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Improving productivity of rundown sown grass pastures

Volume 1: Project overview, key findings and recommendations

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Abstract

Sown pasture rundown in grass-only pastures reduces production by approximately 50% and will cost beef producers in northern Australia >$17 billion at the farm gate over the next 30 years. This project aimed to increase the productivity of ageing sown grass pastures (primarily in southern and central Queensland) through an extension program to support landholders to assess and implement on-farm options to improve pasture productivity; and a coordinated research and development (R&D) program to improve the reliability and performance of legumes in grass pastures.

The extension program used a learning-based approach to assist graziers to understand the causes, costs and management options for improving productivity of rundown sown grass pastures and testing them on-farm. Workshops on understanding the causes of pasture rundown and management options to improve productivity of these pastures were attended by 418 graziers. Graziers documented 237 management plans and initiated 157 on-farm trials to test management options. Collectively these graziers manage 814,000ha of sown pastures; 286,000 head of cattle and 42,000 sheep.

Research conducted as part of this project has demonstrated that desmanthus and Caatinga stylo can be persistent and productive on clay soils over a large geographic area of Queensland. Both of these legumes have persisted at a greater percentage of old trial sites than other legume options such as leucaena, butterfly pea or Siratro. Results from grazing trials suggested that desmanthus and Caatinga stylo can improve long-term productivity by approximately 40-100% in live-weight gain per hectare compared to grass only pastures.

Despite the large production benefits demonstrated in trials, both desmanthus and Caatinga stylo have not been widely commercially successful over the last 20 years since they were released to industry. Poor establishment is the most common reason for failure of pasture legumes in existing sown grass pastures, however the methods most commonly used by graziers are low cost and low reliability. 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 competitive grass pastures for them to realise their potential to improve productivity and economic returns in the sub-tropics.

Executive summary

Background:

Productivity decline in sown grass pastures is widespread in northern Australia and has been shown to reduce production by approximately 50%. The economic impact of the decline has been estimated at over $17B at the farm gate over the next 30 years (Peck *et al.*, 2011). Buffel grass (*Cenchrus ciliaris*) is the most widely established sown species in northern Australia (>75% of plantings) (Walker *et al.*, 1997). The decline in pasture productivity with age is directly attributable to a lack of available nitrogen (N) in the soil as the nitrogen and other nutrients become 'tied-up' in soil organic matter, roots and crowns of old grass plants and is commonly referred to as "pasture rundown". This lack of available nitrogen limits dry matter production and may be exacerbated by overgrazing that can lead to reduced pasture condition and land degradation.

Industry has used a variety of management options to cope with rundown in grass pastures in tropical pastures that can be classified into one of the following "mode of action" groups:

1. Accept lower pasture production. This is the most commonly used management option by industry.
2. Increase the rate of N cycling. The second most commonly used practice has been pasture renovation, although most often part of controlling regrowth of woody vegetation.
3. Add additional N to the pasture. Either nitrogen (N) fertiliser or biological N fixation with legumes. A high percentage of graziers have "tried" legumes, but commercial results have generally been poor with sown pastures in the sub-tropics.

The most commonly used management practice has been to accept lower pasture production and reduce stocking rates to maintain land condition and animal performance through either not adopting or having poor results from other options. Some management options used by industry provide marginal or negative returns. The best economic returns and most sustainable long-term option is to establish well-adapted legumes. However, commercial results from legumes established into sown grass pastures have been mixed with a few notable successes, but mainly failures.

Some older legume varieties were not persistent and productive enough to be successful in the long-term with sown grass pastures in the sub-tropics (e.g. Siratro). The more recently released varieties for clay soils in the sub-tropics, desmanthus and Caatinga stylo, had performed well in trials but have often failed in commercial sowings. These poor commercial results has led many graziers and farm advisors to conclude that industry needs better legume varieties; while others have concluded that industry needs to improve management of legumes if <u>any</u> are to succeed.

Graziers, farm advisors and researchers have become increasingly concerned about the impact of declining pasture productivity on livestock production, economic returns and environmental outcomes (i.e. maintaining high ground cover and biomass, reducing erosion and resilience to drought). Graziers and their advisors have been disappointed with the unreliable and often poor results from legumes with competitive grass pastures for inland sub-tropical environments.

This project aimed to work with industry to improve understanding of the causes, costs and management options for rundown pastures; and to conduct research to improve the reliability and productivity of pasture legumes which have been identified as the best long-term option to improve productivity in these pastures.

Project overview:

This project focussed on RD&E recommendations from the review on productivity decline in sown grass pastures (Peck *et al.*, 2011). The project consisted of an integrated suite of participatory Research, Development and Extension (RD&E) activities that brought together the knowledge and experience of scientists, graziers, grazier groups, and their advisers. The project had three main components:

1. Improving understanding and testing of mitigation options with industry. This project used a learning based approach to work with industry (graziers, advisors, seed industry) to better understand the process and impact of pasture rundown, identify and test mitigation options on-farm. The main activities were workshops with graziers and on-farm demonstrations/trials of management options.
2. Testing persistence and comparative productivity of legumes in sown grass pastures in Queensland. This component of the project aimed to assess whether the relatively recently released desmanthus and Caatinga stylo can be persistent and productive enough under grazing in the Brigalow Belt with sown grass pastures to be commercially successful in the long-term.
3. Improving reliability of establishing legumes into existing grass pastures. Establishing legumes into grass pastures is widely perceived to be risky and unreliable. Reliable and cost effective techniques for legume augmentation of existing buffel grass (& other competitive grass) pastures need to be developed to change this paradigm. Agronomic practices developed for grain cropping were assessed for small seeded pasture legumes.

Major conclusions:

Industry engagement:

Graziers and their advisors showed a strong interest in the project activities. A total of 32 workshops were delivered to 418 graziers between 2011 and 2015 across central and southern Queensland. Participants in these workshops managed more than 814,000ha of sown pastures, 286,000 head of cattle and 42,000 sheep. During the workshops, graziers developed management strategies for their sown pastures with the most common intended management being to introduce legumes to their pastures (84% of respondents).

One hundred and fifty seven on-farm demonstrations or research trials were initiated with workshop participants. The most common on-farm trial was to use green urea to test how rundown pastures were, that is how nitrogen deficient. The second most common was introducing pasture legumes into existing grass pastures.

Persistence and productivity of legumes:

Research in this project has demonstrated that desmanthus and Caatinga stylo can be persistent and productive on clay soils over a large geographic area of Queensland. Both of these legumes have persisted at a greater percentage of old trial sites (85% of sites for Caatinga stylo, 79% desmanthus) than other legume options such as leucaena (44% of sites), butterfly pea (45%) or siratro (20%).

Measurements conducted as part of two grazing trials in this project demonstrate a clear benefit from including desmanthus or Caatinga stylo in the long-term when planting sown pastures. The production benefits from using persistent pasture legumes 15 years after sowing at the two trial sites were:

- Better pasture composition. A higher percentage of the total biomass was made up of good pasture species in the legume with grass than in the grass only paddocks.
- More total standing dry matter. There was 50% and 100% more pasture biomass with the grass/legume then in grass only paddocks.

- Higher dry matter production. There was approximately 30% and 140% more biomass grown in the two years the trials were measured in the grass/legume paddocks.
- Higher animal live-weight gain. Both trial sites showed higher live weight gains, however due to issues with livestock not being in the paddock for the duration of the trials, the annual benefit was not determined.
- GRASP pasture growth modelling suggests the long-term annual benefits from the legume to be 15% and 63% increase in pasture productivity; and 37% and 105% benefit in animal production (live-weight gain per hectare).

These results clearly demonstrate that both desmanthus and Caatinga stylo offer a large opportunity to the beef industry to increase the area of pasture with a persistent and productive legume component in Queensland.

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 them to the paddock scale using commercial equipment.

Recommendations:

Pasture legumes have been identified as the best long-term option to increase the productivity and returns from both rundown sown grass pastures. Future RD&E priorities therefore should focus on improving commercial results and reliability from legumes in sown grass pastures (especially buffel grass pastures) to realise the potential of the existing suite of legumes. High priorities for further research, development and extension are:

1. Improving reliability of establishing small seeded legumes into existing, competitive sown grass pastures.
2. Improved nutrition of legumes. Phosphorus (P) and sulphur requirements for many of the summer growing legumes has not been well studied. Critical P requirements in the soil have not been adequately studied for desmanthus, Caatinga stylo and leucaena to give reliable fertiliser recommendations.
3. Improved reliability of establishing rhizobia of summer growing legumes when sown onto hot soils. Alternative rhizobia delivery methods that protect the rhizobia from the hot and dry soil surface need to be developed and adopted for summer growing legumes to be successful.
4. Better varieties. A review by Bell *et al.* (2016) identified clay soils in the inland sub-tropics as being the highest priority for developing better legume varieties in northern

Australia. The highest priority genera for further evaluation were *Desmanthus* and *Stylosanthes*.

