final report

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Improving productivity of rundown sown grass pastures

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

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Executive summary

Background:

Pasture legumes have been identified as the best long-term option to increase the productivity and returns from both rundown sown grass pastures and native pastures 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 commonly used successfully by industry in the Brigalow Belt bio-region.

Desmanthus and Caatinga stylo are species of legumes that 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. Graziers and seed companies have questioned whether desmanthus and Caatinga stylo are well enough adapted to be persistent and productive. 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.

Project overview:

This component of the project aimed to determine whether desmanthus and Caatinga stylo can be persistent and productive enough with sown grass pastures under grazing in the Brigalow Belt bio-region to warrant further research, development and extension (R, D&E) investment to address technical issues on how to more reliably and productively grow them. Alternatively, if they are not adequately productive, industry may be better served by R&D focussing on releasing better varieties or investing in other aspects of animal nutrition.
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 see which legumes were persisting.
- New legume persistence trials. Four new trial sites were established.
- 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.
- Two phosphorus fertiliser trials to test Caatinga stylo and desmanthus response to applied phosphorus (P).

Major conclusions:

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 old trial sites evaluated by this project. The project team evaluated 44 old pasture trial sites and found 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%). Legume species were classified into four levels of persistence at the old trial sites (soils mainly clays and loams) that were evaluated:

- Highly persistent: Caatinga stylo and *Desmanthus 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.

Ironically desmanthus and Caatinga stylo have 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.

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 (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.
- Higher dry matter production. There was approximately 30% and 140% more biomass grown in the grass/legume paddocks in the two years the trials were measured.
- 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).

Results from trials in this project demonstrate that both desmanthus and Caatinga stylo are responsive to P fertiliser on low P soils resulting in higher total pasture productivity. 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. Further research is required to clarify productivity responses and economic returns.

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 on clay and loam soils in Queensland, especially in the Brigalow Belt bio-region

Recommendations:

The high persistence of Caatinga stylo and desmanthus over a wide geographic area combined with large production benefits 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 recommendations and management is likely to dramatically improve the establishment reliability and productivity of these legumes in commercial paddocks. When combined with other commercial legume species, there is a fairly good range of legume options available to graziers for clay soils in the inland sub-tropics of Queensland.

Some commercial experience and trial results suggest current varieties of desmanthus and Caatinga stylo may not be persistent in more southerly latitudes with cooler and wetter winters (e.g. Darling Downs). 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. Research is required to better define the climatic limits of current varieties of these legume species as well as to identify improved varieties for southerly locations.

Acknowledgements

This component of the overall project involved evaluating legume persistence at 44 old pasture evaluation trials across central and southern Queensland. Most of these trials are hosted on private properties. The completion of the work would not have been possible without the participation, cooperation and input of many graziers whose support is gratefully acknowledged. In particular, the following grazier families made significant contributions through hosting the more detailed trials:

- Sam and Laurice Morris, formerly of "Thisit", Moura.
- Darryl and Vanessa Ahern, "Rosedale" and "Thisit", Moura.
- Alan and Karen Postle, "Kookaburra", Wandoan.
- Alan and Joy Gath, "Amaroo", Chinchilla.
- Paul and Maria Keys, "Toston", Condamine.
- Richard McClymont, "Morennan", Goondiwindi.
- Ian and Steven Peck, "Lily waterhole" Kalbar.

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.

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1 Background

1.1 Pasture productivity decline and legumes

Productivity decline in sown grass pastures is widespread in northern Australia and reduces productivity by approximately 50% (Graham *et al.*, 1981; Radford *et al.*, 2007; Robbins *et al.*, 1987). This decline in productivity is directly attributable to a reduction in the supply of available nitrogen (N) in the soil as it is progressively 'tied-up' in soil organic matter (Graham *et al.*, 1981; Robertson *et al.*, 1997). 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 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.

Despite legumes being identified as the best long term option to improve productivity of sown grass pastures, they are not widely used by industry. It has been estimated that approximately 70% of sown pastures in northern Australia have been planted only with grass, with buffel grass (*Cenchrus ciliaris*) being the main species planted (75% of the area sown) (Walker and Weston, 1990; Walker *et al.*, 1997). Even where legumes were sown, most of the early plantings failed due to poorly adapted varieties, poor establishment and high competition from grasses due to high nitrogen (N) availability after the clearing of native vegetation (Peck *et al.*, 2011).

The production benefits from legumes can be significant, for example, on-farm research studies in central Queensland (Wandoan to Capella) reported a 60-160% increase in live weight gain per hectare and a doubling of gross margins with legumes compared to grass only pastures (Bowen *et al.*, 2015). These production benefits have stimulated interest within industry, especially in more recent times and has resulted in significant areas of some legumes being planted. For example:

- Shrubby and Caribbean stylos (*Stylosanthes scabra* and *S. hamata*) have proven to be effective on light soils in monsoonal and coastal regions mainly with native grasses, however the same establishment and management techniques have proven to be ineffective in buffel pastures in the sub-tropics.
- Leucaena (*Leucaena leucocephala*) is one of the most widely grown pasture legumes in the Brigalow belt bioregion and has been estimated to be planted on 250,000ha (The Leucaena Network pers. comm.). However this represents adoption on only about 3% of the area of pasture land to which it is adapted (Peck *et al.*, 2011).

The low adoption rates of pasture legumes mean there is a huge opportunity to increase beef production through the wider adoption of pasture legumes in sown pastures, and thereby to provide significantly higher economic returns for decades to come. Achieving the high production gains demonstrated from legumes requires well adapted legumes with good management. Leucaena technology has been extensively researched and developed over many decades to the point that it is reliable and effective. The first leucaena variety released in Australia was released in 1962. Other legume options (e.g. desmanthus (multiple *Desmanthus spp.*), Caatinga stylo (*Stylosanthes seabrana*) for the buffel grass pastures of northern Australia have not had similar levels of development and are in relative terms under-developed technologies.

Desmanthus and Caatinga stylo performed well in evaluation trials on clay soils which led to their release as commercial varieties in 1995 and 1997 respectively. Additional desmanthus varieties have been released in recent years. These two “newer” legume species offer potential to extend the range of land types and climates within which it is possible to establish productive legume infused sown pastures. However commercial results for desmanthus and Caatinga stylo have been mixed with some notable successes but mostly failures. Wider adoption of Caatinga stylo and desmanthus have been hindered by technical issues such as seed quality, specific rhizobia requirements, reliable establishment, and management practices to promote persistence and production. Several people in the seed industry suggest that because of these technical issues (especially specific rhizobia requirements), that desmanthus and Caatinga stylo are doomed to fail as legumes for wide scale adoption in northern Australia (Peck *et al.*, 2011). By contrast, other graziers, farm advisors and researchers have concluded that management of legumes needs to be improved, especially when sown into existing pastures, for <u>any</u> legume variety to be reliably productive.

Industry faces two possibilities with regards to the “newer” legumes, desmanthus and Caatinga stylo, for permanent pasture in the buffel regions of northern Australia, either:

1. The new alternative legumes are not well enough adapted and/or productive enough; therefore the focus should be on finding better varieties, or
2. New alternative legumes are well enough adapted but have technical issues that can be overcome and therefore the focus should be on improving agronomic and grazing management.

1.2 Project activities

This component of the project aimed to determine whether desmanthus and Caatinga stylo can be persistent and productive enough with sown grass pastures under grazing in the Brigalow Belt bio-region to warrant further research, development and extension (R, D&E) investment to address technical issues on how to more reliably and productively grow them. Alternatively, if they are not adequately productive, industry may be better served by R&D focussing on releasing better varieties or investing in other aspects of animal nutrition.

