fertiliser rates and therefore the costs aspect of economic analysis. This activity has been partially funded under the livestock productivity partnership.
3. Test the field responses of legumes to applied fertiliser (rate and application method). Key measures to be quantified include pasture yield, nitrogen fixation response and pasture composition changes. Results from these trials will link to pot trial studies to better define likely production responses to fertiliser.
4. Understand Brigalow clay soil responses to fertiliser P, i.e. how much fertiliser and how often does it need to be applied to achieve critical P levels.
5. Develop a better understanding of the extent and impact of P deficiency on animal production (i.e. screen herds for their P status, mapping soil P, soil testing).
6. Test the extent of other nutrient deficiencies (e.g. sulphur, potassium) for pasture legumes.

6.5 Improved reliability of establishing rhizobia

Effective nodulation with rhizobia is essential for the productivity and persistence of pasture legumes (Drew *et al.* 2014). Inoculation with rhizobia is essential for legumes that have specific rhizobia requirements. Both desmanthus and Caatinga stylo have specific rhizobia requirements and therefore should be inoculated when sown. Being summer growing legumes with small seeds means they must be sown at or near the soil surface in summer when the soil is hot. Traditional coating of the seed with rhizobia is unlikely to result in successful rhizobia establishment in many instances under these conditions. The widespread practice of pre-inoculating legume seed within the pasture seed industry has been repeatedly shown to be ineffective (Brockwell *et al.* 1975; Gemell *et al.* 2005; Hartley *et al.* 2012) and yet it continues to be marketed as an effective option by seed companies.

Alternative rhizobia delivery methods that protect the rhizobia from the hot and dry soil surface need to be developed and adopted for Caatinga stylo, desmanthus and other legumes with specific rhizobia requirements to enable the legumes to be highly productive.

6.6 Reliable seed quality

Poor seed quality and inadequate labelling has been a major impediment to the reliable establishment of tropical pastures in Australia (McCormick *et al.* 2009).

The quality and reliability of supply of seed of commercial varieties of tropical pastures is variable with poor quality seed often being sold. Commercial seed has at times had poor germination percentages, poor seedling vigour and high levels of contamination with other species. Poor quality seed results in poor seedling emergence.

Clear labelling of seed is required to calculate suitable sowing rates that provide an adequate number of germinable seeds per square metre. Sowing rates need to consider germination percentage and coating ratio. Commercial seed coating generally adds between 3-10 kg of coating material for 1 kg of pasture seed (for small seeded pastures), therefore seeding rates need to be 4-11 times higher to achieve the same sowing rate of germinable seed per square metre. Graziers often use the same sowing rate for coated seed as uncoated seed which results in poor plant populations and lower production. Inadequate labels means that it is often impossible to calculate a suitable sowing rate based on germination percentage, purity and seed coating ratio.

The seed industry needs to address seed quality and labelling issues if legumes are to be more reliable and successful when sown into commercial paddocks with competitive sown grass pastures. Research and extension organisations need to provide information and tools to graziers and their advisors to calculate suitable sowing rates and compare the value of seed lots.

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8 Appendix

8.1 Detailed on-farm trials and demonstrations

The following sections describe the objectives, methods and results of nine detailed on-farm trials conducted during this project.

8.1.1 D1: Legume and grass nutrition trial, Wandoan

8.1.1.1 Objective

The aim of this trial was to compare pasture production from a grass only pasture to a grass-legume pasture with and without fertiliser treatments.

8.1.1.2 Methodology

The trial site was an existing buffel grass and native Queensland bluegrass dominated pasture with scattered desmanthus, Caatinga stylo and medic plants. The soil is a Brigalow grey clay (Vertosol) with low phosphorus (6 mg P/kg Colwell). The site was cultivated by the grazier and fallowed for approximately four months before applying treatments. The non-replicated treatments are:

1. Grass only.
2. Grass + N fertiliser.
3. Grass + P fertiliser.
4. Grass + N fertiliser + P fertiliser.
5. Grass + legume (Caatinga stylo).
6. Grass + legume (Caatinga stylo) + P fertiliser.

Fallowing started in October 2017. Treatments were applied and sown by the grazier using his own equipment, in February 2018 (Figure 29). Gatton panic was sown over the whole trial area at the same time but failed to establish so buffel grass and Queensland bluegrass re-established from existing seed in the soil.

Figure 29: Sowing the detailed on-farm trial using the grazier's air-seeder, in February 2018.

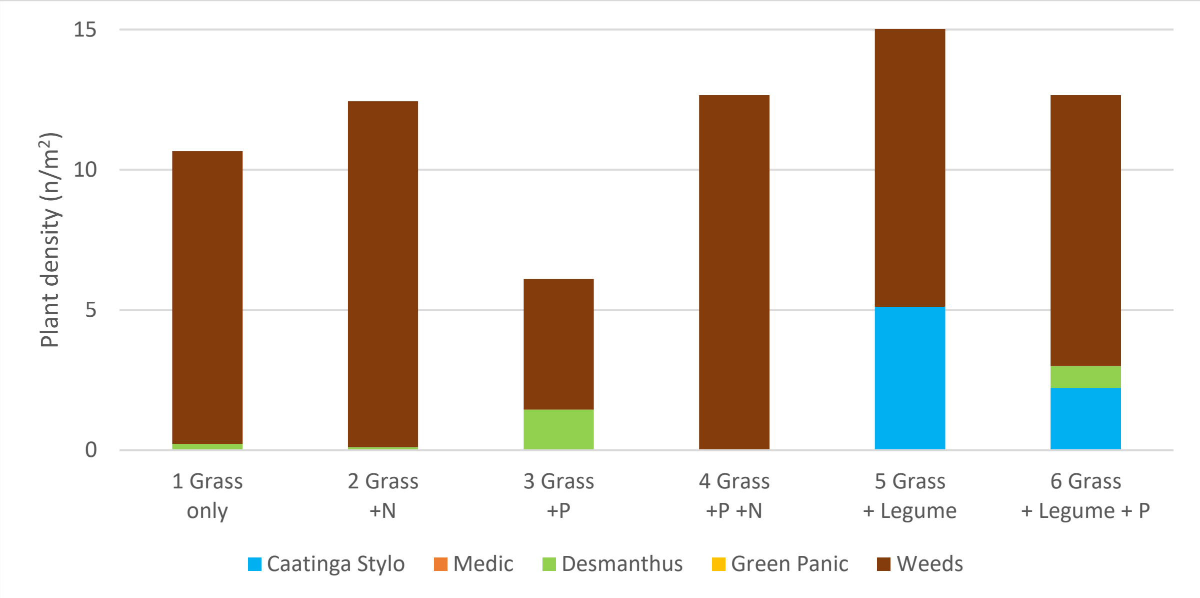
8.1.1.3 Results

Plant density data was collected at this site in May 2018, May 2019 and April 2021. In 2021, after four years of growth, the sown Caatinga stylo numbers have persisted in the grass+ legume treatments, although seems to be in higher density without phosphorus (P) than with P.

Background medics and desmanthus were also monitored, as both contributed to the overall pasture yield. Early observations from the first four years indicate that the background population of desmanthus responded to the P better than the sown Caatinga stylo. Figure 30 shows desmanthus numbers increased in the two P treatments, whereas the Caatinga stylo population reduced in the treatment with P applied.

Weeds, including roly-poly and other broadleaf plants, continue to be in high numbers; however the background populations of buffel grass and Queensland bluegrass may potentially outcompete the weeds over time. The first few years of establishment can expect to see a high weed population, especially after a permanent pasture is fallowed only for a short amount of time. In this case, four months fallow is insufficient time to removing the weed seedbank before sowing.

Figure 30: Legume, weed and sown grass plant density in April 2021 at the detailed on-farm trial in Wandoan. The legume sown in the two grass + legume treatments was Caatinga stylo.

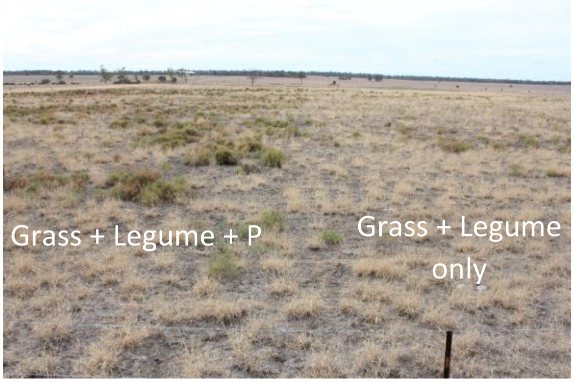


The photo sequence below (Figure 31) illustrates the condition of the trial site from winter 2019 – after the second growing season – to early summer December 2021, comparing the 'grass with legume and P fertiliser' treatment on the left, and 'grass with legume only' treatment on the right.