In addition to these RD&E priorities there is a need for better seed quality of tropical legumes. The quality and reliability of seed supply for many of the tropical legumes has regularly been poor. Commercial seed has regularly had poor germination percentages, poor seedling vigour and high levels of contamination with other species. Collectively the seed industry needs to address these seed quality issues if legumes are to be more successful when sown into commercial paddocks with competitive sown grass pastures.

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Final report outline

The final report has been organised in volumes due to the project having three components, each with multiple activities. The report has four volumes, volume one reports on the main results across the whole project with more detail being provided in the following volumes on each of the three components of the project. The titles of the four volumes are:

Volume 1: Project overview, key findings and recommendations.

Volume 2: Improving understanding and testing mitigation options with industry.

Volume 3: Persistence and comparative productivity of legumes in sown grass pastures.

Volume 4: Improving reliability of establishing legumes into existing grass pastures.

Table of contents: Volume 1

List of figures

List of tables

1 Background

1.1 Sown pastures in northern Australia

Well-adapted sown pastures enable higher productivity and profitability in grazing enterprises because they can produce more feed, of a higher quality, for a longer period of the year than native pastures (Quirk and McIvor 2005). They have been widely sown in northern Australia and continue to improve production and economic returns from grazing, especially in the beef industry (Chudleigh and Bramwell 1996; Walker *et al.* 1997).

Of the total area planted to sown pasture in northern Australia, 70% has been sown only with tropical grasses (Walker and Weston, 1990). Buffel grass (*Pennisetum ciliare*) is the dominant sown pasture across northern Australia comprising >75% area of sown pasture and is widely affected by rundown (Walker *et al.*, 1997; Peck *et al.*, 2011). Buffel grass is “dominant” on 5.8M ha and “common” on a further 25.9M ha in Queensland alone (Peck *et al.*, 2011).

1.2 Declining productivity of sown pastures: “Pasture rundown”

Sown pasture grasses are very productive when they are planted after clearing virgin forest or into fertile cropping soils. However, the productivity of these pastures typically declines with time, a phenomenon often described as “pasture rundown” (Myers and Robbins, 1991). The annual dry matter production from sown grass pastures can decline by 50 – 60% within five to ten years of establishment across a range of soil and seasons (Radford *et al.*, 2007; Graham *et al.*, 1981; Myers and Robbins, 1991). Animal production shows a similar trend with a linear decline of 20-70% in live weight gains over the first five years of pastures when stocking rates are held constant (Radford *et al.*, 2007; Robbins *et al.*, 1987). However, individual animal performance may be maintained if stocking rates are reduced (Radford *et al.*, 2007; Burrows, 1991). The economic impact of pasture rundown to Queensland’s grazing industry has been conservatively estimated at over $17B at the farm gate over the next 30 years (Peck *et al.*, 2011).

The majority of soil nitrogen (N) is in organic forms, however plants can only use mineral forms of N in the soil. The decline in pasture productivity with age is directly attributable to a lack of plant available nitrogen in the soil as the nitrogen and other nutrients become ‘tied-up’ in soil organic matter, roots and crowns of old grass plants. The large quantities of dry matter produced initially when pasture grasses are established is a response to the high levels of available nitrogen and water that accumulate in fertile soils during a fallow prior to planting. However, dry matter production and subsequent animal performance decline as the available N reserves decline and become less available to pasture grasses (Graham *et al.*, 1981; Robbins *et al.*, 1987). The reduction in dry matter production can result in overgrazing if stocking rates are not adjusted accordingly, which in turn can lead to poor land condition and land degradation.

Land condition and pasture rundown clearly interact and a reduction in land condition will exacerbate the rundown process, however land condition and nutrient tie-up are separate processes. Land condition can change independently of the amount of available nitrogen and nutrient tie-up occurs even when land condition is maintained at a high level.

1.3 Management options for rundown sown grass pastures

The reduction in productivity of sown grass pastures as they age is due to a reduction in the supply of available N in the soil. With age since sowing, more of the mineral N is incorporated into organic material and its subsequent availability for plants each growing season is governed by the rate of mineralisation. Strategies for mitigating the impact of pasture productivity therefore need to either:

- Accept the reduction in pasture productivity and adjust management of other aspects of the farm business to maintain animal, environmental and economic performance.
- Increase the rate of N cycling. N is mineralised and made available to pasture plants through the decomposition of organic matter, therefore those practices that increase the rate of decomposition increase the amount of N supply e.g. mechanical renovation.
- Add addition N to the pasture sward through either fertiliser or biological N fixation (i.e. legumes).

Table 1 summarises specific management practices into their mode of action described above. Graziers have tried a wide range of mitigation strategies to reduce the impact of pasture rundown(Peck *et al.*, 2011), the most commonly used approaches are:

- Live with rundown and accept lower production. In effect this is the most common strategy used with graziers reducing stocking rates to maintain land condition and animal performance through either not adopting or having poor results from other mitigation options.
- Mechanical renovation ranging from single cultivations (e.g. chisel ploughs, ripping or blade ploughing) through to short term cropping or crop/pasture rotations has been used by industry. However, the most commonly used mechanical renovation treatment used has been blade ploughs used primarily for woody weed control with the side effect of stimulating the release of N from soil organic matter.
- Legumes for improved feed quality and nitrogen fixation. These benefits are recognised through improved land prices for established leucaena but not for other legumes. Producers reported mixed results from legumes with a few notable successes but mainly failures. The most common point of failure with legumes is poor establishment, however industry routinely uses low cost, low reliability establishment techniques when establishing legumes into grass pastures (except for when establishing leucaena).

Table 1: Management practices for mitigating the impact of pasture rundown group by mode of action. Adapted from scientific literature, focus group workshops and phone surveys across southern and central Queensland (Peck *et al.*, 2011)**.**

Accept lower pasture production	Increase nitrogen cycling	Increase nitrogen inputs
• <u>Reduce stocking rates</u> • Supplement stock • Develop another paddock • Buy more land • Invest in other aspects of the business (e.g. water, genetics, fences, off-farm) • Plant grasses more tolerant of low fertility	• <u>Mechanical disturbance (regrowth control)</u> • Mechanical disturbance (cultivation) • Crop/pasture rotation • Herbicide renovation (?) • Grazing management (?) • Slashing (?) • Biological treatments (?) • Tree rotations (?) • Fire (X)	• <u>Legumes</u> • Fertiliser

Notes: The most commonly used management options by graziers are underlined. ? – practices that have marginal or no improvement in production or have not been well studied; X – tested in trials and showed no improvement in pasture growth over a whole growing season.

Peck *et al* (2011) conducted whole farm economic analysis to compare 12 strategies that industry has used to increase productivity on ageing buffel grass pastures across four districts of inland Queensland (Peck *et al.*, 2011). Mitigation strategies were dry season protein supplements, nitrogen fertiliser (2 rates), mechanical renovation (3 methods), renovation with herbicides and legumes (leucaena and other legumes established 4 different ways). Mechanical renovation appears viable only for high production pastures (i.e. higher rainfall districts and higher fertility soils). Returns from mechanical renovation can be improved significantly if used to successfully introduce a legume. Herbicide renovation does not seem to be viable from this analysis. Nitrogen fertiliser was not viable at any location unless repeated fertiliser applications results in a build-up in soil N levels. Dry season protein supplementation provided marginal returns at all locations. Legumes were identified as the most cost-effective mitigation option with the potential to reclaim 30-50% of lost production providing whole farm returns of up to $1,300/ha over 30 years, and benefit: cost ratios of 4 - 10.

Legumes have been identified as the best long-term option for improving the productivity of rundown sown grass pastures. Legumes can improve production of rundown grass pastures through biologically fixing atmospheric N and thereby improving diet quality directly through providing higher quality forage; and indirectly by improving the growth and quality of companion grasses from increased N availability. However, commercial use of legumes has achieved mixed results with a few notable successes, but mainly failures. The production potentials of many legumes recorded from research trials is often much higher than what is generally achieved commercially. There is significant opportunity to improve commercial results from legumes using existing technologies, however, there is a need for targeted development to improve the reliability of establishment and research to increase the productivity of legumes.

1.4 Industry concern

Graziers, farm advisors and researchers have become increasingly concerned about the impact of declining pasture productivity on livestock production, economic returns and environmental outcomes (i.e. maintaining high ground cover and biomass, reducing erosion and resilience to drought). This project aimed to work with industry to improve understanding of the causes, costs and management options for rundown pastures; and to conduct research to improve the reliability of pasture legumes which have been identified as the best long-term option to improve productivity in these pastures.

2 Project overview

The MLA/DAF “Review of productivity decline in sown grass pastures” (Project: B.NBP.0624) identified legumes as the best option to claw back much of the decline in productivity due to pasture rundown (reduced nitrogen availability), with:

- extension needed to help graziers understand the process of rundown and to apply mitigation strategies with current best technology; and
- research to help overcome the major constraints to the effective use of legumes.