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 see which legumes were persisting.
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- 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; and grazing management for persistence.
- Two phosphorus fertiliser trials to test Caatinga stylo and desmanthus response to applied phosphorus.

The location of the trial sites is shown in Fig. 1.

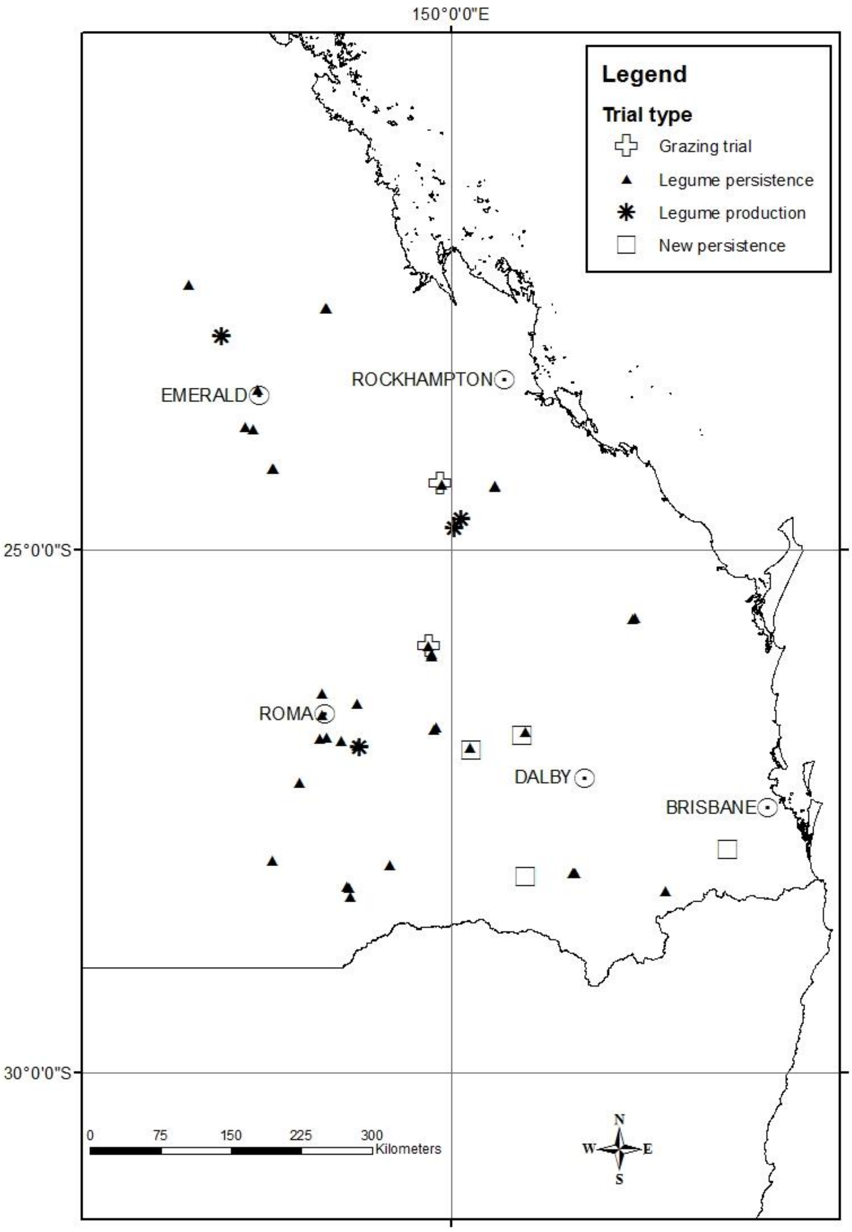


Fig. 1: Location of legume persistence and productivity trial sites. (Sites symbols for persistence, dry matter (DM) production, grazing, new persistence. Major towns for location).

2 Legume persistence

2.1 Background/introduction

Legumes can improve production on rundown sown grass pastures through biologically fixing atmospheric nitrogen and thereby improving diet quality directly through higher protein levels as well as nitrogen cycling to companion grasses (which improves both the dry matter production and feed quality of the grass). However incorporation of legumes into sown grass pastures has not been extensive with 70% of the total area planted in northern Australia being sown only with tropical grasses and even when planted many earlier legume varieties proved not to be persistent with grass pastures (Peck et al. 2011; Walker et al. 1997; Walker and Weston 1990). Legumes cannot be productive in the long-term if they are not strongly persistent. Graziers described persistence as the most important attribute for grass and legume varieties for long term pastures during focus group discussions in the Brigalow Belt bio-region (Peck *et al.*, 2011).

Graziers report that many commercially available legumes have not persisted long term with sown grass pastures in inland districts of Queensland, however several commercially available varieties showed promise during evaluation trials and in some commercial pastures (Peck *et al.*, 2011; Clem and Jones, 1996). The 'newer' varieties of legumes (especially Caatinga stylo and desmanthus) offer the potential to extend the range of land-types and climates where pasture legumes can improve animal production if they prove to be adapted and persistent.

Due to the large difference between trial results and grazier experience, industry faces two possibilities with regards to commercial varieties, especially the "newer" legumes (desmanthus and Caatinga stylo), for permanent pasture in the buffel regions of northern Australia, either:

1. The new alternative legumes (and older varieties) are not well enough adapted and/or have technical issues that cannot be overcome and therefore the focus should be on finding better varieties, or
2. New alternative legumes are well enough adapted but have technical issues that can be overcome, therefore the focus should be on learning how to manage these legumes for higher productivity.

Pasture legumes need good persistence under grazing with sown grasses, especially buffel grass, to be productive in permanent pastures. This paper reports the persistence of commercially available pasture legumes across forty four pasture evaluation trials, demonstration or commercial plantings across southern and central Queensland that have been established for greater than ten years.

2.2 Methodology

2.2.1 Trial site descriptions

Forty four old pasture evaluation and demonstration sites were inspected to observe the persistence of legumes. All sites were established for greater than 10 years. The oldest sites recorded were sown in 1978.

The old trial sites varied dramatically in the design and layout when they were sown. The trial sites varied from single row plantings, small plots (approximately 10 – 50 m^2), large plots (50 – 200m^2), demonstrations (> 3 – 10 ha per legume) and commercial paddocks. In some instances the original plots were still apparent, at other trial sites the legumes have spread or died-out such that the current location of legume species does not reflect the original plot location.

2.2.2 Legume species recorded

The legumes evaluated for persistence were:

- Caatinga stylo (*Stylosanthes seabrana*).
- Desmanthus (multiple species planted, however *Desmanthus virgatus* and *D. leptophylla* were the focus of this study).
- Leucaena (*Leucaena leucocephala*).
- Butterfly pea (*Clitoria ternatea*).
- Siratro (*Macroptilium atropurpureum*).
- Burgundy bean (*Macroptilium bracteatum*).
- Shrubby stylo (*Stylosanthes scabra*).
- Caribbean stylo (*Stylosanthes hamata*).
- Lucerne (*Medicago sativa*).
- Lotononis (*Lotononis bainesii*).
- Round-leaf cassia (*Chamaecrista rotundifolia*).
- Fine-stem stylo (*Stylosanthes guinensis var. intermedia*).

Other legumes were planted at only a few trial sites. Observations were recorded where they occurred but permitted very limited interpretation of their persistence in this region.