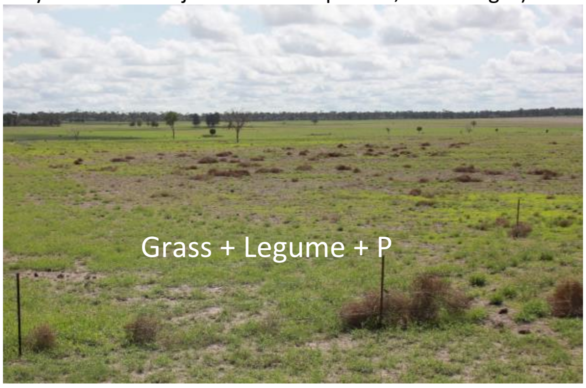
This trial will continue as a legacy for the landholder to monitor and use as part of their grazing management.

Figure 31: Photos over the sown legume (Caatinga stylo) treatments with and without phosphorus over time. A) August 2019; B) January 2020; C) April 2020; D) August 2020; E) April 2021; F) December 2021).

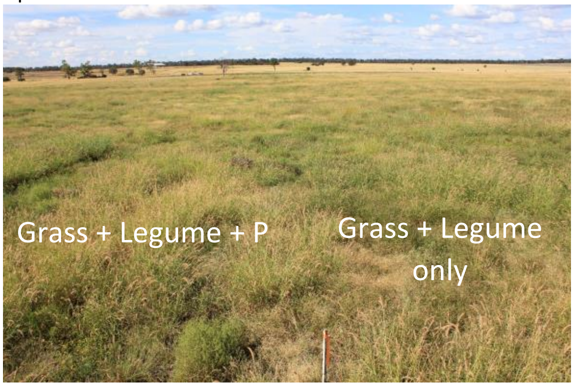
A) Winter groundcover in the trial area in the driest year on record, August 2019.



B) A break from the dry, January 2020 ('grass + legume only' treatment is just out of the picture, on the right)

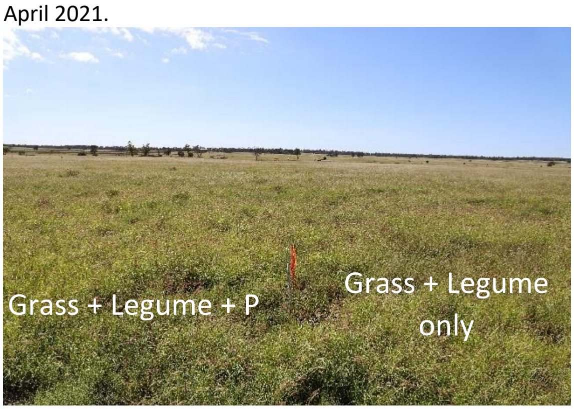


C) Recovering pastures with high annual grass load with the buffel and Caatinga stylo after good autumn rain, April 2020.



D) Before grazing in winter, August 2020.

E) Good pasture growth with reducing weed competition, buffel grass, Queensland bluegrass and Caatinga stylo, in April 2021.



F) Dry season recovery with an early wet season start: grass growth, weeds and legumes, in December 2021.

8.1.2 D2: Variety and nutrition, Moura

8.1.2.1 Objective

The aim of this trial site was to demonstrate the impact of a range of seedbed preparation techniques with and without fertiliser (N, P, S and Zn blend applied) on the establishment of two perennial legumes Caatinga stylo and desmanthus cv Marc.

8.1.2.2 Methodology

The existing grass pasture at this trial site was severely 'rundown' at the time of selection, that is, plant-available nitrogen was low, mostly owing to the age of the pasture. The pasture consisted of buffel and Sabi grasses with native species, and a very low population of shrubby stylo. The soil type is a light duplex with sandy-loam topsoil over a heavier textured subsoil.

Treatments were initiated by the grazier in September 2017 and are outlined in Table 35. There is only one replication of each treatment, but the treatments ranged in size from 4 to 10 acres (1.6 – 4 ha). Soil samples were tested from the top 10 cm at the time of site selection which highlighted very low levels of nutrients important for legume growth, including phosphorus (<5 mg/kg Colwell), sulphur (2.3 mg/kg) and zinc (0.42 mg/kg). A commercial fertiliser blend 'Zinc Star' (N 10%, P 22%, S 2%, Zn 1%) was applied at 250 kg/ha to provide a comparison to areas without fertiliser. The site was broadcast sown on 10 February 2018 after a below-average summer season during the fallow period. This resulted in minimal subsoil moisture being stored across the site. Two legumes sown were Caatinga stylo and desmanthus cv. Marc.

Table 35: Treatments imposed at the seedbed preparation, variety and nutrition trial near Moura.

Legume	Paddock preparation	Fertiliser
Caatinga stylo (coated seed)	Sprayed only	None
	Sprayed and cultivated	None
	Cultivated	None
	Cultivated and fertiliser added	Zinc Star added
	Lightly cultivated	None
	Undisturbed pasture	None
Desmanthus cv. Marc (coated seed)	Sprayed only	None
	Sprayed and cultivated	None
	Cultivated	None
	Cultivated and fertiliser added	Zinc Star added
	Lightly cultivated	None
	Undisturbed pasture	None
Desmanthus and Caatinga stylo	Cultivated	None

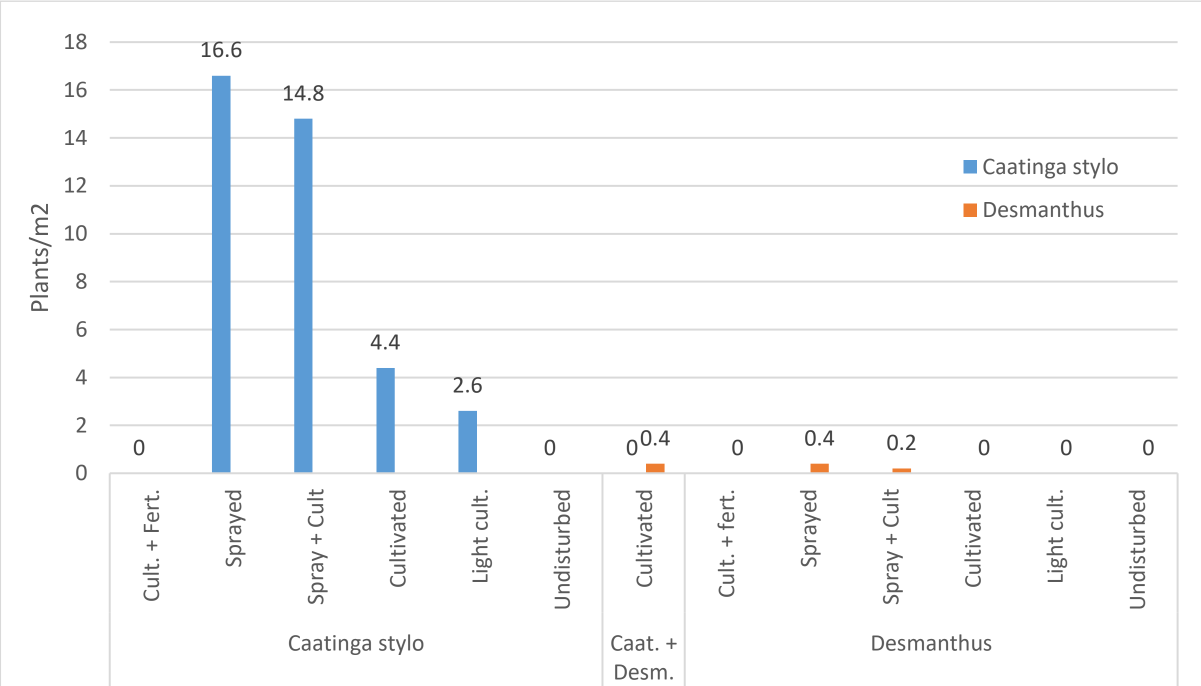
8.1.2.3 Results

Plant density data was collected in June 2018, August 2019 and May 2020.

The first two growing seasons produced low plant density of both legume species, both below the recommended target of 4 plants/m^2. Caatinga stylo had higher population (2.1 plants/m^2) than the desmanthus (0.8 plants/m^2) averaged across all treatments in June 2018, 4 months after sowing. In the second year Caatinga stylo maintained its population and recruited better than the desmanthus, averaging 1.8 plants/m^2 compared to a desmanthus population of 0.03 plants/m^2 averaged across all treatments (August 2019, 18 months after sowing).

Measurements after the third growing season in May 2020 (Figure 32) indicated a significant improvement in plant population, especially for the Caatinga stylo. The Caatinga stylo plant density in both of the sprayed fallow treatments was the highest, with 16 plants/m^2 in the sprayed only treatment, and 14 plants/m^2 in the sprayed and cultivated treatment. It is possible this is owing to the good population at establishment (3 plants/m^2) at these treatments and ongoing protection from the heat allowed by the sprayed out grass acting as mulch.