This project focussed on RD&E recommendations from the review on productivity decline in sown grass pastures (Peck *et al.*, 2011). This project’s aim was to increase the productivity of ageing sown grass pastures (primarily in southern and central Queensland) through an extension program to support landholders to assess and implement on-farm options to improve pasture productivity; and a coordinated RD&E program to improve the reliability and performance of legumes in grass pastures.

An integrated suite of participatory RD&E activities brought together the knowledge and experience of scientists, graziers, grazier groups, and their advisers. RD&E activities utilised past research to help graziers recognise and understand rundown, and to apply current best practices that mitigate the impacts of rundown on their own farms. At the same time, research with pasture legumes confirmed the most persistent and productive species, and further developed practical ways to establish them into existing grass-only pastures.

The project focussed on the grass-only (largely buffel) pastures across southern and central Queensland, however some activity occurred in other regions. The large areas of sown pasture in southern and central Queensland are important to the northern Australia beef industry as they have high carrying capacities, are commonly used for fattening or backgrounding stock (before entering feedlots) and therefore produce high value livestock. Pasture production in these regions has declined and future beef production is under threat from continued pasture rundown from both animal production and environmental sustainability perspectives. However, there is significant opportunity for enterprises to improve productivity of these pastures for flow on benefits to the beef industry as a whole.

There were three main components to this project:

1. Improving understanding and testing of mitigation options with industry.

Understanding of the process and impact of rundown varies across industry (graziers and advisors) with little adoption of effective mitigation strategies by graziers. There are significant opportunities for industry to increase productivity and returns from sown grass pastures using mitigation strategies. This project used a learning based approach to work with industry (graziers, advisors, seed industry) to better understand the process and impact of pasture rundown, identify and test mitigation options on-farm. The on-farm testing provided real farm data and practical experiences that can be extended to the wider grazing community.

2. Testing persistence and comparative productivity of legumes in sown grass pastures in Queensland.

Legumes have demonstrated they have the capacity to improve pasture and animal production in many environments, however persistence and productivity of legumes that performed well in previous evaluation trials needed to be confirmed for inland districts of sub-tropical Queensland to provide confidence in available varieties. This component of the project aimed to address the issue of whether the relatively recently released legumes, desmanthus and Caatinga stylo, can be persistent and productive enough under grazing in the Brigalow Belt bio-region with sown grass pastures to be commercially successful in the long-term. If they are persistent and productive, they would warrant further RD&E investment to address technical issues on how to more reliably and productively grow them. If not persistent and productive enough, research priorities would move to finding better varieties. Other legumes (e.g. butterfly pea, burgundy bean, shrubby stylo etc.) were also recorded for their suitability to permanent pastures in the Brigalow Belt bio-region.

3. Improving reliability of establishing legumes into existing grass pastures.

Establishing legumes into grass pastures is widely perceived to be risky and unreliable. Reliable and cost effective techniques for legume augmentation of existing buffel grass (and other competitive grass) pastures need to be developed to change this paradigm. Agronomic practices developed for cropping and leucaena establishment were assessed for small seeded pasture legumes.

The review of productivity decline identified cultivated or herbicide strips as approaches that should allow reliable establishment while reducing costs. Trials were conducted to assess how wide fallowed strips need to be to effectively store soil moisture.

2.1 Project objectives

The stated aims by the end of the project were for the research organisation to have:

1. Increased awareness and understanding of pasture productivity decline through publication in popular media and other extension products, (e.g. fact sheets, field days, field walks) and the use of existing sites as demonstrations.
2. Developed a learning package and, using this, engaged with 26 grazier groups to demonstrably improve understanding of pasture rundown processes, impacts and mitigation options, and to identify and test mitigation options on-farm (160 documented management strategies, 90 on-farm research trials, 12 trials with detailed analyses).
3. Defined persistence, productivity, feed quality and animal performance of available pasture legumes (desmanthus, Caatinga stylo, butterfly pea and burgundy bean) from old trial sites and/or commercial plantings across at least two growing seasons.
4. Established additional sites to fill gaps in existing sites and better defined the environmental suitability of desmanthus, Caatinga stylo, butterfly pea and burgundy bean (where there are gaps amongst existing sites in Southern Queensland and Central Queensland, with respect to representative climate and/or soils, or the suite of legumes present).
5. Measured the impact of seed bed preparation and fallow management on Caatinga stylo and desmanthus establishment across two soils and three seasons, and updated agronomy recommendations on legume establishment with graziers, farm advisors, EDGEnetwork packages, and the LeyGrain package.
6. Developed and communicated grazing recommendations for legume persistence for Caatinga stylo and desmanthus from measurement of (a) seasonal diet selection patterns and (b) response to seasonal rest from grazing.

2.1.1 Success in achieving objectives

The project made progress against all objectives with clear results in most areas, however not all of the objectives were fully met. A brief overview of the work and results to address the objective is provided below.

Objective 1. Increased awareness and understanding of pasture productivity decline through publication in popular media and other extension products, (e.g. fact sheets, field days, field walks) and the use of existing sites as demonstrations.

The project team engaged with graziers and industry at 32 workshops, 27 field days and 57 information events were either coordinated or attended by project staff. A range of less formal yet highly valuable engagement also occurred with specific industry personnel, including seed companies and re-sellers, Queensland government extension staff, NRM personnel, retired agronomists and scientific peer audiences. Engagement with the general community occurred through the publication of three fact sheets, 25 newspaper and magazine articles, one radio interview, and two webinars. Engagement with scientific audiences occurred at six national conferences through 23 papers. Anecdotal and direct feedback from seed companies indicate practice change is occurring. More information on project activities that addressed this objective is provided in Section 3 of this report and in Volume 2.

Objective 2. Developed a learning package and, using this, engaged with 26 grazier groups to demonstrably improve understanding of pasture rundown processes, impacts and mitigation options, and to identify and test mitigation options on-farm (160 documented management strategies, 90 on-farm research trials, 12 trials with detailed analyses).

The “learning package” consisted of a learning based process involving workshops, developing management plans and testing management on-farm in demonstration trials. The learning package was not a physical document, rather it was a workshop linked to other activities that developed and evolved as research trial results from other project activities (and elsewhere) became available. In total there were 32 workshop groups, with 418 participants who documented 237 management strategies for their farms. Workshop participants initiated 157 on-farm demonstration or research trials. More information on this objective is in Section 3 of this report and in Volume 2.

Objective 3. Defined persistence, productivity, feed quality and animal performance of available pasture legumes (desmanthus, Caatinga stylo, butterfly pea and burgundy bean) from old trial sites and/or commercial plantings across at least two growing seasons.

Forty four old trial sites were inspected for legume persistence to identify superior legumes which demonstrated that desmanthus and Caatinga stylo are more persistent than other species. Legume dry matter production was measured at four sites. Two old grazing sites were remeasured for legume and cattle productivity, grazing management and response to phosphorus fertiliser. Desmanthus and Caatinga stylo have been shown to be persistent and productive over a large geographic area of Queensland. The need for R&D on the management of these legumes was identified. Further information is provided Section 4 of this report and in Volume 3.

Objective 4. Established additional sites to fill gaps in existing sites and better defined the environmental suitability of desmanthus, Caatinga stylo, butterfly pea and burgundy bean (where there are gaps amongst existing sites in Southern Queensland and Central Queensland, with respect to representative climate and/or soils, or the suite of legumes present).

Forty four old pasture evaluation trials were inspected for legume persistence which provides a good coverage of Central Queensland and the northern parts of Southern Queensland. The Darling Downs and Border Rivers (Goondiwindi and surrounds) districts were identified as having no old trial sites that have currently available legume varieties to observe their persistence. Four new trial sites were established to provide information of the adaptation of commercially available varieties. Additional trial sites will be established in a new project (MLA code B.PAS.0355). More information on this objective is provided in Volume 3, Section 3.

Objective 5. Measured the impact of seed bed preparation and fallow management on Caatinga stylo and desmanthus establishment across two soils and three seasons, and updated agronomy recommendations on legume establishment with graziers, farm advisors, EDGEnetwork packages, and the LeyGrain package.

Two fallow moisture trials, two seeding rate trials, six fallowing trials and six rate of legume spread trials were conducted. The trial results showed that establishment legumes into existing grass pastures can be greatly improved if good agronomic practices are used. Initial trial results were incorporated into workshop materials and other extension materials. Several of these trials are on-going and will continue to be measured as part of a new project titled “Legume best management practice in the Brigalow Belt bio-region” (MLA code

B.PAS.0355). Extension materials will be updated as part of this new project. More information for this objective is provided in Volume 4 and in Section 5 of this report.

Objective 6. Developed and communicated grazing recommendations for legume persistence for Caatinga stylo and desmanthus from measurement of (a) seasonal diet selection patterns and (b) response to seasonal rest from grazing.