2.2.3 Recordings at trial sites

All sites were established for greater than 10 years. At each site the following information was collected:

- Site description (property name, trial name, GPS coordinates)
- Soil and vegetation description
- Legume species planted
- Legume species found and descriptions of persistence including current patch sizes, plant density, population structure (i.e. mainly old plants, mainly young plants, range of ages) and evidence of spread
- Legume health and vigour
- Grass health and vigour (including land condition)
- Current grazing management
- At some sites, nodule number

Eight variables that can impact legume persistence were described for each site:

1. Mean summer growing season rainfall (October-April)
2. Mean annual rainfall
3. Soil surface texture
4. Soil type
5. Grazing pressure on grass
6. Grazing pressure on legumes
7. Grass competition
8. Land condition

2.2.4 Legume ratings

The information recorded at each trial sites was used to rate each legume at each site for:

- Plant numbers (0 – 6 rating)
- Degree of legume spread (1 – 6 rating)

- These numbers were multiplied together to produce a “persistence index”.

A description of plant number rating and degree of spread is provided in Table 1. The area originally planted with legumes was taken into consideration when assessing legume persistence i.e. the larger the area planted, the larger the area with legume plants and number of plants required to be rated the same.

Table 1: Legume number and degree of spread rating.

Rating	**Plant numbers rating[a]**	**Degree of spread rating**
0	*No plants found.*	
1	*Extremely low plant numbers.* A few isolated plants found.	*No spread*.
2	*Very low plant numbers.* Very low plant numbers i.e. significantly fewer plants than what was originally in the trial.	*Very limited spread*. Isolated plants found close to original plot.
3	*Low plant numbers*. Decline in plant numbers relative to what was likely to have been established in the original trial. Plants found close to the original plot with isolated plants and/or very small patches (few plants together) elsewhere. Low plant number when assessed across the trial site.	*Limited spread*. Plants or patches found but close to original plot.
4	*Moderate plant numbers.* Slight increase in plant numbers. Moderate plant numbers in original plots. Moderate plant numbers when assessed across the site for paddock plantings.	*Moderate.* High plant numbers (perhaps in patches) and moderate (20-30m) distance from original plots.
5	*High plant numbers*. Moderate increase. High plant numbers compared to what was originally planted. High plant numbers for paddock plantings.	*High*. High plants numbers in patches 30-100m from original plot.
6	*Very high plant numbers.* Large increase in plant numbers.	*Extreme*. High plant numbers at a moderate distance 50m + from original plots but patches of plants found at greater distance e.g. >100m away from the original plot.

a: Plant numbers rating was for plants within or near where that species was planted in the original trial area.

Persistence ratings were used to classify the legume persistence index at each trial site for all legumes other than leucaena as follows:

- High: persistence rating ≥20
- Moderate: persistence rating of 11-19
- Low: persistence rating of 4-10
- Not persistent: persistence rating ≤3

2.2.4.1 Leuceana persistence ratings

Only the plant number rating was used to classify leucaena persistence due to it being a tree. Recommended management for leucaena is to reduce seed set and recruitment to minimise weed potential and maximise forage production. The modification to plant number rating for leucaena and the persistence rating in relation to plant number rating is shown in Table 2.

Table 2: Leucaena plant number rating and persistence rating.

Rating	Plant numbers rating[a]	Persistence rating
0	*No plants found.*	*Not persistent.*
1	*Extremely low plant numbers.* A few isolated plants found.	*Not persistent.*
2	*Very low plant numbers.* Very low plant numbers i.e. significantly fewer plants than what was originally in the trial.	*Not persistent.*
3	*Low plant numbers*. Decline in plant numbers relative to what was likely to have been established in the original trial.	*Low.*
4	*Moderate plant numbers.* Slight decrease in plant numbers but enough plants still present that they would contribute to animal production.	*Moderate.*
5	*High plant numbers*. Approximately as many plants as originally planted.	*High.*
6	*Very high plant numbers.* Increase in plant numbers.	*High.*

2.2.5 Grazing pressure and grass competition ratings

Grazing pressure, preferential grazing and competition from companion grasses have effects on legume persistence. Grass competition and grazing pressure on both the grass and legumes were rated at each site.

Grazing pressure on the legume as well as the grass was rated using a 6 step rating shown in Table 3. Grass competition was rated to one of five levels described in Table 3.

Table 3: Grazing and grass competition rating.

Rating	Grazing rating	Grass competition rating
Nil	Either no grazing or very occasional, e.g. cultivation paddock with some grazing of stubble occasionally.	
Low	Grazing only at some times for example, grazing of stubble most years.	Grasses with low DM production with gaps in the pasture and low ground cover. Or, no grass planted with little invasion by grass.
Low - Medium	Low year round grazing pressure, or moderate grazing pressure but frequently spelled (e.g. trial site fenced and occasionally opened to grazing).	Grasses with moderate DM production. Some grass competition, but less than most grass/legume pastures. For example, sites planted to legume only and the grass has not fully invaded the trial site; poorer grasses e.g. land condition B or C.
Medium	Grazing controlled to levels similar to recommended practices or district averages.	Well established grasses with moderate to high grazing pressure. Or pastures with moderate pasture and ground cover.
High	Heavy grazing of surrounding paddock with the trial site being similar.	Well established grasses with high DM production dominating the site.
Very High	Preferential grazing of trial site. Very short plants that are frequently and severely defoliated. Trial site with fences pulled down or gate open the vast majority of the time.	Well established grasses with very high DM production dominating the site with little or no grazing.

2.2.6 Rainfall

Long term rainfall statistics for each site were calculated from the closest SILO patched climate station (Jeffrey *et al.*, 2001). Climate stations used infilled data from 1889 till January 2016 to calculate means for average annual rainfall and summer growing season (October to April).

2.2.7 Analysis

Legume persistence ratings were analysed using recursive regression partitioning trees. The partitioning trees build classification or regression models of a very general structure where the resulting models can be represented as binary trees (Therneau and Atkinson, 1997). Eight explanatory variables were related to legume persistence in the model and allowed the recursive partitioning tree to determine the best variables to include in the tree. The 8 explanatory variables were:

1. Mean Rainfall (October - April)
2. Mean Rainfall (December – January)
3. Soil surface texture
4. Soil type
5. Grazing pressure on grass
6. Grazing pressure on legumes
7. Grass competition
8. Land condition

This process was completed for 4 different measurements for 6 species of legumes. The measurements were:

- Persistence rating (factor)
- Persistence index (continuous)
- Plant number (continuous)
- Plant spread (continuous)

The six legume species analysed were:

1. *Desmanthus virgatus*
2. *Desmanthus leptophyllus*
3. Caatinga stylo
4. Shrubby stylo
5. Leucaena (plant number only)
6. Butterfly pea

Other legumes were recorded at an insufficient number of sites to allow analysis.

It is important to note that any patterns found via recursive partitioning trees are not necessarily statistically significant. They are simply an indication of what patterns may exist in the data. It is also important to remember that this is an observational study and therefore can only suggest a correlation or association exists between two or more variables rather than a causal effect.

2.3 Results

2.3.1 Sites and recording

Legume persistence at 33 old trial and demonstration sites were recorded in May 2011 across southern and central Queensland. An additional three sites were recorded in October and November 2011 in central Queensland. Four additional sites were recorded in southern Queensland in January 2013. Four sites were recorded in May 2016 in southern Queensland.

The majority of sites were recorded after the wettest summer in decades; therefore the plant density of legumes may have been higher than in more 'normal' years. However the majority of sites consist of relatively small areas containing legumes within much larger paddocks containing few (if any) legumes and therefore the trial sites are often heavily grazed. A wet year presented an ideal opportunity to record these sites as the legumes were able to grow well enough to identify species, and obtain an estimate of persistence and productivity whereas in dry years it may have been difficult to find more than chewed off stems.