Figure 32: Plant density after 3 growing seasons (May 2020), at Moura, compared with the recommended 4 plants/m^2 plant density



Overall, by the treatments where any fallow was used had a legume population whereas the treatments with no fallow had little to none. It is likely that this is owing to the fact that fallowed treatments stored moisture over a few months prior to sowing and then in addition to this, sprayed fallow treatments are often more effective at killing grass plants, creating a groundcover and therefore storing more moisture than cultivated fallows.

The desmanthus has been comparably unsuccessful at this site with very few plants established (maximum was 1.8 plant/m^2 in the first year). This supports the recommendation that desmanthus is not well-suited to this sand-loam soil type.

After 27 months of growth (May 2020), the fertiliser treatments on both legume species did not support a legume population (zero plants/m^2). This followed a declining trend noticed in the previous years. The nitrogen in the fertiliser blend would have promoted grass growth, creating competition for moisture and light to the smaller legume seedlings. The second year (2019) was one of the driest years on record and therefore there would have been high competition for moisture between the legume and grass plants and higher-than-normal death rates. In 2020, it was observed that the legumes in the paddock were small and likely germinated from rainfall during the preceding summer.

8.1.3 D3: Fallow and varieties, Wandoan

8.1.3.1 Objective

The aim of this trial was to demonstrate the impact of a range of fallow lengths and the application of fertiliser on the establishment and growth of two legumes, desmanthus cv. Progardes and Caatinga stylo.

8.1.3.2 Methodology

The existing pasture at this trial site was ‘rundown’ buffel grass with no legume content, on a heavy clay soil.

Four fallow treatments were applied: no fallow (0 months), short (2 months), medium (5 months) and long fallow (10 months). The long fallow treatment started February 2018, and the others started consecutively thereafter. Caatinga stylo and Progardes desmanthus were sown separately perpendicular to the fallow treatments. They were both sown at a seeding rate of 3 kg/ha in December 2018. No effective rain fell until mid-March 2019 with 110 mm, resulting in the germination of the legume seed sown three months earlier. The grazier prepared the fallowed paddocks and sowed the pastures.

A soil test was conducted prior to sowing and measured low phosphorus levels (7.2 mg P/kg Colwell). A fertiliser treatment was applied to one fifth of the area of each of the fallow x legume treatments at a rate of 150 kg/ha using triple superphosphate. The paddock chosen for this demonstration was large enough to include two replications of each treatment.

8.1.3.3 Results

Plant density data was collected in May 2019 and February 2021.

In May 2019, the data suggested that fallow length had no impact on legume population establishment, and both species established to some degree across the treatments. The fertiliser application had a positive impact on the population of desmanthus in this first year, whereas this result was not so clear with the Caatinga stylo treatments.

Visual observations made in May 2020 suggested that fallow length had an impact on the grass biomass that established, as well as an impact on the legume population. A comparison between long fallow treatment (A) and no fallow treatment (B) is shown below in Figure 33.

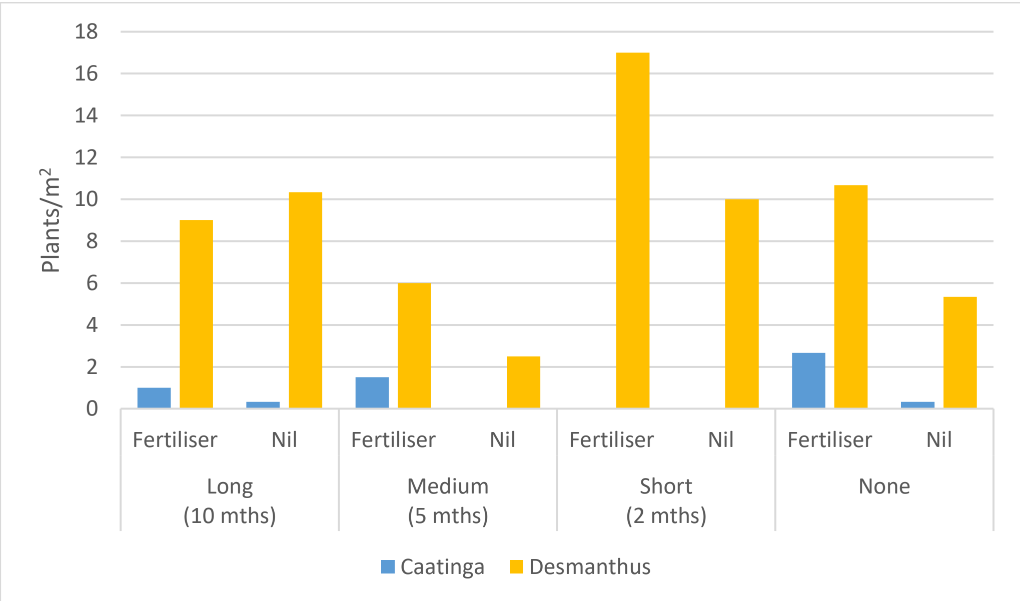
Figure 33: In May 2020, a visual comparison between the long and no fallow treatments showing the difference in biomass A) long fallow; B) no fallow.

A) Long fallow treatment with desmanthus visible in the foreground with the long grass.	B) Zero fallow treatment with desmanthus planted but now in very low population.
	

Plant density data collected in February 2021 after 3 growing seasons, is shown in Figure 34. Desmanthus had good plant density with 2.5 – 17 plants/m^2. Caatinga has had poor plant density since establishment and continued into 2021 with 0 – 2.7 plants/m^2. One of the possible causes for the difference between the species to the seed coating on the Caatinga stylo, whereas the desmanthus was bare seed.

It was expected that more plant numbers would be found in the long fallow, and in the fertilised treatments. By the third growing season in February 2021, most of the treatments produced more legume numbers where fertiliser was applied. The difference between fallow treatments is less informative. This could be the result of variation in the soils and landscape over the trial area.

Figure 34: Plant density over the different treatments, measured in February 2021.



Rainfall in early 2021 was below average for this district, and as a result pasture growth was minimal (short and senesced growth). Figure 35 shows the condition of the pasture at the time of the February 2021 data collection, showing the dividing line of steel pickets between the sown Caatinga stylo treatment in the foreground, and the sown desmanthus treatment (after the steel pickets).

Figure 35: In February 2021, looking across the dividing area between sown Caatinga stylo (in the foreground, before the steel pickets), and desmanthus (in the mid-ground after the steel pickets).

This trial has not resulted in conclusive evidence about fallow length to maximise production, however the producer was keen to test out the concept and has already hosted a field day where this trial was visited and the activities discussed (in June 2018). It is expected this trial will continue as a legacy for the cooperating producer to monitor and used as needed.

8.1.4 D5: Faecal seeding, Wandoan

8.1.4.1 Objective

This trial aimed to test the effectiveness of faecal seeding desmanthus into an existing buffel grass pasture.

8.1.4.2 Methodology

The paddock is an established buffel grass pasture on undulating country with a range of Brigalow clay soils.

Between August and September 2018, a loose lick supplement was blended with uncoated desmanthus cv. Progardes and fed to stock in a 50ha paddock near Wandoan. The lick troughs were shifted within the paddock every three to four days, always away from the water trough in the western corner of the paddock. Fifty cows with calves were in the paddock during this time grazing the pastures. At this time of the year – late winter/early spring – pasture quality was low and the loose lick supplements were well accepted by the livestock. During a six-week timeframe, the seed and loose lick blend was consumed by the stock, and seed excreted in faeces.

Plant density measurements were made using a transect to cover all pasture conditions, locations on the slope and distance from the watering point, resulting in a dogleg transect. The transect started at the trough (in the western corner, Figure 36) and moved up the slope to the eastern paddock boundary. The transect was 810 m long and 2 m wide. Adult desmanthus plants were counted and their distance along the transect recorded.

Figure 36: The water trough in the western corner of the trial paddock has a high population of desmanthus growing in an area that accumulates lots of faeces to spread seed and has ideal conditions for legume establishment.

8.1.4.3 Results

Plant density measurements were collected in over four seasons between 2018 and 2021.

In summer 2021, the plant population peaked at 0.12 plants/m^2 (Table 36) over the whole paddock (i.e. roughly one plant every 10 m). The highest density during measurements was near the water trough with 0.48 plants/m^2. The reason for this was little-to-no pasture around this part of the paddock providing very little competition for moisture for the desmanthus seedlings. Across the paddock where there was strong buffel grass competition, the desmanthus seedlings were far and few between.

Table 36: Seasonal results of faecal seeding into buffel pastures near Wandoan, average plant density over the paddock each year.