The results of this activity were described in Volume 3, Section 6 "Grazing management for persistence". Unfortunately the trials on seasonal rest did not achieve the objective for reasons outside of the control of the project team. At one site the stock provided were very flighty and would not enter into the fenced off areas to graze while at the other site the owner totally removed stock at critical times of the year so no grazing pressure was imposed on some treatments. One of the trials had no cattle for a full year due to the property being sold. As a result no meaningful data on the effect of spelling on pasture composition was collected from the spelling trials. However, one of the trial sites had diet selection measured for a full year via faecal NIRS which showed that cattle grazed desmanthus all year round with the highest intake being in summer coinciding with peak legume growth. Recommendations for future R&D on pasture spelling were described and reasons for this research being considered a lower priority than other knowledge gaps are described.

3 Improving understanding and testing of mitigation options with industry

This section of the report provides an overview of the extension component of the project. The project team used a range of different approaches to engage with graziers and their advisors. More detail on the projects engagement with industry is provided in Volume 2.

3.1 Background/aim

Graziers in southern and central Queensland have become increasingly concerned about the continuing decline in productivity of their sown grass pastures, especially in the large areas dominated by buffel grass (Peck *et al.*, 2011). This concern is shared by researchers and the red meat industry through Meat & Livestock Australia (MLA). Key research in the 1980s and early 1990s documented the decline in productivity as grass pastures age, and identified the underlying cause to be reduced available soil nitrogen for pasture growth (Myers and Robbins, 1991). However, concern about the continuing decline in productivity suggests that current mitigation strategies and/or the way they are used on-farms must be improved (Peck *et al.*, 2011).

Understanding of the process and impact of rundown varies across industry (graziers and advisors) with little adoption of effective mitigation strategies by graziers. Graziers are using a range of mitigation strategies to reduce the impact of 'rundown' (Table 1). Most have accepted lower productivity either through not adopting or having poor results from mitigation strategies. Mechanical tillage to stimulate mineralisation of organic soil nitrogen has been used, although primarily for woody regrowth control. However, economic analysis suggest these options provide poor or negative returns in many situations. The best long-term solution that provides good economic returns for individual graziers and the beef industry is to establish a range of adapted legumes into the existing grass-only pastures.

There are significant opportunities for industry to increase productivity and returns from sown grass pastures using mitigation strategies. This project used a learning based approach to work with industry (graziers, advisors, seed industry) to better understand the process and impact of pasture rundown, identify and test mitigation options on-farm. This on-farm testing provided real farm data and practical experiences that can be extended to the wider grazing community.

3.2 Methodology

The two main activity types in this component of the project were to:

- Develop and deliver a "learning package" to graziers and industry on causes of pasture productivity decline and management option for improving productivity of rundown sown grass pastures. The learning package included on-farm demonstration and trials of management options.
- Increased awareness and understanding of pasture productivity decline through publication in popular media and other extension products (e.g. fact sheets, field days, field walks).

3.3 Key results and conclusions

3.3.1 Grazier engagement

A "learning package" was developed to facilitate graziers through an action learning process to improve understanding and test management options. The process involved graziers:

- Learning about the causes, impacts and management options available for mitigating the impacts of pasture rundown.
- Assessing the management options that are applicable to their situation, (i.e. which management strategies are most suitable to their property based on availability of machinery, landscape features, soil types, pasture types etc.).
- Developing a management plan on what management options they intend to use on their own property.
- Trialling management options on farm.
- Sharing the results of the trials or demonstrations with other graziers.

The learning package was delivered as a workshop with follow up activities. Workshop included:

- Presentations covering the:
    - Symptoms and causes of declining pasture productivity (i.e. pasture rundown).
    - Costs to animal productivity, environmental performance and economic returns.
    - Nitrogen (N) cycling and the impact of low N availability on productivity and stability of pastures.
    - Overview of the management options available to graziers. This included likely impacts on pasture and animal productivity, and economic returns.
- Documenting management strategies. Participants were facilitated through a process to plan what management options suited their property on a paddock by paddock basis.
- Planning on farm trials. Participants were supported to trial management options on their own property.

The technical content of the learning package changed over time as the industry needs changed and new and updated information from research trials were developed. Also, the process used was modified to suit the event and audiences. Existing training packages were reviewed (e.g. LeyGrain, Grazing Land Management Edge) and information incorporated where applicable. As results and outcomes from the research activities within this project became available they were included in the workshop process.

There was strong interest from graziers to participate in workshops during the project which led to a change in project delivery. Strong grazier interest resulted in more workshops being conducted in the first year and less on-farm testing and follow up with people in groups than originally proposed. In year 1, the project team engaged with 13 grazier groups, developed the learning package, and to a lesser extent tested mitigation options which contrasts with the 6 groups described in the project proposal. The strong interest and importance to graziers resulted in more participants and workshops being delivered than was anticipated in the project proposal (Table 2).

Table 2: Indicative participation numbers anticipated in the project proposal and actuals delivered during the project for delivery of the "learning package".

Learning package deliverable	Indicative number in project proposal	Actual number achieved
Groups	26	32
Participants	208	418
Documented management strategy	160	237
Supported on-farm demonstration	90	157

3.3.1.1 Workshops

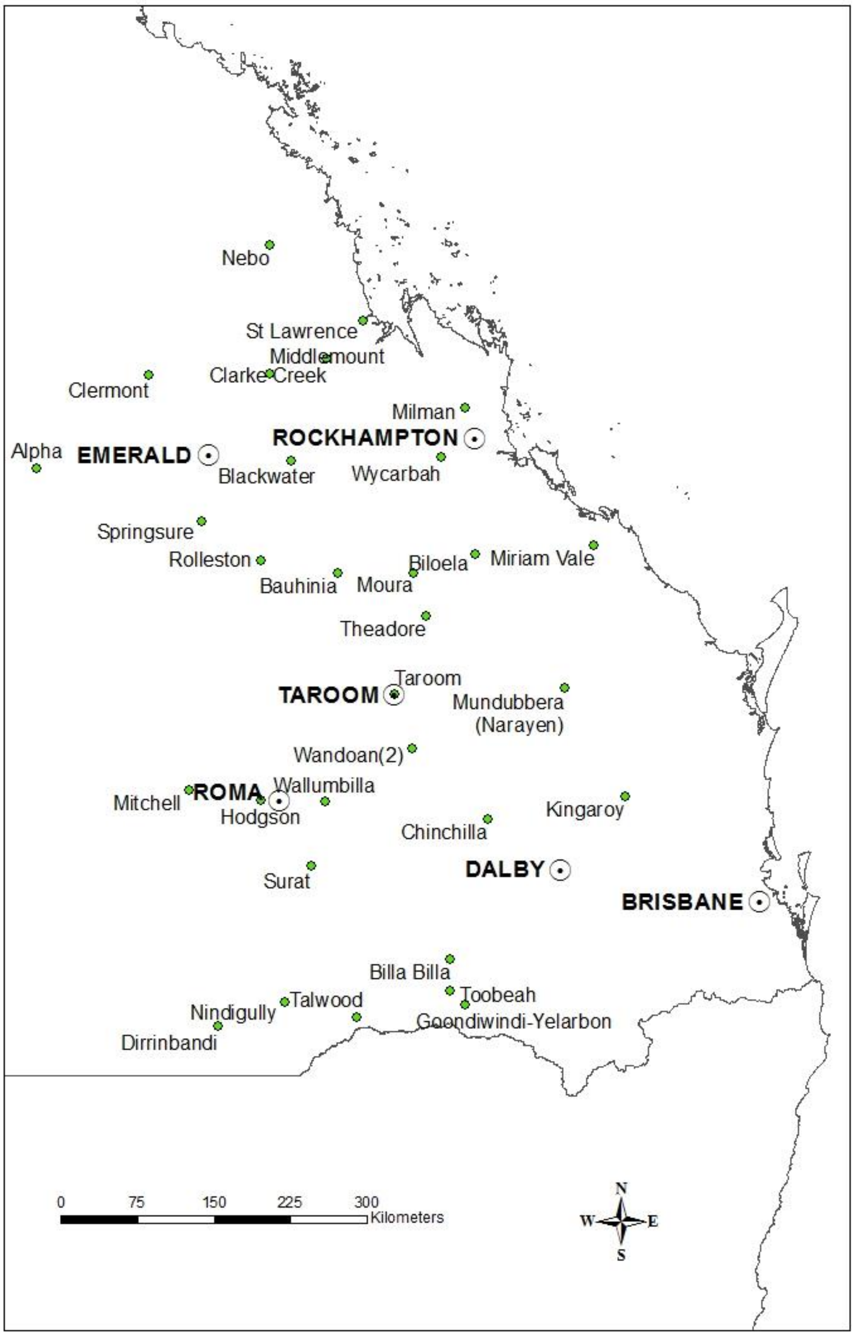

Fig. 1: Location of managing pasture rundown workshops.