The sites ranged from single rows and small plots for evaluating multiple lines across a wide range of species; larger plots for promising lines and commercially available varieties and; large plots or grazing trial paddocks for commercially available varieties (or at the time pre-release) for demonstration purposes or in some cases commercial plantings. The large plot trials (200m^2 plot size) were much better for testing persistence as they had a much greater number of plants when fences were pulled down. The larger plots therefore had a better chance of surviving under grazing than a much smaller number of plants in a row or small plot. The other issue with the small plot trials was that there were a large number of accessions planted, therefore the plants persisting now may or may not be the commercially available varieties. On the positive side, due to the large number of accessions planted, the small plots are more likely to have genotypes that could be useful as varieties for the future.

The majority of sites in central Queensland were from the “Legumes for clay soils” project large plot trials (Clem and Jones, 1996). These sites consisted of large plots (10 x 20m) and generally speaking, the well-adapted persistent varieties could be located in their original plots. In southern Queensland the sites were dominated by small plot trials where it was often difficult to locate the original plots.

2.3.2 Geographic spread of sites

Fig. 2 shows the geographic spread of the sites across southern and central Queensland. The sites visited provide reasonably broad coverage of the Brigalow Belt bio-region.

There is a gap in comparative legume production sites on the Darling Downs and Border Rivers grazing land management (GLM) regions. The site near Warwick (southern Darling Downs region) did not have desmanthus or Caatinga stylo planted. The sites on the eastern side of the Border Rivers region had no Caatinga stylo planted and did not have the commercially available varieties of desmanthus planted. Only one of the four sites in the west of the Border Rivers region had both desmanthus and Caatinga stylo planted.

Clay soils in central Queensland are well represented in the spread of sites.

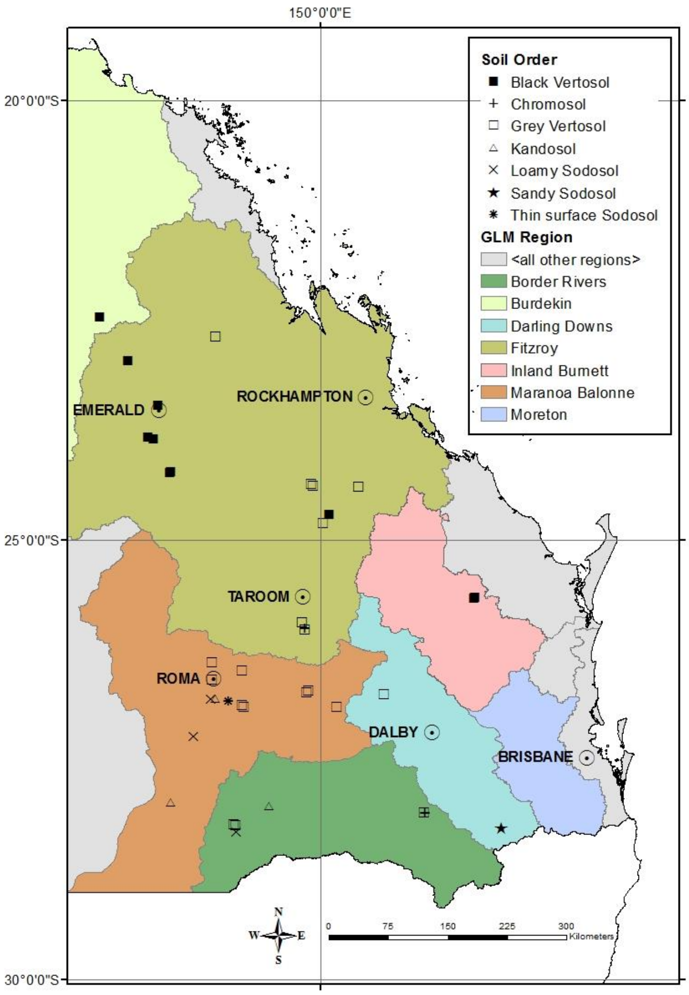


Fig. 2: Location of legume persistence trial sites.

2.3.3 Climate zones

The trial sites in relation to two different climate classifications is shown in Fig. 3 and Fig. 4. Fig. 3 shows the trial site locations relative to the Köppen climate zones of Queensland while Fig. 4 shows agro-climatic zones based on plant growth.

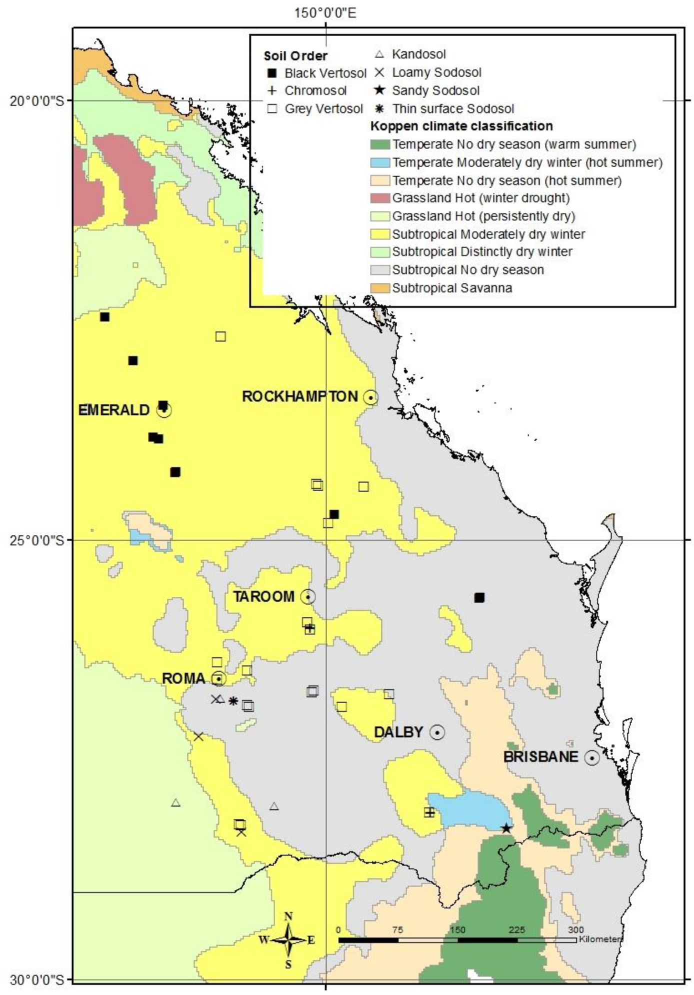


Fig. 3: Trial sites in relation to Köppen climate zones of southern and central Queensland.

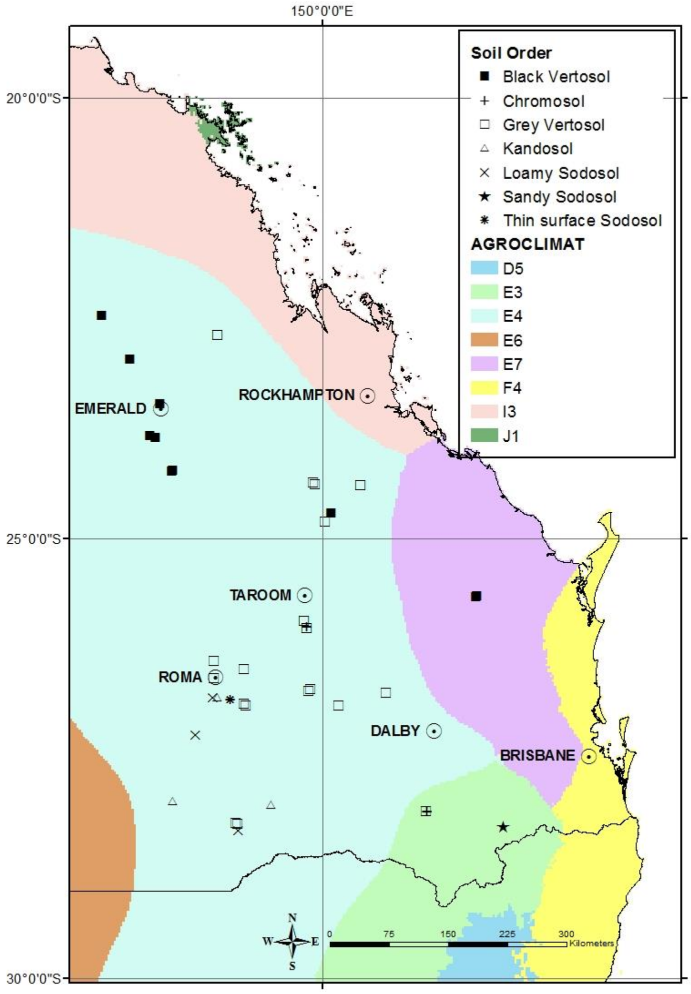


Fig. 4: Trial sites in relation to agro-climatic zones of southern and central Queensland (Hutchinson et al., 2005).