Year	Season	Plants per m^2
2018	Winter	0.00
2019	Autumn	0.03
2020	Autumn	0.07
2021	Summer	0.12
	Autumn	0.09
Target population comparison		4.00

Overall, after four years the established population is about 2% of the target (4 plants/m^2) across the whole paddock for production benefits. The desmanthus population that established is not sufficient to provide a production benefit and therefore a return on investment either now or in the immediate future. A legume population of at least 4 adult plants/m^2 is needed and legumes need to contribute more than 10-20% of total pasture biomass before measurable production benefits occur.

The producer was interested in the results and tried faecal seeding once more in another paddock, but in future intends to sow new pastures using existing equipment and best practices.

8.1.5 D6: Fertilising existing grass-legume pasture, Bauhinia

8.1.5.1 Objective

The aim of this trial was to demonstrate the impact of phosphorus fertiliser on the growth of an existing grass-legume pasture, with different rates and placement methods.

8.1.5.2 Methodology

The existing grass-legume paddock near Bauhinia was sown to Caatinga stylo and desmanthus cv. Progardes in 2012, about five years prior to this trial commencing. The trial was established during early summer 2018. The pasture was dominated by Indian couch prior to sowing the legume and no grass seed was sown with legumes. The trial site has low nutrient availability due to an extensive history of grain production before being converted to pasture.

Soil nutrient levels in the topsoil (0-10 cm) were measured prior to fertiliser treatment application. The soil test results indicated moderate available phosphorus (P) (12 mg/kg Colwell), adequate sulphur (S) (5.5 mg/kg) and potassium (K) (0.7 cmol(+)/kg) levels. The critical soil phosphorus level to maximise legume growth is unknown for desmanthus and Caatinga stylo, but the Colwell P measurement of 12mg/kg at this site may be adequate; despite this, the fertiliser treatments were applied as planned.

The fertiliser treatments outlined in Table 37 were applied in mid-December 2018 and replicated three times. The fertiliser used in the phosphorus-only treatments was triple superphosphate (P 20%, S 2% and Ca 17%). Despite reasonable sulphur and potassium levels in the soil, a treatment with these nutrients was also included to determine if additional plant growth benefits could be achieved together with high phosphorus supply. Sulphur and potassium were supplied as sulphate of potash (K 42% and S 17%) at 150kg/ha.

Pasture species present in the trial include Sabi grass, buffel and Indian couch, together with desmanthus (cv. Progardes) and Caatinga stylo.

Table 37: Fertiliser treatments applied at fertiliser trial at Bauhinia.

Phosphorus rate	Application method	Fertiliser product and rate
0 kg/ha	No disturbance	Nil
	Disturbance with discs	
20 kg/ha P	Broadcast	97 kg/ha triple superphosphate
	Drilled with discs	
40 kg ha P	Broadcast	193 kg/ha triple superphosphate
	Drilled with discs	
40 kg/ha P, K and S	Broadcast	193 kg/ha triple superphosphate plus 150kg/ha sulphate of potash
	Drilled with discs	

8.1.5.3 Results

Rainfall over late summer 2020 provided limited but much-needed recovery from the very hot and dry conditions over spring and early summer in 2019. No quantitative data was collected from the trial, since a response to the fertiliser treatments were not visible as the trial went into – and then recovered from – drought conditions.

The trial was observed after the treatments were applied and Figure 37 and Figure 38 show the response of the annual-acting Sabi grass as it recovered from the drought in February 2020, and then collapsed in May 2020. Due to the extremely dry soil profile the rainfall was insufficient to generate a biomass response from the fertiliser treatments imposed. A visual appraisal of the site in July 2020 indicated no biomass responses across the treatments, and it was decided not to undertake a biomass yield assessment of the site.

Figure 37: Rainfall after a very dry period produced quick-growing grasses and not showing any visible response to the fertiliser applications, February 2020.

Figure 38: Annual grasses un-grazed during the summer collapsed and made data collection and interpretation difficult. Photo taken in May 2020.

This site will continue to be utilised and monitored by the grazier going forward and as pastures rest and recover it may provide visual results for the grazier.

8.1.6 D9: Planting strips and applying fertiliser, Durong

8.1.6.1 Objective

The aim of this trial was to compare sowing strips to whole paddock planting and the impact of fertiliser application.

8.1.6.2 Methodology

A 30 ha paddock of improved and native grasses on Brigalow clay was selected for this trial. The paddock was fallowed using zero-till and split into two treatments:

1) 'whole' paddock, and
2) 8m wide strips.

The first attempt at sowing occurred in March 2018, but it was late in the season and the plants were slow to establish before going into winter frosts. The blend of legumes and grasses planted in 2018 were Angleton grass (*Dicanthium aristatum*) cv. Floren, lucerne (*Medicago sativa*) cv. Sequel, desmanthus (*Desmanthus spp*.) cv. Progardes, and Caatinga stylo (Stylosanthes seabrana). The producer replanted with just desmanthus and Caatinga stylo in December 2018 before a good rainfall event.

Soil tests indicated that the paddock had sufficient phosphorous (P) (21 mg/kg Colwell) and sulphur (S) (11mg/kg) nutrition for legume growth, however fertiliser response was of interest to the producer so at the time of sowing he applied three different fertilisers. The fertilisers applied were urea (46% N); Gran-Am (20% N, 24% S); and 50:50 blend of DAP (17% N, 20% P) with urea. The fertiliser was applied in three separate strips perpendicular to the direction of the planting across both the 'whole' paddock and the strips.

8.1.6.3 Results

There was no visible difference to the legumes sown between where the fertiliser was applied and where it was not, as all fertiliser treatments included N and the season that followed was the driest year on record for the district (2019) restricting growth.

Over both planting attempts, three legume species were sown and all established in the first year (Figure 39) but none were measured in significantly high numbers in 2021. No lucerne was found in 2021, however Caatinga stylo and desmanthus had low plant numbers both averaging 0.2 and 0.3 plants/m^2 respectively (Figure 40). Floren Angleton grass was not found during the assessment in 2021.

In early 2022, the grazier observed "desmanthus doesn't seem to be happy here – it gets up (establishes) but doesn't stick around, whereas Caatinga seems to be coming good, finally". He was planning on sowing Caatinga stylo that same summer, as a result of this trial.

Figure 39: Newly emerged strips of legumes and grass in May 2019.

Figure 40: A team member standing in the middle of one of the sown strips - desmanthus and Caatinga stylo in low population in February 2021.

8.1.7 D10: Fertiliser into existing grass-legume pastures trial, Wandoan

8.1.7.1 Objective

The aim of this trial is to test the response of established grass-legume pastures to a range of phosphorous fertiliser applications.

8.1.7.2 Methodology

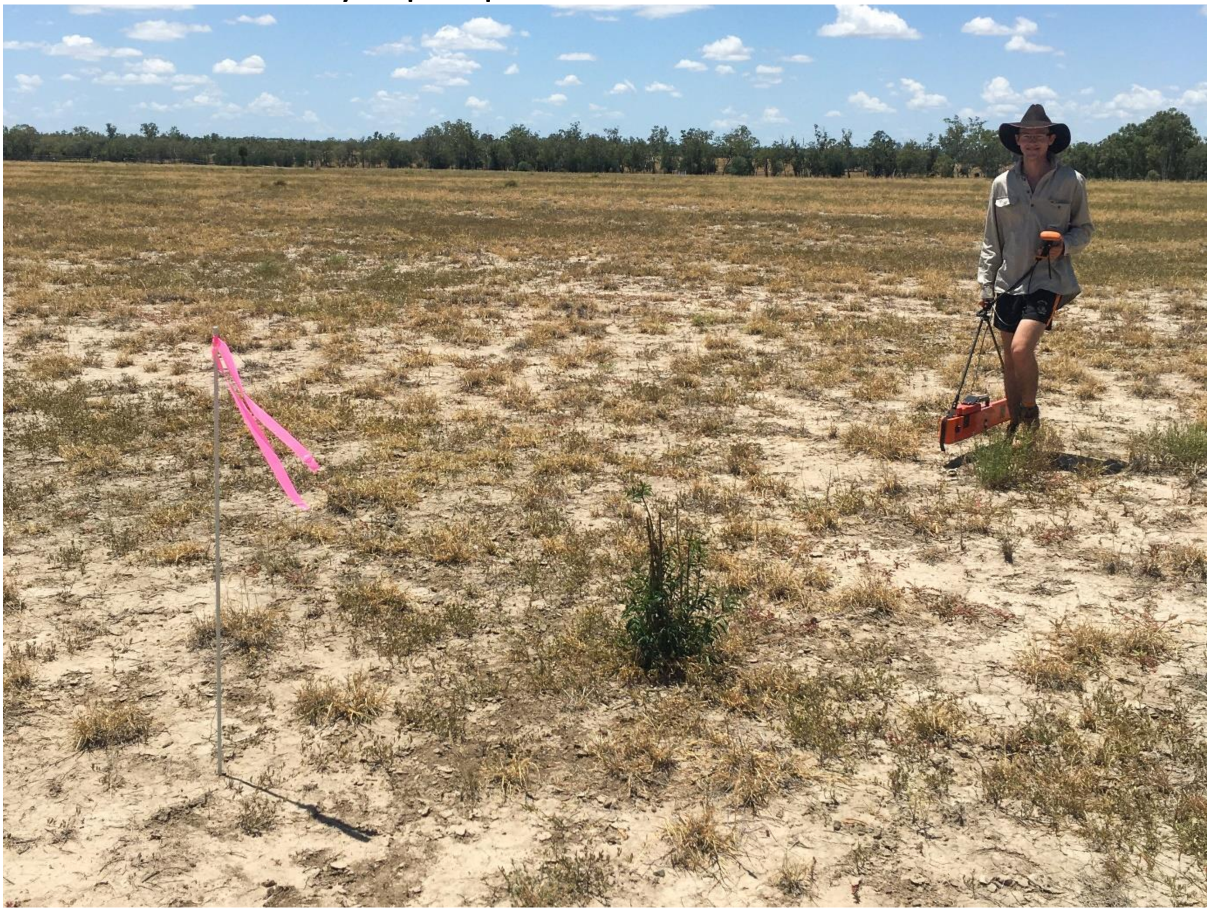
In an existing grass-legume pasture growing on Brigalow clay soils near Wandoan, soil samples were collected for testing in August 2018 which indicated that the soils were low in phosphorus (5.3mg/kg Colwell P) and sulphur (3.4mg/kg MCP S). The samples were taken from a paddock that has an established population of desmanthus and Caatinga stylo with Queensland bluegrass and buffel grass.