A total of 32 workshops were delivered between 2011 and 2015 across central and southern Queensland (Fig. 1). A total of 418 people attended workshops on managing rundown sown grass pastures with 237 documented management strategies being developed. From evaluation conducted during the workshops (326 surveys, approximately 78% of attendees), participants in these workshops managed:

- 814,000ha of sown pastures.
- 881,000ha of native pastures.
- 180,000ha of cropped area.
- 286,000 head of cattle.
- 42,000 head of sheep.

Management strategies have been collated into modes of action to determine how many participants intend to implement which strategies as a result of attending a workshop; and these are summarised in Table 3. Increasing nitrogen (N) inputs through the use of legumes is clearly the most commonly intended management strategy, followed by mechanical renovation to increase nitrogen cycling.

Table 3: Grazier's intended management strategies following workshop attendance to deal with nitrogen tie-up grouped by mode of action. (Numbers in brackets for overall strategies is the percentage of respondents).

Mode of action	Management technique	% of respondents
Accept rundown and lower productivity (13%)	Break up new country if available	2
	Purchase more land	1
	Reduce stocking rates	5
Increase nitrogen cycling (41%)	Mechanical renovation	35
	Chemical renovation	2
Increase nitrogen supply (96%)	Apply nitrogen fertiliser	27
	Introduce legumes	84

3.3.1.2 On-Farm demonstrations and trials

As part of the workshops (described above) participants were encouraged and assisted to develop a documented strategy for managing sown pasture rundown on their farm. From the management strategies, participants were supported to develop on-farm activities, including demonstrations or research trials, to test aspects of mitigation options. One hundred and fifty seven on-farm demonstration or research trials were initiated.

The most common on-farm trial has been N fertiliser with 93 trials. The majority of the N fertiliser trials were designed to help graziers assess whether or not, and to what extent their pastures were 'rundown' due to nitrogen deficiency (76 trials). However, the size of the responses in many of these pastures has led to subsequent more detailed and/or replicated trials to assess the extent of dry matter and crude protein responses on established pastures. While assessing how rundown their pastures are (i.e. how responsive to available N) is a logical first step for producers, the focus of the on-farm research trials later in the project has moved towards using legumes as the most cost effective way to increase N availability to pastures.

Legumes were the second most common On-farm research or demonstration (OFR) trial type (58 trials). Species adaptation/performance, and phosphorus nutrition, have similar numbers of OFR's (15 and 17 respectively). However, due to the issues of successfully establishing legumes, there were a greater number of OFR's investigating establishment options (26 trials).The remainder of the OFRs have been looking at different pasture renovation options, including mechanical and herbicide renovation.

On-farm demonstrations and trials were effective in engaging a large number of graziers and to demonstrate management practices. Unfortunately, quite a few demonstrations or trials were initiated, but not completed, with graziers committing their time elsewhere in their business, especially during the severe drought years that were experienced in the latter half of the project. Most of the on-farm demonstrations and trials were intended to be graziers testing practices themselves on their own property for their own learning, therefore the on-going maintenance and measurement was meant to be up to the individual. For future projects, the learning from this loss of commitment over time is to support a smaller number of trials, but with a greater degree of oversight so the trials can become a focus for other extension activities.

3.3.1.3 Field days

A total of 27 field days were held during the project period, with the majority during the last years i.e. 2015 and 2016 (Fig. 2). The topics and discussion points were dictated by what was demonstrated in the paddock. The majority of the field days showcased successful legume establishment and increased production by introducing legumes into existing pastures. Other field days covered outcomes of fertiliser use and pasture responses.

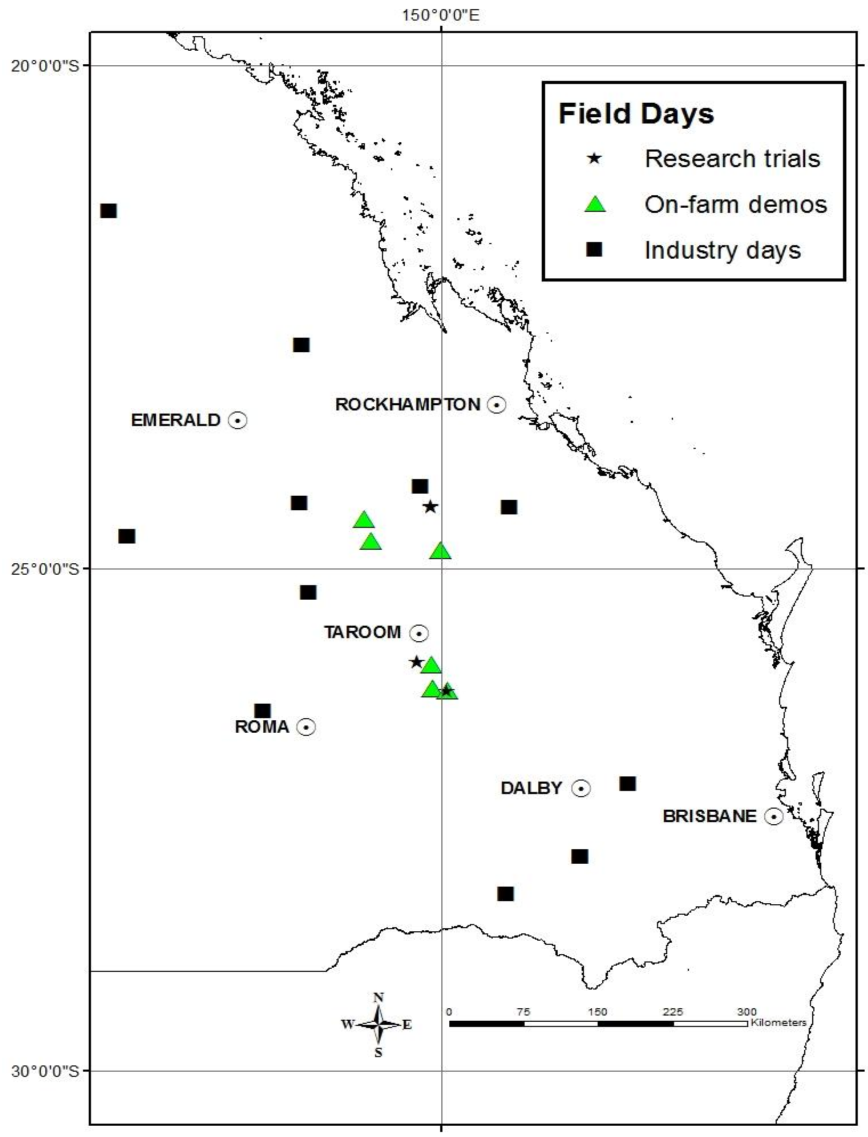

Fig. 2: Location of field days

3.3.2 Industry engagement

A broad range of engagement occurred to complement the extension activities targeted at graziers. Many of the conversations with industry have been one-on-one, over multiple meetings or discussions and involved two way sharing of information and results. Industry groups that have engaged with the project include:

- Seed companies, resellers and commercial agronomists.
- Beef extension and pasture agronomists within state departments and universities.
- Retired pasture agronomists. Retired agronomists have been very generous with their time, knowledge and data to support the project. They have also been very interested in results.
- Natural Resource Management groups.
- Scientific peers. Engagement with other scientists has occurred in a range of forums, but in particular through conferences.

Anecdotally and feedback from seed companies indicate that the project has contributed to practice change occurring, examples include:

- Some of the seed companies have updated their brochures on legume establishment based on this projects trial results.
- Farm advisors, resellers and seed companies have reported that there is more use of fallowing before sowing legumes, more graziers are seeking information before sowing legumes, more soil testing is being conducted in existing and for new pastures, and phosphorus fertiliser is now being applied to some existing legume-grass pastures.

3.4 Recommendations

During the five years of the project, the project team has developed considerable interest and enthusiasm within the grazing community on improving the productivity of rundown sown grass pastures. The strong interest shown by the grazing community reflects the importance of improving the productivity of rundown sown pastures to graziers and the grazing industries as a whole. It is important to maintain activity in improving productivity of the feedbase to maintain graziers enthusiasm as it has the potential to dramatically improve productivity and returns within the grazing industries.

These engagement activities confirm that productivity decline due to nitrogen tie-up in sown grass pastures is a significant problem across large areas of southern and central Queensland. Large numbers of graziers are seeking information, and the majority identify introducing legumes as the most appropriate way to increase productivity.

4 Testing persistence and comparative productivity of legumes in sown grass pastures in Queensland

The section of the report provides an overview on several research activities to quantify the persistence and productivity (dry matter and animal live weight) of available pasture legumes for the inland sub-tropics. The project focussed on the more recently released legumes desmanthus and Caatinga stylo. More detail on this component of the project is provided in Volume 3.

4.1 Background/aim

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). Nitrogen fixation by legumes results in a higher quality diet for livestock 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.

Despite legumes being identified as the best long-term option to improve productivity of sown grass pastures, they are not widely used by industry in the Brigalow Belt bio-region. The Brigalow Belt bio-region has a climate that is unique in the world from a plant growth perspective (Hutchinson, 1992). Research over several decades had difficulty in finding pasture legumes adapted to the Brigalow Belt bio-region due to the unique climate, competitive grass and heavy clay soils typical of the region. Leucaena technology has been extensively researched and developed over many decades to the point that it is reliable and effective in central Queensland and parts of southern Queensland, however leucaena is not suitable for all situations.