Fig. 4 shows the trial sites location compared to agro-climatic zones (Hutchinson *et al.*, 2005; Hutchinson, 1992). This climate classification system is based on a general plant growth model. A description of the agro-climatic zones on the map are:

- D5 cool, wet. Moisture availability high in winter-spring, moderate in summer, most plant growth in spring.
- E3 warm, seasonally wet/dry. Most plant growth in summer, although summers are moisture limiting. Temperature limits growth in winter.
- E4 warm, seasonally wet/dry. Growth is limited by moisture rather than temperature and the winters are mild. Growth is relatively even through the year. Unique in the world to the Brigalow Belt bio-region of Queensland and NSW.
- E6 warm, seasonally wet/dry. Semi-arid climate that is too dry to support field crops. Soil moisture tends to be greatest in winter.
- E7 warm, seasonally wet/dry. Moisture is the main limit on crop growth. Growth index lowest in spring.
- F4 warm, wet. Warmer, wet sub-tropical climates.
- I3 hot, seasonally wet/dry. Monsoonal wet/dry. Cooler and longer growing season parts of the monsoonal climate zones.
- J1 hot, wet. Moisture and temperature regime supports growth for 8-9 months of the year, with a 3-4 month dry season.

Almost all of the trial sites recorded occur within E4, the Brigalow Belt agro-climatic zone. The only trial site within the temperate area of Queensland did not have desmanthus or Caatinga stylo planted and is on a very poor, shallow and gravelly soil.

2.3.4 Relative persistence of species

Persistence of pasture legume species across all trial sites that they were sown is shown in Table 1. Caatinga stylo and *Desmanthus virgatus* showed high levels of persistence across the trial sites that they were planted. At the other end of the spectrum Lucerne, Caribbean stylo and round-leaf cassia persisted at none of the trial sites where they were planted.

Table 4: Number of trial sites at which 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

2.3.4.1 Persistence of Caatinga stylo

Caatinga stylo had the greatest persistence of the legume species studied at these old trial sites. It persisted at 85% of the sites it was planted (i.e. 23 of the 27 sites it was planted). Recursive partitioning tree analysis identified high grass competition (i.e. high or very high ratings based on the scale in Table 3) as the main variable that negatively impacted its persistence. One-way analysis of variance (ANOVA) showed no statistically significant difference in persistence between high grass competition sites and other sites for this legume (Fig. 5).

Summer growing season mean rainfall of <430 mm also negatively impacted persistence based on recursive partitioning but no statistical differences were detected.

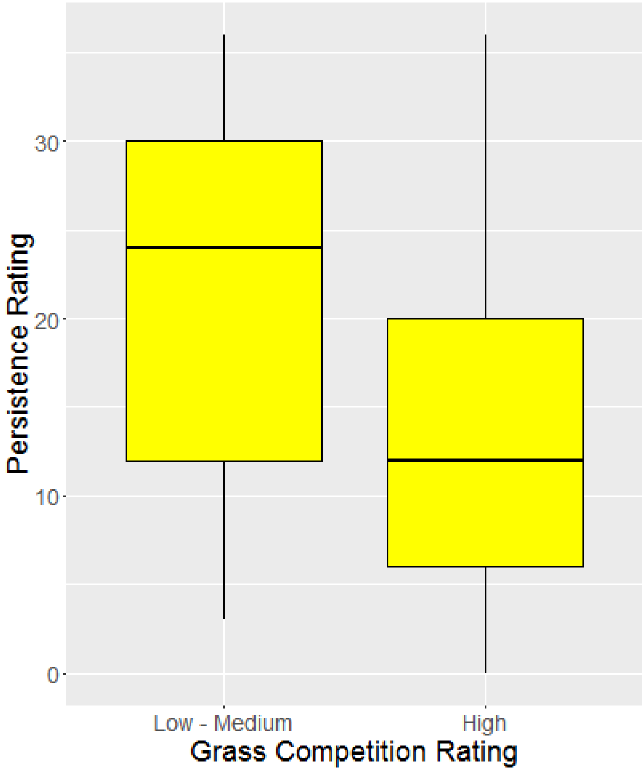


Fig. 5: Caatinga stylo persistence compared to grass competition.

2.3.4.2 Persistence of desmanthus

Multiple species of desmanthus were planted at the trials sites, however identification to the species level was difficult when observations were taken. Due to the difficulty in identifying species, only *D. virgatus* and *D. leptophylla* were identified and analysed.

D. virgatus is the second most persistent legume at the old trial sites. It persisted at 79% of the trial sites it was planted at (Table 4). Recursive partitioning tree analysis (Fig. 6) identified that *D.virgatus*:

- Persisted better on Grey Vertosols and Loamy Sodosols than on Black Vertosols or sandier soils (Chromosols, Kandosols and Thin-surfaced Sodosols).
- For Grey Vertosols and Loamy Sodosols it persisted better at trial sites with summer mean rainfall >443mm.

One way ANOVA identified that *D.virgatus* persisted significantly better on Grey Vertosols or Loamy Sodosols with >443mm rainfall than at other sites Fig. 7.

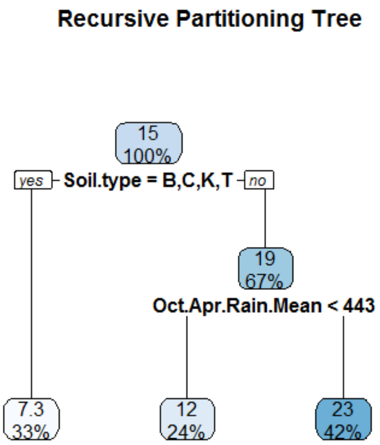


Fig. 6: Recursive partitioning tree of factors affecting the persistence of *D.virgatus*. Numbers show the average persistence rating and the percentage of sites. Rainfall (October – April) is expressed in mm. Soil codes are B: Black Vertosol; C: Chromosol; G: Grey Vertosol; K: Kandosol; L: Loamy Sodosol; S: Sandy Sodosol; T: Thin surface Sodosol.