The landowner was interested in using a particular fertiliser product and was encouraged to test out other recommended fertiliser options alongside it. The trial start was delayed due to the drought peaking in 2019 (Figure 41), and the landholder was keen to increase pasture groundcover before applying the fertiliser treatments.

Figure 41: Rainfall in March 2019, produced new growth but at a time when pastures should be green and growing well, the record dry conditions in this district delayed the start of this project.

In February 2021, the site was measured for sub-surface variation in moisture, clay content and salts using am EM-38 tool (Figure 42). The data from this activity will be used to identify where to avoid invisible variation in the paddock, which is otherwise flat.

Figure 42: Measuring the sub-surface soil variation with an EM-38. Significant variation could affect trial results when they are put in place.



Despite the delays, the location is very suitable for the type of trial the grazier is still interested in undertaking. It is expected that up to six different treatments will be applied including broadcasting phosphorus fertiliser, broadcasting and cultivating phosphorus, drilling phosphorus and/or using different phosphorus fertiliser sources (e.g. single superphosphate, diammonium phosphate (DAP), rock phosphate) compared to a 'do nothing' control treatment. The trial area is approximately 2.6 ha.

8.1.8 D11: Variety trial, Alpha

8.1.8.1 Objective

The aim of this trial was to demonstrate the growth and production potential of a range of legumes in a drier location of the Brigalow Belt.

8.1.8.2 Methodology

This trial site is located at the western edge of the Brigalow Belt north of Alpha in central Queensland. The pasture is buffel grass on loam-textured soil.

Soil samples were collected and analysed in April 2019. They reported low levels of sulphur (<1.0 mg/kg), low levels of plant-available phosphorous (<5.0 mg/kg Colwell) but adequate potassium levels (0.46 cmol(+)/kg). At this time, the trial site was sprayed with herbicide to begin a fallow to store soil moisture. Each plot measured 25 x 10 m. The plot areas were sprayed again with herbicide and cultivated using a rotary hoe before planting.

Planting took place in early February 2020 after significant rainfall fell in January storing some moisture in the soil profile. Five legume species were sown at 12 kg/ha in the cultivated strips including three desmanthus varieties (cvv. Marc, Progardes and Cowpower), and two stylo species (Caatinga stylo, and Caribbean stylo cv. Amiga).

Six months after establishment, phosphorus fertiliser was broadcast over half of each plot.

8.1.8.3 Results

The rainfall at the start of the year got the legumes established, but there was low rainfall subsequent to that during most of autumn and winter in 2019.

No difference between the fertiliser and no-fertiliser treatments was observed, however there has been a difference observed in how successful each legume variety has been three years since sowing.

Caatinga stylo and Progardes desmanthus did best of all the varieties sown. All species emerged and went to seed, but the Amiga stylo and the Marc and Cowpower desmanthus did not persist. Adding to this, the grazier observed that when the trial area was grazed, the cattle ate the strips first, grazing both the grass and legumes within the strips at the same time.

Photos show the cultivated strips before sowing (Figure 43) and the first year's growth (Figure 44). The trial will continue to provide the grazier with information about species persistence and suitability.

Figure 43: Fallowed and cultivated strip just ahead of sowing, end January 2020.

Figure 44: Aerial photo of the detailed on-farm trial strips among a buffel grass pasture, taken October 2020.

8.1.9 D12: Rate of spread trial, Theodore

8.1.9.1 Objective

The aim of this trial is to determine the rate of spread of legume plants sown in prepared strips through a grass-only pasture over time.

8.1.9.2 Methodology

This demonstration site near Theodore was initiated by the producer who engaged with the project team at the end of a previous project (Improved productivity of rundown sown grass pastures; B.NBP.0639). The existing pasture was good buffel grass with some shrubby stylo, on a light-medium clay soil.

Cultivated strips, about 4 m wide (with 4 m of grass-pasture in-between), were prepared in an existing grass-only pasture by the property owner. Three legumes, desmanthus cv. Progardes and Caatinga stylo cvv. Primar and Unica were sown in early January 2015. Each legume cultivar was sown in a separate strip in twin rows (1 m apart) centred in the middle of the prepared seedbed. Four strips/repetitions of each legume were sown (not randomised), and one permanent measurement station located in each strip.

Seedling recruitment has been measured at the end of the growing season every year since sowing, i.e. 2016 – 2020. Using a 1 m^2 quadrat, seedling numbers have been counted at three distances away from the row of adults:

- 0 to 1 m away
- 1 to 2 m away
- 2 to 3 m away (this third measurement runs into the existing, undisturbed grass-only pasture between the strips).

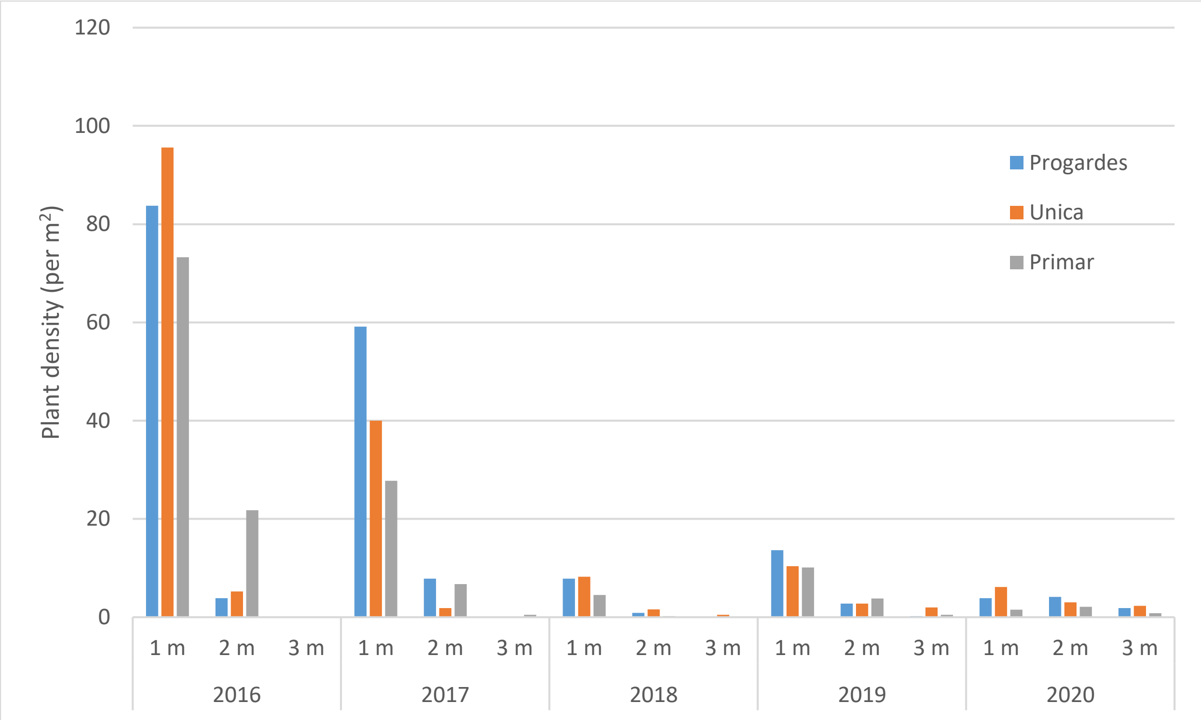
8.1.9.3 Results

The initial legume establishment plant density measurement at this site was very high (20 – 90 plants/m^2) in 2016, much higher than the target 4 plants/m^2. Over time the population of all three legume varieties has steadily declined to the stage where plant population out to 2 m from the originally planted row was around 2 – 4 plants/m^2 in 2020, with no difference between legume varieties. Generally, data collected in autumn 2020 indicated a reduction in plant density from the previous year, which is likely due to the very dry seasonal conditions especially at the end of 2019 and into early 2020.