Desmanthus and Caatinga stylo performed well in evaluation trials on clay soils and were released to industry in 1995 and 1997 respectively. These two newer legumes offer potential to extend the range of land types and climates that it is possible to establish productive legume infused sown pastures. Despite their good results in evaluation trials, commercial results for desmanthus and Caatinga stylo have been mixed, with a few notable successes, but mainly failures. Many graziers and some seed companies have questioned whether desmanthus and Caatinga stylo are well enough adapted to be persistent and productive; however others have concluded that industry needs to improve management of legumes for any variety to be reliable and productive in commercial pastures. If these two legumes are not good enough to be commercially successful, there is a large area of productive grazing lands that does not have a well-adapted range of legume varieties.

This component of the project aimed to assess whether desmanthus and Caatinga stylo can be persistent and productive enough under grazing in the Brigalow Belt to be commercially successful in the long-term.

4.2 Methodology

The activities included in this component of the project were:

- Legume persistence at old trial sites. Forty-four old pasture trials (>10 years since sowing) were inspected to test which legume species were persisting and being productive in the long-term.
- Four legume productivity trials. Legume dry matter production was measured at four sites from the 44 sites inspected for legume persistence.
- Two old grazing trials were re-measured for legume and cattle productivity. Co-located with these trials were trials on grazing management for persistence and Caatinga stylo and desmanthus response to applied P fertiliser.
- New legume persistence trials. Four new trial sites were established to test the persistence of desmanthus and Caatinga stylo in additional climates and soils.

The location of the trials is shown in Fig. **3**.

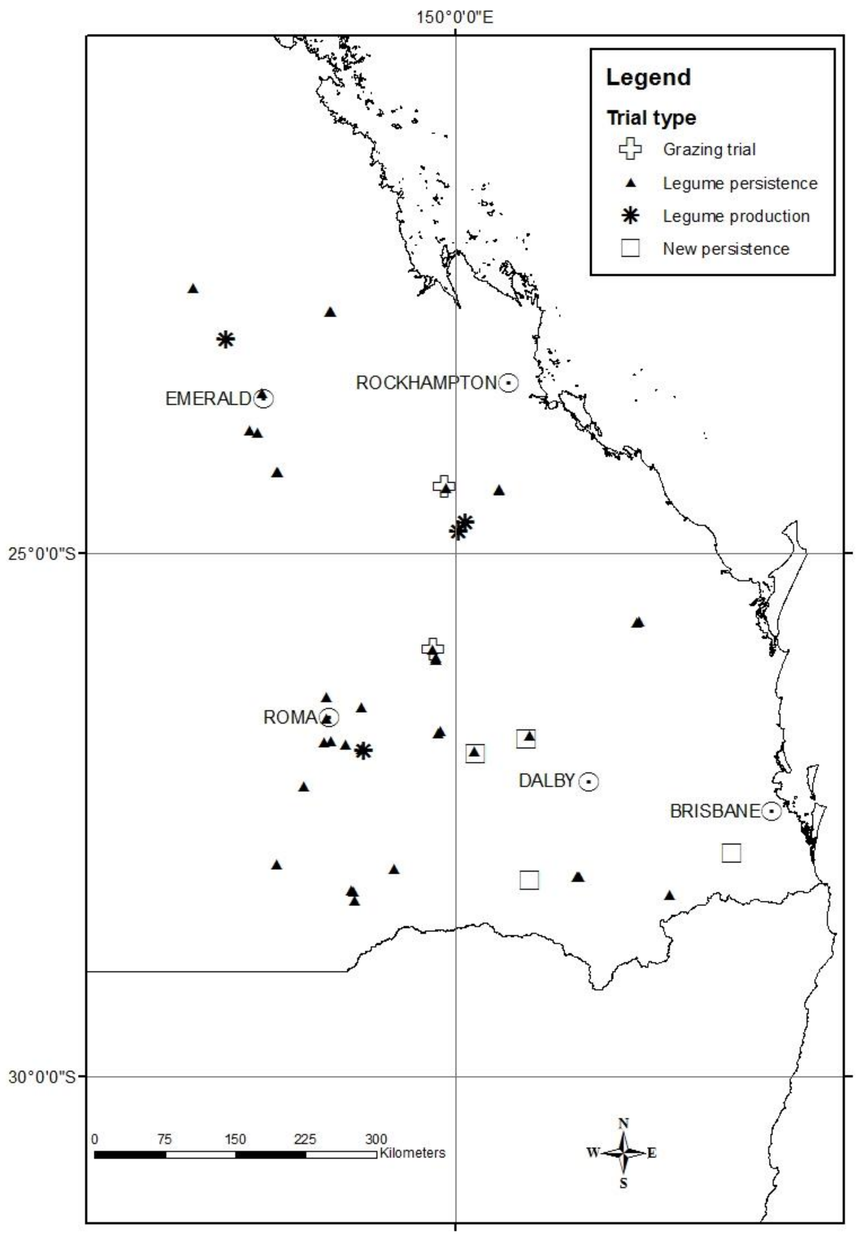

Fig. 3: Location of legume persistence and productivity trial sites. (Sites symbols for persistence, DM production, grazing, new persistence. Major towns for location).

4.3 Key results and conclusions

4.3.1 Persistence of desmanthus, Caatinga stylo and other legumes

Desmanthus and Caatinga stylo can be persistent and productive on clay soils over a large geographic area of Queensland.

Despite mixed reports from commercial plantings, both Caatinga stylo and desmanthus persisted at a large percentage of the sites they were planted at (Table 4). Ironically they both persisted at a higher percentage of sites than leucaena and shrubby stylo which both have the commercial reputation of being widely persistent (as long as their specific management requirements are met). Both desmanthus and Caatinga stylo have persisted on low phosphorus soils and Caatinga stylo can also persist on lighter soils. These results concur with the previous evaluation trial results that led to the release of commercial varieties for both of these species.

Legume species were classified into four groups:

- Highly persistent: Caatinga stylo and *D.virgatus*
- Moderately persistent: *D.leptophyllus*, butterfly pea, leucaena, shrubby stylo and fine-stem stylo
- Low persistence: burgundy bean, Siratro and lotononis
- Not persistent: Lucerne, Caribbean stylo and round-leaf cassia.

These results differ from conventional industry perception for several of these species, that is leucaena; round-leaf cassia; shrubby, Caribbean and fine-stem stylos have the reputation for being persistent (Peck *et al.*, 2011). The differences between these trial results and commercial experience are most likely due to:

- Some legumes doing better in other climate zones or soil types.
- Different levels of management input into pasture and stock management e.g. leucaena is normally established using good agronomy and stock management in commercial pastures; whereas most other legumes are simply broadcast into un-disturbed grass pastures.
- A longer history of use by industry and therefore more experience in managing the needs of the legume.
- Use in native pastures rather than with more competitive sown grass pastures, e.g. shrubby, Caribbean and fine-stem stylos are normally sown into native pastures.

Table 4: Number of trial sites where legumes were planted and the number of sites where they persisted. (Dark green: persistent at a high percentage of sites; Light green: persistent at a moderate number of sites; Orange: persistent at low percentage of sites; Red: persistent at no trial sites).

Common name	Species	Number of sites planted	Not persistent	Persistence		
				Low	Moderate	High
Caatinga stylo	*Stylosanthes seabrana*	27	3	5	7	12
Desmanthus	*Desmanthus virgatus*	33	7	5	7	14
Desmanthus	*Desmanthus leptophyllus*	22	6	11	2	3
Butterfly pea	*Clitoria ternatea*	20	11	2	2	5
Leucaena *	*Leucaena leucocephala*	16	9	2	0	5
Shrubby stylo	*Stylosanthes scabra*	23	17	0	2	4
Fine-stem stylo	*Stylosanthes guianensis var. intermedia*	7	4	1	1	1
Burgundy bean	*Macroptilium bracteatum*	15	13	1	1	0
Siratro	*Macroptilium atropurpureum*	15	12	1	2	0
Lotononis	*Lotononis bainesii*	7	5	0	1	1
Lucerne	*Medicago sativa*	13	13	0	0	0
Caribbean stylo	*Stylosanthes hamata*	13	13	0	0	0
Round-leaf cassia	*Chamaecrista rotundifolia*	9	9	0	0	0

4.3.1.1 Persistence of Caatinga stylo

Caatinga stylo persisted at 85% of the trial sites where it was planted and was moderately or highly persistent at 70% of sites (Table 1). Key points from the old trial sites for Caatinga stylo include:

- It persisted on a wide variety of soils, from sandy loams (Kandosols) through to heavy cracking clays (Vertosols). A wide range of adaptation could assist the longevity of the commercial varieties as it should mean the market is potentially larger.
- It is widely adapted, persistent and productive across southern and central Queensland. It's high persistence ratings indicate that it is able to thicken up and spread over time. It appeared widely productive and seems to retain its leaf for longer than desmanthus.
- In southern Queensland, Caatinga stylo has been promoted for lighter clays to sandy loams. The results from the central Queensland heavy clay soils suggests that it should also be recommended on heavier clay soils in southern Queensland.
- A wide range of Caatinga stylo lines were found persisting and spreading south of Roma on a loamy Sodosol. These frost tolerant Caatinga stylo lines provide an

exciting opportunity to extend the range of stylos further south. These stylo lines are now being evaluated in a separate project.
- It did not do as well on sites with high grass competition e.g. un-grazed trials. It is unlikely that a pasture legume will be un-grazed in commercial paddocks, however it does give some insights to management that favours Caatinga stylo. Grazing management that puts some pressure on the grass component of the pasture e.g. moderate grazing early in the growing season is likely to favour Caatinga stylo.
- It has persisted on some extremely low phosphorus (P) soils (<5 mg P/kg Colwell in the top 10cm).