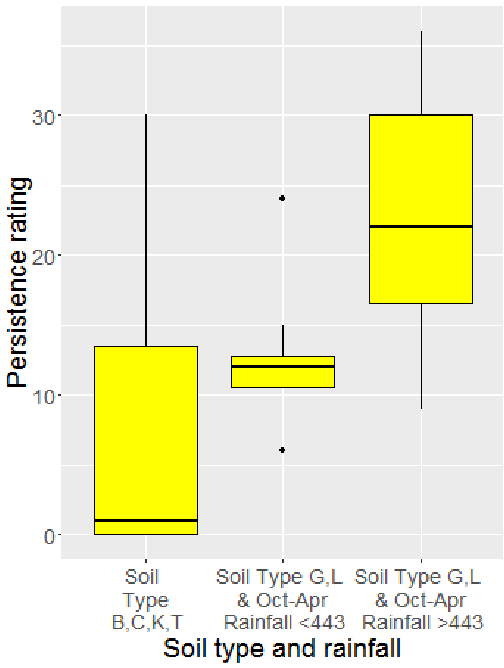


Fig. 7: Factors affecting persistence of *D.virgatus*. Soil codes are B: Black Vertosol; C: Chromosol; G: Grey Vertosol; K: Kandosol; L: Loamy Sodosol; S: Sandy Sodosol; T: Thin surface Sodosol.

D. leptophyllus was persistent at 73% of sites, however it showed low persistence at 50% of sites. Due to *D. leptophyllus* showing moderate or high persistence at only 23% of sites, it has been classified as a moderately persistent legume (Table 4). It persisted better on Grey Vertosols than on Black Vertosols or Loamy Sodosols (Fig. 8).

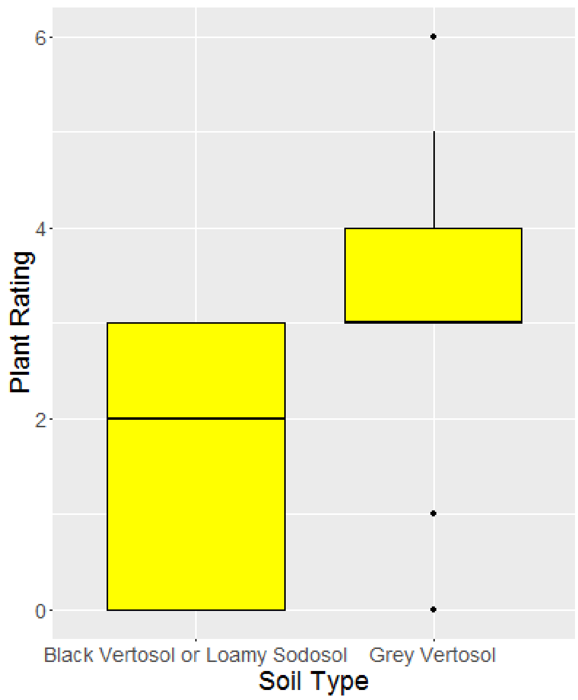


Fig. 8: *D. leptophyllus* persistence on different soil types.

2.3.4.3 Persistence of butterfly pea

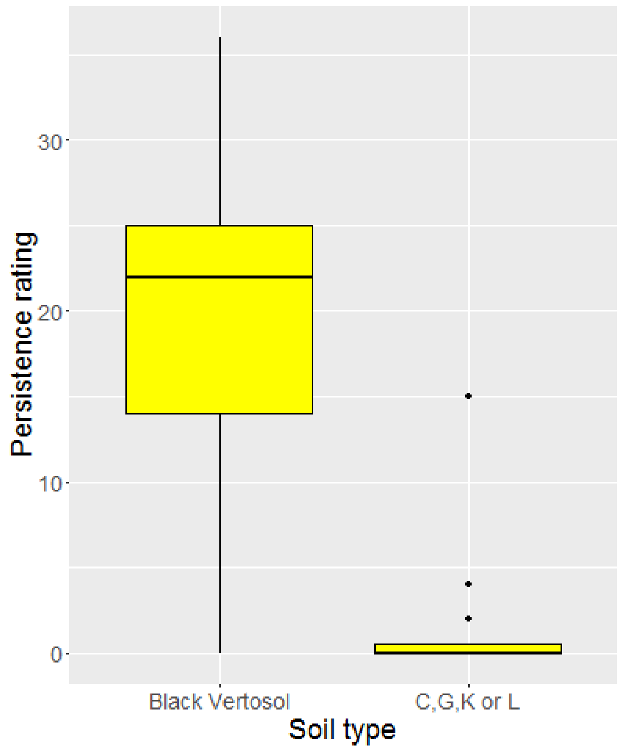


Fig. 9: Factors affecting persistence of butterfly pea. Soil codes are B: Black Vertosol; C: Chromosol; G: Grey Vertosol; K: Kandosol; L: Loamy Sodosol.

Persistence of butterfly pea is strongly influenced by soil type and climate. It persisted only on Black Vertosol soils in central Queensland (Fig. 9).

2.3.4.4 Persistence of shrubby stylo

Shrubby stylo did not persist on Vertosols (cracking clay soils) but did persist on sandier soils (Chromosols, Kandosols, Loamy Sodosols and Sandy Sodosols) (Fig. 10). It was also planted on one shallow sodic duplex soil (Thin-surfaced Sodosol) where it did not persist.

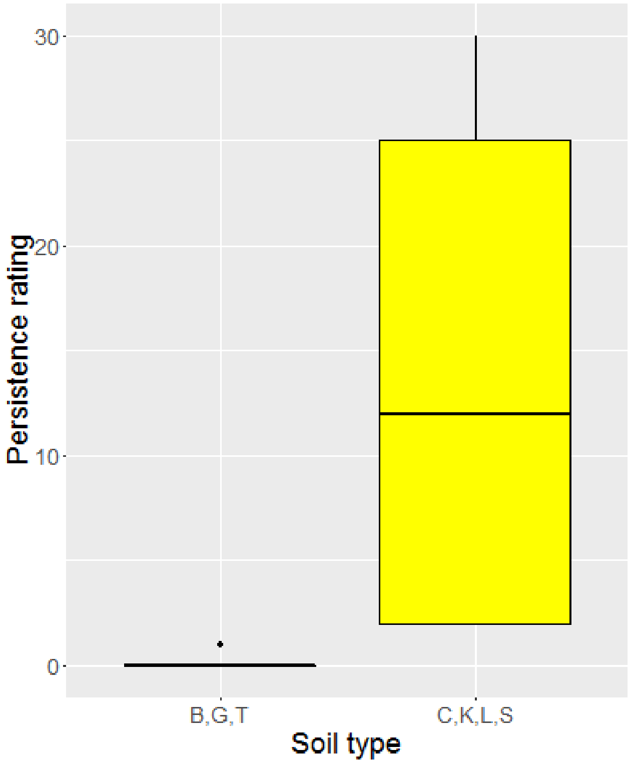


Fig. 10: Soil type impacts on shrubby stylo persistence. Soil codes are B: Black Vertosol; C: Chromosol; G: Grey Vertosol; K: Kandosol; L: Loamy Sodosol; S: Sandy Sodosol; T: Thin surface Sodosol.

2.4 Discussion

2.4.1 Persistence of legume species

The main aim of this study was to gain a better understanding of the persistence of Caatinga stylo and desmanthus because they are:

- more recently released varieties,
- have had mixed results in commercial sowings, and;
- are both important for extending the range of climate and soils with commercially available pasture legume options.

Despite mixed reports from commercial plantings both Caatinga stylo and desmanthus persisted at a large percentage of the sites they were planted at. Ironically they both persisted at a higher percentage of sites then leucaena and shrubby stylo which both have the commercial reputation of being widely persistent (as long as their specific management requirements are met). 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, i.e. leucaena, shrubby and Caribbean stylos and round-leaf cassia have broad reputations for being persistent (Peck *et al.*, 2011). The differences between these trial results and commercial industry perceptions 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 whereas most other legumes are simply broadcast into un-disturbed grass pastures, which almost always results in poor establishment (Volume 4).
- A longer history of use by industry.
- Usage of these legumes in native pastures rather than with more competitive sown grass pastures (mainly buffel grass).