From the 2020 data, very few (1 – 2 plants/m^2) legume plants of any variety were growing at 3 m or more from the planted row. Up until 2020 there had been a high number of grass plants in the undisturbed grass strips between the planted areas and it is likely this has restricted the amount of legume able to establish between them.

The dry conditions in 2019 reduced the amount of grass between the sown strips, so it will be interesting to monitor what happens after in future summer growing seasons. Figure 45 illustrates the plant population over time, comparing each of the legume varieties and the distance from the sown strips.

Figure 45: Rate of spread demonstration at Moura, plant population per square meter from inception (2016) to May 2020.



The photo in Figure 46 was taken during a visit in November 2017, at the beginning of the third growing season after some spring rainfall. The two shorter strips on the left and right of the photo show the sown strips, and the area in the middle shows the undisturbed grass-only pasture.

Figure 46: Rate of spread strip of Caatinga stylo after being grazed, November 2017.

8.2 Legume density over time at persistence trials

Legume density over time at the legume persistence trials is shown in the graphs below. The St George clay site results are not shown as it was resown and therefore has not been established for long enough to show trends over time.

Figure 47: Allora Flat trial site Desmanthus and Stylo variety population density trend graph. Planting date 20.12.2017

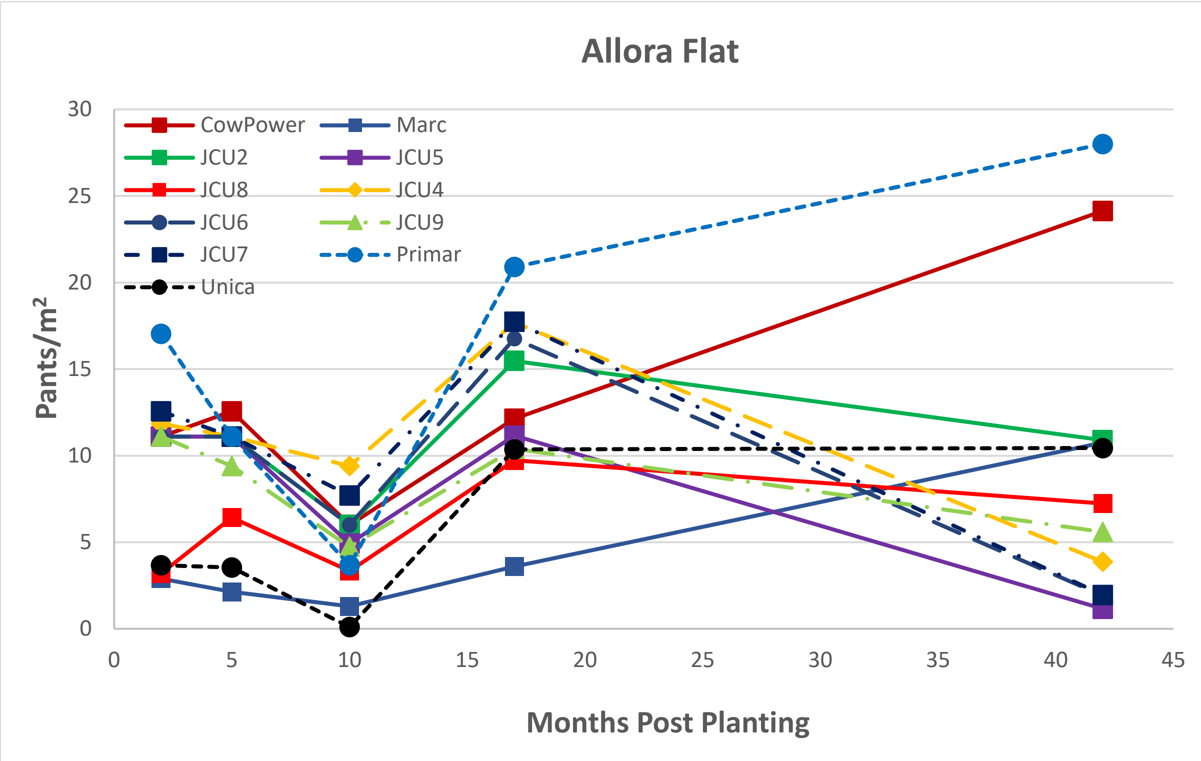


Figure 48: Allora Hill trial site Desmanthus and Stylo variety population density trend graph. Planting date 19.12.2017

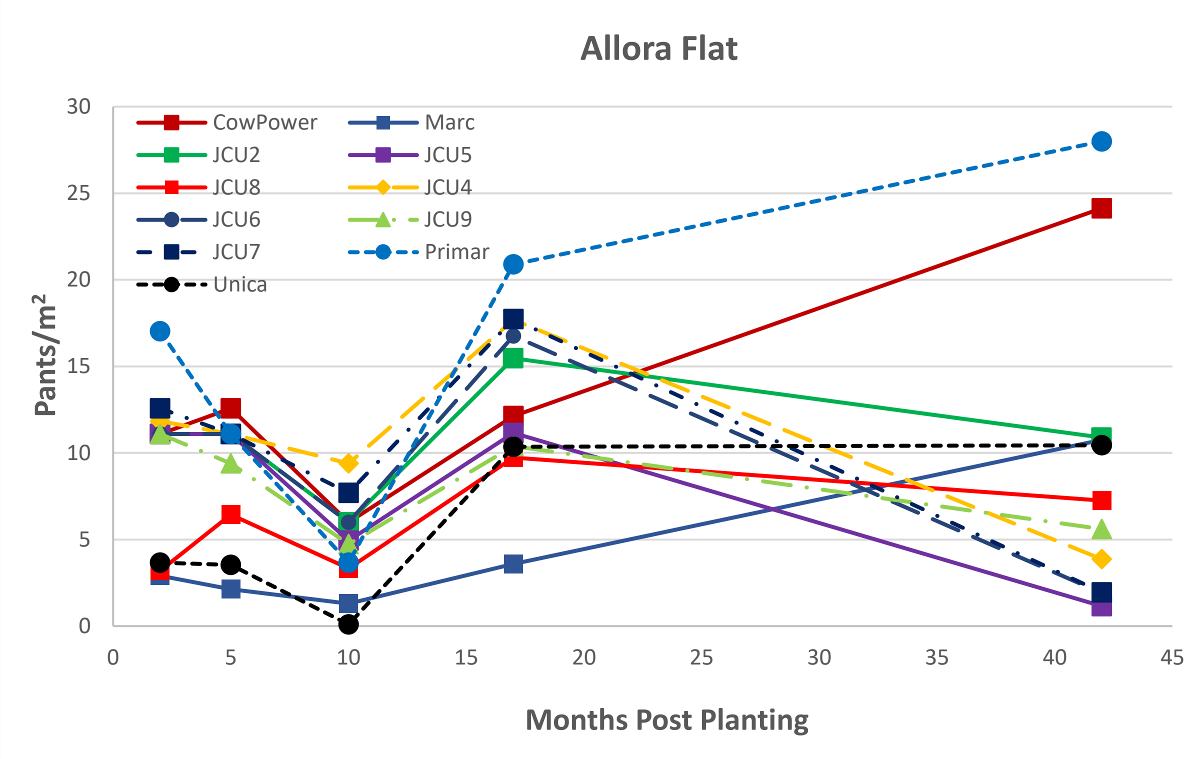


Figure 49: Goondiwindi clay trial site Desmanthus and Stylo variety population density trend graph. Planting date 12.02.2018