4.3.1.2 Persistence of desmanthus

Multiple species were planted across the different sites which were difficult to identify. Due to this constraint, the persistence ratings were confined to *D.virgatus* and *D.leptophyllus*. These species varied in their level of persistence with *D.virgatus* being highly persistent while *D.leptophyllus* was moderately persistent.

Key points for D.virgatus are:
- It was widely persistent, persisting at 79% of sites and was moderately or highly persistent at 64% of sites.
- The most commonly planted accession was cv. Marc. There are questions about Marc and other accessions productivity for grazing livestock across the sites as it seemed to have relatively lower dry matter and poorer leaf retention into autumn/winter. Some accessions seem to retain their leaf better than Marc.
- It did not persist well on sandier soils or on Black Vertosols. Low persistence on Black Vertosols while persisting well on Grey Vertosols is an intriguing result. Further work is required to try and determine why it shows good persistence on some clay soil types but not others.
- It has persisted on some extremely low phosphorus (P) soils (<5 mg P/kg Colwell in the top 10cm).
- Cultivar Marc was dominant at several locations with very low amounts of grass in the original plots where it was planted. Management and grass species selection may be important to maintain optimum grass: legume ratios. At one of the sites where Marc was dominant the grass has recolonised, however the composition has changed from being Bambatsi panic dominated to buffel grass dominated.

Key points for *D. leptophyllus* (and other larger, taller species of desmanthus) are:
- Bayamo was the main cultivar planted across the trial sites.
- It persisted at a fairly high percentage of sites (73%) but it was moderate or highly persistent at only 23% of sites. It preferred Grey Vertosol soils.
- At several sites where it did persist, it often appeared more productive with better leaf retention than *D.virgatus*.
- Due to their higher production potential and better leaf retention, this species and other larger species deserve further evaluation to try and select for more widely adapted and persistent accessions. James Cook University has released a new variety of *D. leptophyllus* which shows promise for being more widely persistent, it is one of the five lines included in the Progardes blend.

4.3.1.3 Adaptation limits of desmanthus and Caatinga stylo

The adaptation limits of desmanthus and Caatinga stylo is still to be determined. There are concerns with both of these species in districts with cooler and wetter winters. Graziers have reported both of these legumes not persisting on the Darling Downs. There has been a dramatic loss in plant numbers at two out of four new trial sites; one on the Darling Downs, the other in the West Moreton district, testing the adaption of these legumes to cooler and wetter locations. Additional trial sites will be established in a new project to test the performance of these legumes in these more southerly latitudes.

4.3.2 Productivity of desmanthus and Caatinga stylo

In comparative productivity and grazing trials, both desmanthus and Caatinga stylo have demonstrated that they can be productive in the long-term. Both legumes demonstrated that they can produce a large percentage of total pasture production greater than 15 years after sowing at four old trial sites.

Measurements conducted as part of the grazing trials demonstrate a clear benefit from including desmanthus or Caatinga stylo in the long-term when planting sown pastures. The production benefits from using persistent pasture legumes 15 years after sowing at the two trial sites were:

- Better pasture composition. At both grazing trials, a higher percentage of the total biomass was made up of good pasture species in the legume with grass paddocks (99% and 90%) than in the grass only paddocks (80% and 87%).
- More total standing dry matter. There was 50% and 100% more pasture biomass with the grass/legume than in grass only paddocks at the grazing trials.
- Higher dry matter production. There was approximately 30% and 140% more biomass grown in the two years the trials were measured in the grass/legume paddock than in the grass only paddock.
- Higher animal live-weight gain. Both trial sites showed higher live-weight gains, however due to issues with livestock not being in the paddock for the duration of the trials, the annual benefit was not determined.
- GRASP pasture growth modelling suggests the long-term annual benefits from the legume to be 15% and 63% increase in pasture productivity; and 37% and 105% benefit in animal production (live-weight gain per hectare).

4.3.3 Desmanthus and Caatinga stylo respond to phosphorus fertiliser

Results from trials in this project demonstrate that both desmanthus and Caatinga stylo are responsive to P fertiliser on soils with low P supply resulting in higher total pasture productivity. Legume productivity can be dramatically increased through applying phosphorus fertiliser on low P soils. At a trial site near Wandoan with desmanthus, the legume DM production was three to six times higher with P fertiliser. Legume DM production is directly related to biological nitrogen fixation, therefore N fixation was increased by three to six times in three out of four years after the application of P fertiliser. This extra N fixation will cycle to companion grasses leading to extra grass DM production.

The Moura trial site increased legume productivity by two-fold in the first year. This higher legume production led to more grass production in year three.

Currently there is very low use of fertiliser on pastures for beef production in Queensland. These trial results suggest that productivity of sown legumes could be improved dramatically by using P fertiliser on deficient soils. Economic analysis suggests good returns from the use of P fertiliser on legume based sown pastures in the Brigalow Belt bio-region and elsewhere (Peck *et al.*, 2015). In contrast to southern Australia where P fertiliser use on clover based pastures is common, it is likely to require a major change in attitude by graziers to start using fertiliser on pastures in northern Australia. However, some leucaena growers are currently conducting a Producer Demonstration Site project to investigate the animal production benefits from fertilising leucaena/grass pastures.

4.4 Recommendations

The persistence over a wide geographic area combined with large production benefits from Caatinga stylo and desmanthus that have been demonstrated by research trials and some commercial paddocks support the need for R&D to overcome technical issues on how to grow and manage these legumes better. Better recommendations and management is likely to dramatically improve the reliability and productivity of these legumes in commercial paddocks. When combined with other legume species, there is a fairly good range of legume options available to graziers for clay soils in the inland sub-tropics of Queensland. There remains a gap in suitable trial sites to assess the limits of adaptation of these two legumes in southerly latitudes with cooler and wetter winters.

5 Improving reliability of legume establishment

Poor establishment is the most common reason for persistent legume varieties failing when sown with sown pastures in the inland sub-tropics of Australia (Peck *et al.*, 2011). This section of the report provides an overview of results from several research trials on different aspects of improving the reliability of establishing legumes into existing grass pastures. More detail on the research trials on legume establishment are provided in Volume 4.

5.1 Background/aim

A major constraint to the successful incorporation of legumes into existing sown grass pastures is the lack of establishment reliability. Legumes like desmanthus and Caatinga stylo have been shown to be well adapted and productive in the Brigalow Belt bio-region (Volume 3 of this report) and have been available to graziers for 20+ years. There have been many tons of legume seed sold over multiple decades to graziers in the Brigalow Belt, but very few pastures with a meaningful amount of legumes present to show for the investment. Graziers involved in focus group discussions identified poor establishment as one of the major constraints to the use of legumes with existing sown grass pastures (Peck *et al.*, 2012; Peck *et al.*, 2011).

Although good establishment is recognised as critical to the long-term productivity and persistence of pasture legumes, most producers use low-cost and low-reliability establishment techniques such as broadcasting out of planes after either no or minimal pasture disturbance (e.g. fire), one-pass cultivation where seed is sown at the same time or severe soil disturbance and a rough seed bed behind a blade plough used for controlling woody regrowth (Peck *et al.*, 2011). These techniques of introducing legumes have been considered successful in many years in monsoonal areas which have a much higher chance of germinating rain with follow up rain shortly after and less competitive native grasses on less fertile soils but have been woefully inadequate in the vast majority of years with competitive sown grass pastures on fertile soils in the sub-tropics.

Although good establishment is recognised as critical, many producers don't think they can afford to use more expensive establishment techniques and defer grazing to allow establishment. A focus on establishment difficulties and negative short term economic returns by producers needs to be balanced with the opportunities of higher production of legume grass pastures over the long-term demonstrated by research. Despite the opinion expressed by graziers during focus group discussions, economic analysis suggests that spending more money on legume establishment in this environment will provide better returns, especially compared to techniques that have been failing graziers for decades (Peck *et al.*, 2011).