2.4.1.1 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 4). 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. 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. Its high persistence ratings indicate that it is able to thicken up and spread over time. It appeared widely productive and was observed to be retaining its leaf for longer than desmanthus in this study.
- In southern Queensland, Caatinga stylo has been promoted for light 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 provide an exciting opportunity to extend the range of stylos for light soils 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. ungrazed trials (Fig. 5). 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 to high grazing pressure 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).

2.4.1.2 Persistence of desmanthus

Multiple desmanthus 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 common accession planted was cv. Marc. There are questions about Marc and other accessions productivity for grazing livestock across the sites as it seems to have relatively lower dry matter and poorer leaf retention into autumn/winter compared to stylos and the taller species of desmanthus. Some other accessions seem to retain their leaf better than Marc.
- It did not persist well on sandier soils or on Black Vertosols (Fig. 6). 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 cracking 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 species deserve further evaluation to try and select for more widely adapted and persistent accessions.

2.4.1.3 Moderately persistent legumes

Butterfly pea, leucaena, shrubby stylo and fine-stem stylo were moderately persistent across the trial sites at which they were planted. These results differ from the conventional perception for leucaena and shrubby stylo which are both considered highly persistent by industry (Peck *et al.*, 2011). Butterfly pea and fine-stem stylo persisting at only some sites aligns with industry recommendations.

<u>Butterfly pea:</u>

Butterfly pea persisted on Black Vertosol soils in central Queensland (CQ) but did not persist on other soils or in southern Queensland. These results align with previous research and commercial experience (Collins and Grundy, 2005). Butterfly pea is recommended only for short term pastures on other soils in CQ.

<u>Shrubby stylo:</u>

Shrubby stylo persisted on lighter soils but did not persist on heavy cracking clay soils. These results align with previous research and commercial experience which recommends shrubby stylo for lighter soils in low frost incident locations (Partridge *et al.*, 1996; Lambert and Graham, 1996).

The commercially available varieties (cv. Seca and Siran) have not performed well in southern inland Queensland due to the high frost incidence, however this work has found shrubby stylos persisting in frosty locations. These frost tolerant shrubby stylo provide an exciting opportunity to extend the range of stylos for light soils further south. These stylo lines are now being evaluated in a separate project. There is also a high likelihood that adaptation for more southerly locations with colder winters exists within this species or closely related species that has not yet been evaluated. There is likely to be accessions within existing genetic resource banks that could yield new varieties.

Fine-stem stylo:

Fine-stem stylo has been recommended for sandy soils with slightly higher rainfall than what is experienced in most of the Brigalow Belt bio-region (Partridge *et al.*, 1996). Fine-stem stylo persisted only on sandier soils on the eastern, higher rainfall trial sites. These results align with previous research results and industry experience.

Leucaena:

Leucaena has been shown to be highly persistent in research trials and in commercial plantings (Dalzell *et al.*, 2006; Shelton and Dalzell, 2007), however it persisted at only 44% of sites and was moderately or highly persistent at only 31% of sites. Due to the range of variables considered and limited number of sites that it was planted (16) no recursive partitioning tree trends were detected. The likely contributing factors for leucaena not persisting at a high percentage of sites in this study are:

- Soil type. Leucaena is recommended for better soils with high water holding capacity, that is loams to clays with deep rooting depths. Some of the trial sites where leucaena did not persist were sandy soils with low water holding capacity.
- Soil fertility. Leucaena has a relatively high fertility requirement. Some of the trial sites where leucaena did not persist were low in phosphorus (and probably other nutrients), however this could not be analysed as part of this study as soil test information was not available for all sites.
- Grazing management. After the original trials were finished, the trial sites were grazed as the land owners decided. In most cases this meant uncontrolled grazing resulting in very high grazing pressures through preferential grazing as the trial sites were small legume trials (a high protein island) in large grass-only paddocks (low protein). Some of the trial sites where leucaena did not persist have been heavily grazed.

The fact that desmanthus and Caatinga stylo have persisted in a greater range of locations than leucaena in old trial sites provides confidence that further development work on these “newer” species is worthwhile. In particular, both desmanthus and Caatinga stylo have persisted on very low P soils where leucaena and other legumes have perished, and this may offer opportunity to extend the range of soils were legumes can be planted.

2.4.1.4 Non-persistent legumes

The legumes that showed very poor persistence were:

- Burgundy bean. Persisted at 13% of sites it was planted.
- Siratro. Persisted at 20% of sites.
- Lotononis. Persisted at 29% of sites.

Both burgundy bean and Siratro have been widely recommended and sown in pastures in Queensland. They have not been persistent at the trial sites measured in this study and they have persisted in very few commercial pastures when combined with grass under grazing (Peck *et al.*, 2011). They can however perform strongly in the first 2-5 years after sowing. They continue to appear in seed companies recommendations for permanent pastures despite their poor performance in long term pastures. They should not be recommended for long term pastures in the Brigalow Belt bio-region.

Lotononis persisted at two of the more easterly, higher rainfall trial sites. It has also persisted for >10years in commercial pastures in more coastal districts. It should not be recommended for the Brigalow Belt, however it could have a role in higher rainfall districts. Seed has not been commercially available for many years.

Lucerne, Caribbean stylo and round-leaf cassia persisted at none of the trial sites that were measured as part of this study. Conclusions from this study, previous research and commercial experience for the persistence of these species are:

- Lucerne can be useful in short term pastures in southern Queensland but does not persist long term (Lloyd *et al.*, 2007).
- Caribbean stylo has been widely used commercially and has persisted on light soils from central Queensland north, however all of the trial sites in CQ in this study were on clay soils.
- Round-leaf cassia has persisted to the point of dominating pastures in more easterly districts (e.g. the Burnett River catchment) and northerly districts (i.e. central and north Queensland; parts of the Northern Territory). It has not persisted at old trials in Southern Queensland and the authors are un-aware of examples where it has persisted in commercial pastures unless protected from frost (e.g. under trees, tops of hills).

2.4.2 Geographic coverage of sites

The trial sites were spread across a wide geographic area of southern and central Queensland and are representative of a large percentage of the soils and climates within these regions (Fig. 2 - Fig. 4). The coverage should provide confidence to industry that the results from this study are useful for a large part of the sub-tropics, especially for clay soils.

2.4.2.1 Soils

Fig. 2 shows the range of soil types that the trial sites are located on. All sites in central Queensland were on clay soils (black Vertosols and grey Vertosols). Southern Queensland sites had a range of soils from sandy soils (Kandosols, Chromosols and sandy Sodosols) to loams (loamy Sodosols) to heavy clays however there were no black cracking clay soils (Black Vertosols) (Fig. 2).

There is arguably a gap in trial sites for lighter textured soil in central Queensland, however shrubby and Caribbean stylo have been commercially successful in these conditions. Southern Queensland sites had a range of soils from sands to heavy clays, however there were few heavy clay soils which reflects land use with many of these soils being cropped. Increasing areas of land in southern Queensland have been taken out of cropping and put back to pastures, therefore a better understanding of adaptation to heavy clays is important for the grazing industry into the future.

There is a gap in trial sites for the commercially available varieties on heavy soils in southern Queensland. There are no sites on black cracking clay soils derived from basalt often referred to as Queensland bluegrass downs (Black Vertosols) on the Darling Downs (or elsewhere in southern Queensland) compared to eight in central Queensland.

2.4.2.2 Climate

The trial sites provided a good coverage of the main climate zones of the Brigalow Belt, however there are some gaps:

- The only trial site within the temperate area of Queensland did not have the current desmanthus varieties or any accessions of Caatinga stylo planted.
- There were no sites in the Border Rivers that had both Caatinga stylo and desmanthus planted together. Northern NSW and southern Queensland are mapped as having the same climate zones (E4 in Fig. 4), however the percentage of rainfall occurring in winter increases with more southerly latitudes. This gap in trial sites limits the understanding of the southerly adaptation of current varieties.