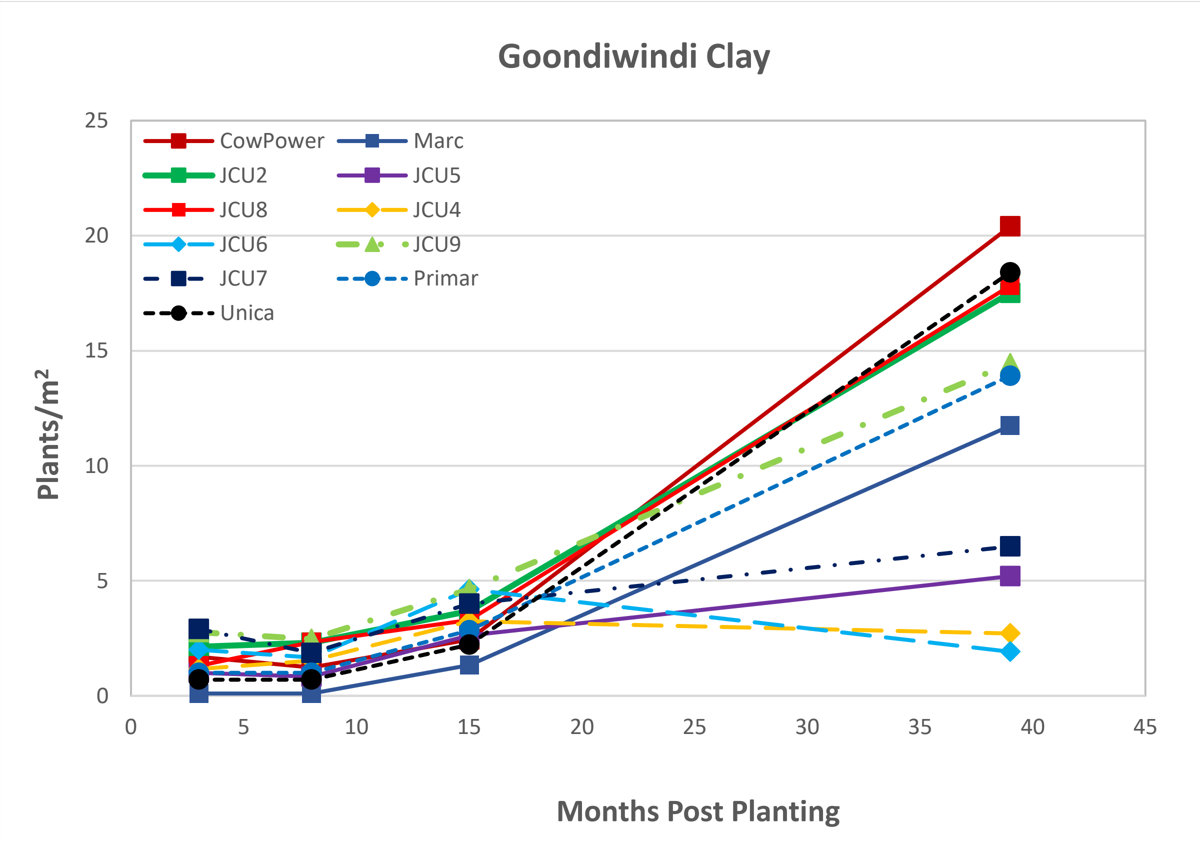


Figure 50: Goondiwindi Loam trial site Desmanthus and Stylo varieties population density trend graph. Planting date 12.02.2018

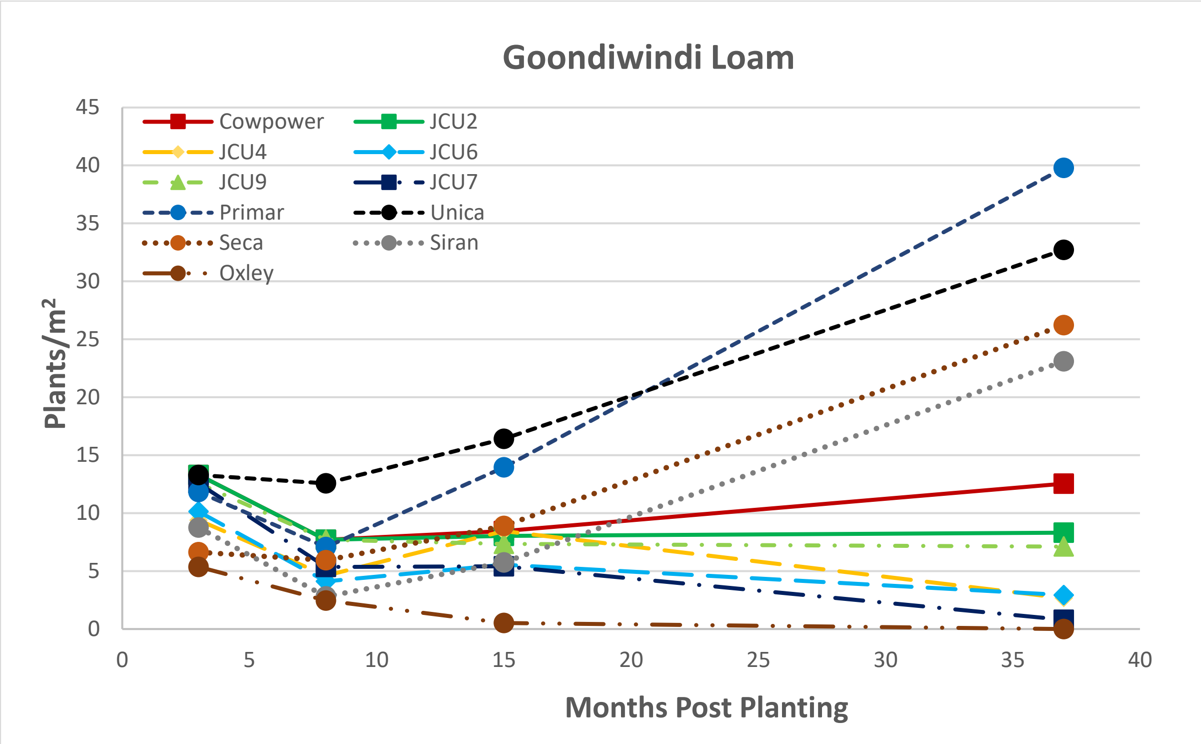
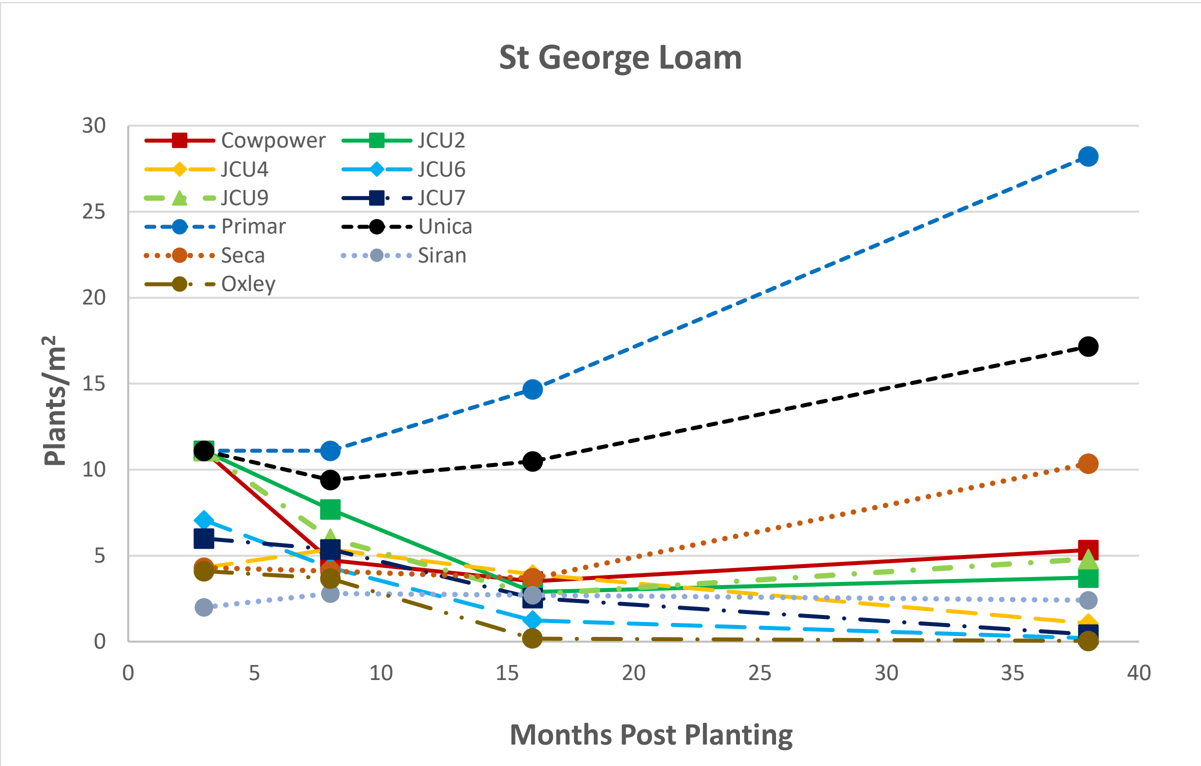


Figure 51: St George Loam trial site Desmanthus and Stylo varieties population density trend graph. Planting date 15.02.2018



8.3 Soil test results for phosphorus fertiliser and legume persistence trials

Soil analysis results from soil samples collected from the phosphorus fertiliser trials (i.e. Wandoan and Goondiwindi sites) and the legume persistence trials (i.e. Allora, Goondiwindi and St George sites). The samples were collected prior to preparing the site for sowing or applying fertiliser.