The un-reliable results from commercial sowings of legumes into existing sown grass pastures has led to more reliable establishment techniques being a research priority for this project. The aims of this component of the project were to quantify the impacts of using better agronomic practices before establishing legumes into existing grass pastures.

5.2 Methodology

Sixteen trials were conducted to test different aspects of establishing legumes into existing grass pastures. The locations of the trials are shown in Fig. 4. The trials conducted as part of this project were:

- Two fallow moisture storage trials. These trials aimed to determine how far buffel grass roots extract water into a fallowed strip. Fallowed strips are seen as a way of improving reliability of establishment while reducing overall costs. If fallowed strips are to be used a key question is how wide do strips need to be to allow adequate soil moisture storage.
- Two seeding rate trials. These trials tested whether increasing seeding rate facilitates better establishment.
- Six fallowing, seed bed preparation and post-emergence weed control trials. These trials aimed to test the impact of using agronomic practices typically used in the grain industry on legume establishment.
- Six rate of legume spread trials. These trials aim to determine how quickly Caatinga stylo and desmanthus spread into existing grass pastures if they are established in strips.

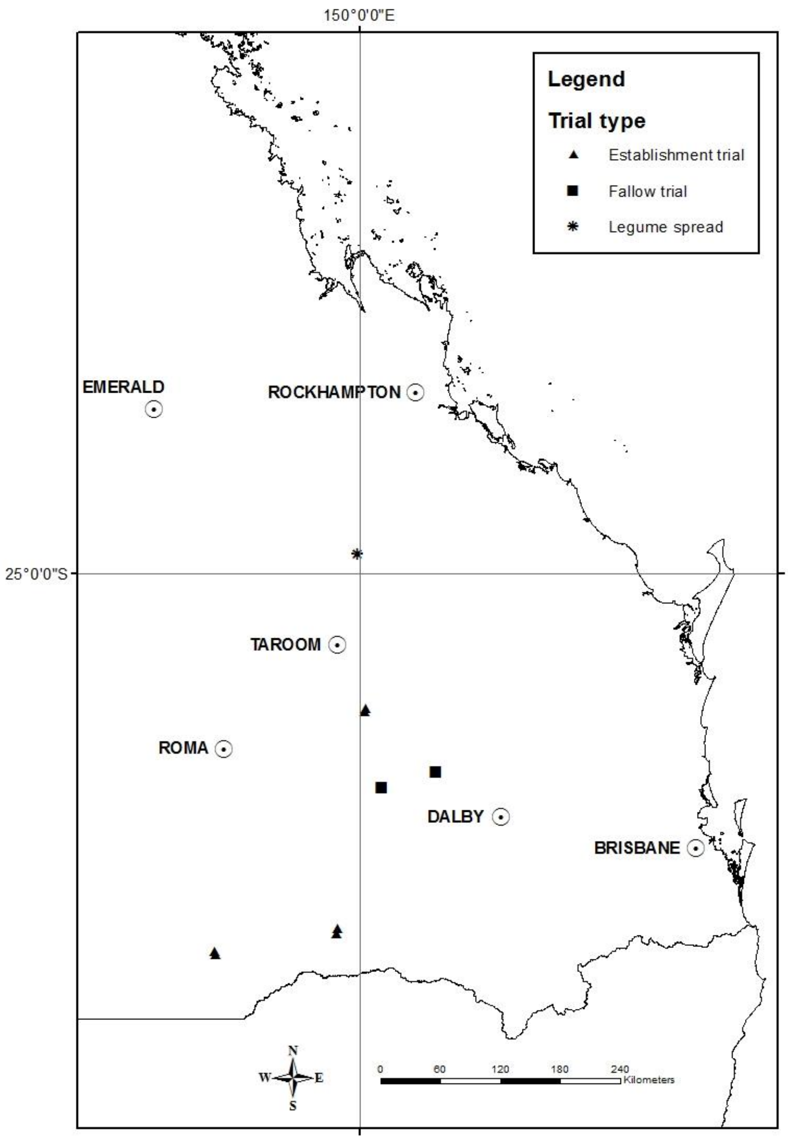

Fig. 4: Location of legume establishment trials.

5.3 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.

5.3.1 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 supply of moisture can come from stored soil moisture and/or rainfall. The available water can either be used by the legume seedlings or through competing plants like the existing grass pasture or other weeds. Reliable legume establishment relies on more water available more often and more of the available water being used to support legume growth.

5.3.1.1 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.

5.3.1.2 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.

5.3.1.3 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.

5.3.1.4 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 month 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.
    - 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.

5.3.2 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.

5.3.3 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 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 dry matter (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.

5.4 Recommendations

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 improve establishment. Greater control of competition through the use of post-emergence herbicides (e.g. Spinnaker) 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 for them to realise their 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 and adapt them to the paddock scale and commercial equipment.

6 Key messages

Pasture legumes have been identified as the best long-term option to increase the productivity and returns from both rundown sown grass pastures by this project and other projects (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. This project measured large production gains from pasture legumes compared to grass only pastures which are the industry norm. The production benefits from using persistent pasture legumes 15 years after sowing at the two grazing trials conducted as part of this project were:

- **Better pasture composition.** At both grazing trials, a higher percentage of the total biomass was made up of good pasture species in the legume with grass paddocks (99% and 90%) than in the grass only paddocks (80% and 87%).

- **More total standing dry matter.** There was 50% and 100% more pasture biomass with the legume then in grass only paddocks at the grazing trials.
- **Higher dry matter production.** There was approximately 30% and 140% more biomass grown in the two years the trials were measured in the legume paddock then in the grass only paddock.
- **Higher animal live-weight gain.** Both trial sites showed higher live weight gains, however due to issues with livestock not being in the paddock for the duration of the trials, the annual benefit was not determined.
- **Higher long-term productivity.** GRASP pasture growth modelling suggests the long-term annual benefits from the legume to be 15% and 63% increase in pasture productivity; and 37% and 105% benefit in animal production (live-weight gain per hectare).

Achieving the high production gains described above requires well-adapted legumes with good management. Research conducted in this project demonstrates that there are suitable legume varieties that can be productive with sown grass for a large part of Queensland. Establishment techniques tested in research trials has demonstrated that it is possible to establish legumes into existing sown grass pastures even in dry years.

For legumes to be successfully introduced to existing commercial sown grass pastures and be productive long-term requires industry to:

- Improve legume management practices. To achieve this requires improved knowledge and skills by graziers and their advisors.
- Develop and adopt better legume establishment techniques, this is especially critical for the sub-tropics where legumes commonly fail to establish when sown into existing sown grass pastures.
- Determine whether existing legume cultivars are adapted to all of the major climate zones of the Brigalow Belt bio-region. There is a gap in trial sites on the Darling Downs, Border Rivers (near Goondiwindi) and lower rainfall districts to test the adaptation (persistence and productivity) of available legume varieties.
- Improve the nutrition of legumes where required.

7 Priorities for future RD&E

Pasture legumes have been identified as the best long-term option to increase the productivity and returns from both rundown sown grass pastures. RD&E priorities therefore focus on improving commercial results and reliability from legumes in sown grass pastures (especially buffel grass pastures) to realise the potential of the existing suite of legumes. High priorities for further research, development and extension are:

1. **Improving reliability of establishing small seeded legumes into existing, competitive sown grass pastures**. Poor establishment is the most common reason for desmanthus, Caatinga stylo and other persistent legumes failing when sown into existing sown grass pastures in the sub-tropics.
2. **Improved nutrition of legumes**. The main legumes for long-term pastures for clay soils in the sub-tropics (Caatinga stylo, desmanthus, leucaena, medics) have all been shown to respond strongly to phosphorus fertiliser. Critical P requirements in the soil are not known for Caatinga stylo, desmanthus or leucaena.
3. **Improved reliability of establishing rhizobia of summer growing legumes when sown onto hot soils**. 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. Alternative rhizobia delivery methods that protect the rhizobia from the hot and dry soil surface need to be developed and adopted for these legumes to be successful.

4. **Better varieties**. A review by Bell *et al.* (2016) identified clay soils in the inland sub-tropics as being the highest priority for developing better legume varieties in northern Australia. The highest priority genera for further evaluation were *Desmanthus* and *Stylosanthes*. There is a high probability that there are better lines of both desmanthus and Caatinga stylo in the Australia Pastures Genebank collection.
5. **Better quality seed**. The quality and reliability of supply of commercial desmanthus and Caatinga stylo seed has regularly been poor. Commercial seed has regularly had poor germination percentages, poor seedling vigour and high levels of contamination with other species. There are exceptions to these generalisations with some seed lots being of better quality and some companies supplying better quality seed. The seed industry needs to address these seed quality issues if legumes are to be more successful when sown into commercial paddocks with competitive sown grass pastures.

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 mitigate the impact of pasture rundown (reduced N availability). For example, strategic use of N fertiliser can have a role to improve productivity and economic returns (Lawrence *et al.*, 2014).

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