Table 38: Soil nutrient analysis for Wandoan and Goondiwindi phosphorous fertiliser trial sites.

Location	Depth cm	Colour/ Texture	pH 1:5 Water	EC dS/m	CEC cmol(+)/kg	P Colwell mg/kg	K meq/100g	S mg/kg
Wandoan	0-10	Grey clay	8.3	0.16	28.0	5.9	0.53	2.8
	10-30	Grey clay	9.1	0.4	41.2	<5.0	0.33	6.9
	30-60	*n.d.*	9.0	0.85	42.5	<5.0	0.32	43.0
	60-90	*n.d.*	9.1	0.93	35.0	<5.0	0.32	59.0
Goondiwindi	0-10	Brown clay	8.1	0.18	25.8	13.0	1.1	5.0
	10-30	Brown clay	8.9	0.48	41.5	<5.0	0.64	14.0
	30-60	*n.d.*	8.4	0.93	38.1	<5.0	0.54	59.0
	60-90	*n.d.*	6.0	1.01	31.4	<5.0	0.46	74.0

Location	Depth cm	Cl mg/kg	Mg cmol(+)/kg	Na cmol(+)/kg	Ca:Mg Ratio	Cu mg/kg	Fe mg/kg	Zn mg/kg	Bo mg/kg
Wandoan	0-10	21	6.0	1.5	3.3	0.83	8.2	0.17	0.76
	10-30	230	7.1	4.5	4.1	0.87	8.0	0.22	1.4
	30-60	750	8.1	8.1	3.2	*n.d.*	*n.d.*	*n.d.*	*n.d.*
	60-90	880	7.5	8.9	2.4	*n.d.*	*n.d.*	*n.d.*	*n.d.*
Goondiwindi	0-10	36	6.6	1.1	2.6	0.7	8.7	0.2	0.62
	10-30	330	11.0	4.3	2.4	0.66	8.2	0.2	1.5
	30-60	850	12.0	7.4	1.5	*n.d.*	*n.d.*	*n.d.*	*n.d.*
	60-90	1100	11.0	8.5	1	*n.d.*	*n.d.*	*n.d.*	*n.d.*

n.d. denotes no data

Table 39: Soil nutrient analysis for Allora, Goondiwindi and St George persistence trial sites.

Location	Depth cm	Colour/ Texture	pH 1:5 Water	EC dS/m	CEC cmol(+)/kg	P Colwell mg/kg	K meq/100g	S mg/kg
Allora Flat	0-10	Grey-brown clay	7.6	0.13	51.8	75.0	1.10	3.9
	10-30	Grey-brown clay	8.0	0.11	52.5	30.0	0.53	2.4
	30-60	*n.d.*	8.4	0.23	58.4	34.0	0.42	1.5
	60-90	*n.d.*	8.7	0.22	58.1	31.0	0.37	<1.0
Allora Hill	0-10	Grey-brown clay	7.0	0.09	54.8	87.0	1.20	5.7
	10-30	Grey-brown clay	8.0	0.24	66.2	9.3	0.43	3.5
	30-60	*n.d.*	8.4	0.35	71.6	9.6	0.41	2.7
	60-90	*n.d.*	8.5	0.53	72.4	11.0	0.39	2.0
Goondiwindi Clay	0-10	Brown clay	8.1	0.18	25.8	13.0	1.10	5.0
	10-30	Brown clay	8.9	0.48	41.5	<5.0	0.64	14.0
	30-60	*n.d.*	8.4	0.93	38.1	<5.0	0.54	59.0
	60-90	*n.d.*	6.0	1.01	31.4	<5.0	0.46	74.0
Goondiwindi Loam (2013) [A]	0-10	Fine sand clay loam	7.2	62 [B]	12 [C]	9.0	860 [D]	1.0
	10-30	Fine sand clay loam	8.2	210 [B]	23 [C]	<1.0	400 [D]	3.0
	30-60	Fine sand clay loam	8.5	620 [B]	39 [C]	<1.0	440 [D]	15.0
	60-90	Fine sand clay loam	8.6	920 [B]	35 [C]	<1.0	450 [D]	33.0
St George Clay	0-10	Grey-brown clay	8.4	0.16	27.1	9.8	1.10	4.3
	10-30	Grey-brown clay	9.1	0.21	34.1	<5.0	0.48	3.0
	30-60	*n.d.*	9.1	0.45	34.4	<5.0	0.43	35.0
	60-90	*n.d.*	8.0	2.34	48.8	<5.0	0.43	2100.0
St George Loam	0-10	Yellow-brown clay	7.8	0.13	10.7	35.0	0.84	7.4
	10-30	Yellow-brown clay	7.7	0.05	9.24	9.2	0.50	2.3
	30-60	*n.d.*	8.1	0.05	10.3	6.3	0.39	2.4
	60-90	*n.d.*	8.0	0.05	12.9	7.3	0.24	2.7

(Continued overleaf)

Table 39. continued

Location	Depth cm	Cl mg/kg	Mg cmol(+)/kg	Na cmol(+)/kg	Ca:Mg Ratio	Cu mg/kg	Fe mg/kg	Zn mg/kg	Bo mg/kg
Allora Flat	0-10	13	20.0	0.23	1.5	1.6	25.0	0.47	1.0
	10-30	15	22.0	0.4	1.4	1.5	18.0	0.26	0.77
	30-60	30	27.0	0.76	1.1	*n.d.*	*n.d.*	*n.d.*	*n.d.*
	60-90	18	30.0	1.2	0.9	*n.d.*	*n.d.*	*n.d.*	*n.d.*
Allora Hill	0-10	11	27.0	0.68	0.96	2.5	46.0	0.67	0.99
	10-30	17	33.0	1.5	0.97	1.8	20.0	0.2	0.6
	30-60	130	40.0	3.0	0.7	*n.d.*	*n.d.*	*n.d.*	*n.d.*
	60-90	370	38.0	3.6	0.79	*n.d.*	*n.d.*	*n.d.*	*n.d.*
Goondiwindi Clay	0-10	36	6.6	1.1	2.6	0.7	8.7	0.2	0.62
	10-30	330	11.0	4.3	2.4	0.66	8.2	0.2	1.5
	30-60	850	12.0	7.4	1.5	*n.d.*	*n.d.*	*n.d.*	*n.d.*
	60-90	1100	11.0	8.5	1.0	*n.d.*	*n.d.*	*n.d.*	*n.d.*
Goondiwindi Loam (2013) [A]	0-10	*n.d.*	2.3 [E]	0.28 [F]	*n.d.*	0.75	28.0	2.20	1.3
	10-30	*n.d.*	7.6 [E]	3.4 [F]	*n.d.*	0.60	8.0	0.48	1.3
	30-60	*n.d.*	9.7 [E]	6.5 [F]	*n.d.*	0.51	4.4	0.21	3.1
	60-90	*n.d.*	9.6 [E]	9.0 [F]	*n.d.*	0.53	4.3	0.40	3.8
St George Clay	0-10	20	5.0	0.52	4.0	0.91	5.8	0.18	0.81
	10-30	29	6.9	2.3	3.5	0.83	6.2	0.25	1.8
	30-60	230	7.9	4.6	2.8	*n.d.*	*n.d.*	*n.d.*	*n.d.*
	60-90	460	8.1	6.4	4.2	*n.d.*	*n.d.*	*n.d.*	*n.d.*
St George Loam	0-10	19	1.5	0.13	5.5	0.77	9.3	0.61	0.67
	10-30	10	1.8	0.04	3.8	0.73	6.4	0.1	0.74
	30-60	<10	2.5	0.098	2.9	*n.d.*	*n.d.*	*n.d.*	*n.d.*
	60-90	<10	3.6	0.28	2.4	*n.d.*	*n.d.*	*n.d.*	*n.d.*

n.d. denotes no data. A – Goondiwindi Loam soil results from 2013; B – Electrical Conductivitiy (EC) measured in µS/cm; C – Cation Exchange Capacity (CEC) measured in meq/100g; D – Potassium (K) measured in mg/kg; E – Magnesium (Mg) measured as exchangeable magnesium in meq/100g; F – Sodium (Na) measured as exchangeable sodium in meq/100g.