2.4.3 Limitations to the study

The persistence of legumes at these old trial sites provides a good indication of their adaptation to the environments at the trial sites in competition with grass and in most instances under grazing. However, there are differences between the trial sites and therefore limitations to the interpretations that can be made. The main identified limitations are:

- Different starting points. The different trial sites had different starting points, that is single rows, small plots, large plots and commercial paddocks. The different starting points meant that the number of plants when grazing commenced were highly variable. This was taken into account when rating legume persistence, however the measurement was at only one point in time.
- Management. When the original trials were completed, the management reverted to whatever the land owner decided. This meant that trial sites varied from no grazing through to heavy grazing pressures. The different management styles would have had an impact on legume persistence. Discussions with current land owners and observations made on the sites were considered when rating legume persistence however there were not detailed histories for the different trial sites.
- Different accessions at different trial sites. Legumes could only be identified to the species level, however it is known that some accessions within a species are more persistent than others. The greatest number of trial sites did have the commercial varieties planted, however the persistence of some species at some sites is most likely non-commercial lines. This is particularly true for shrubby stylo in southern Queensland where the commercial varieties of Seca and Siran have not been persistent.
- Soil nutrient levels. Soil nutrient levels, particularly phosphorus and sulphur, have probably affected persistence. However, soil nutrient levels were only available for some sites but not others.

2.5 Conclusions

2.5.1 Persistent legumes

Although commercial results from incorporating legumes into sown grass pastures in inland Queensland has been considered un-reliable, the old trial sites evaluated during this project demonstrate that there are commercially available persistent legumes for land types with medium and heavy textured soils in southern and central Queensland. Conclusions for different species are:

- Caatinga stylo is widely adapted to a wide variety of soils, including both clays and lighter soils (sandy loams) however there is a gap in trial sites for southern Qld and northern NSW. Caatinga stylo lines persisting and spreading from an evaluation trial south of Roma are likely to be different lines to the commercially available varieties Unica and Primar. These lines are now being evaluated in a separate project to see whether they have potential as new varieties.
- Desmanthus is widely adapted to clay soils, however there is a gap in trial sites for southern Qld and northern NSW. Desmanthus did not persist as well on black cracking clay soils as on grey clays. *D.virgatus* was more persistent than other taller species, however the other taller species appeared more productive at some sites. The higher production potential of some of the other taller species supports the recommendation that further evaluation is warranted to identify more persistent lines.
- Butterfly pea can be persistent with good grazing management on Black Vertosols in central Queensland.
- Leucaena can be persistent with good grazing management on more fertile soils if well established. There is a gap in trial sites for southern Qld and northern NSW.
- Shrubby stylo can be persistent on lighter soils. Shrubby stylo lines persisting in southern Qld are likely to be different lines to the commercially available varieties *Seca* and *Siran*. These lines discovered persisting in southern Queensland are now being evaluated to see whether they offer potential as new varieties.
- Burgundy bean and Siratro were not persistent and should not be recommended for long term or permanent pastures in the Brigalow Belt bio-region.
- Lucerne was not persistent at any trial sites.
- Round-leaf cassia and Caribbean stylo are not adapted to southern inland Qld or for clay soils.
- Lotononis and fine-stem stylo may have a role on sandy soils in more easterly, wetter districts.

The high level of persistence of several legumes tested during this project should provide confidence to industry and RD&E organisations that it is worthwhile to invest resources into improving the reliability and performance of incorporating legumes into sown grass pastures. Some of the non-commercial lines that have shown outstanding persistence and productivity at the small plot evaluation trials, especially in southern Queensland, suggest that further evaluation on these species would produce better varieties.

2.5.2 Geographic spread of sites

The old trial sites visited provide a fairly good geographic coverage of CQ. However all sites recorded were clay soils. There is arguably a gap on medium and lighter textured soils. However shrubby and Caribbean stylos combined with the legumes described in the present study provide a good coverage of suitable legumes for permanent pastures on the land types and climates of CQ.

In SQ there is a gap in the old trial sites visited for the Darling Downs, Goondiwindi and Moonie districts as well as northern NSW for desmanthus and Caatinga stylo as well as other legume species. This gap in legume trials is an important knowledge gap as these regions have high numbers of livestock and large areas of land that could be suitable for improvement with legumes.

Based on the old trial sites visited there is a gap in summer growing legume options for lighter soils (sandy and hard setting surfaced soils) in SQ. Legumes that were rediscovered as part of this study are now being evaluated for these soils and climate.

3 New legume persistence sites

3.1 Background

The persistence of legumes at old pasture evaluation trial sites described in Section 2 provides valuable information on the long term persistence of Caatinga stylo and desmanthus across large areas of sub-tropical Queensland. This work also identified gaps in the trials for covering the soil and climate variability of southern Queensland, in particular the Darling Downs and Border Rivers districts do not have trial sites.

Some experiences from commercial plantings reported by graziers to the project team suggest that there may be limitations for the current commercial varieties in cooler environments which receive more winter rain. Graziers from the north east Darling Downs that participated in a Landcare project and other graziers have reported that both Caatinga stylo and desmanthus have not performed well in their pastures. These anecdotal reports are concerning, however there could be a number of factors contributing to this poor performance including the poor quality commercial seed that was available at that time.

This activity took advantage of other project activities to plant desmanthus and Caatinga stylo in districts with higher winter rainfall and frost incidence.

3.2 Methodology

Four trials were established to test the persistence of Caatinga stylo and desmanthus in more southerly locations than the old trials described in Section 2. The location of the trials are shown in Fig. 1. The trial sites were:

- “Amaroo” near the town of Chinchilla sown on the 19th of February 2014 and re-sown on the 24th of March 2014 due to poor emergence from the first sowing.
- “Toston” near Condamine sown on the 23rd March 2014.
- “Morennan” east of Goondiwindi sown on the 10th February 2015.
- Silverdale near Harrisville sown on the 26th December 2014.

The trials at “Amaroo” and “Toston” were previously used for fallow moisture storage trials described in Volume 4 of this report. These locations are close to old trial sites that had non-commercial lines of desmanthus and Caatinga stylo persisting for >10 years however these sites are close to the district where graziers had reported poor performance of commercially available varieties of these legumes.

The trial site to the east of Goondiwindi and the Silverdale site near Harrisville are in locations where no known trials of commercial varieties of Caatinga stylo and desmanthus exist.

Large plots of legumes (100 – 200m^2) were established with the following varieties:

- Caatinga stylo, varieties Primar and Unica.
- Desmanthus, varieties Marc and Progardes (a blend of five varieties). At the Silverdale site no Marc was sown. At “Morennan” only one of the Progardes lines (JCU2) and cv. Unica was sown.

Plant density was measured in permanently located quadrats.

3.3 Results

Legume density (plants/m^2) for the trial sites is shown in Fig. 11. Chinchilla, Condamine and Goondiwindi all have good legume density at this early stage of the trials. Silverdale had good number going into the first winter but suffered a catastrophic loss of legume density through the first winter, especially for the Caatinga stylo. The Silverdale trial site experienced both waterlogging and frost during the first winter.

Unfortunately the legume density was not measured at Amaroo (near Chinchilla) going into the first winter or the following spring. General observations were that there were good plant numbers going into the winter, albeit relatively small plants due to the late (March) sowing and even during late winter; however by the following summer there were inadequate legume density of Caatinga stylo and Marc desmanthus and additional seed was broadcast onto bare patches within these treatments. The site experienced a dry spring, therefore it is not known if the plants perished during winter from frost or spring from dry weather.

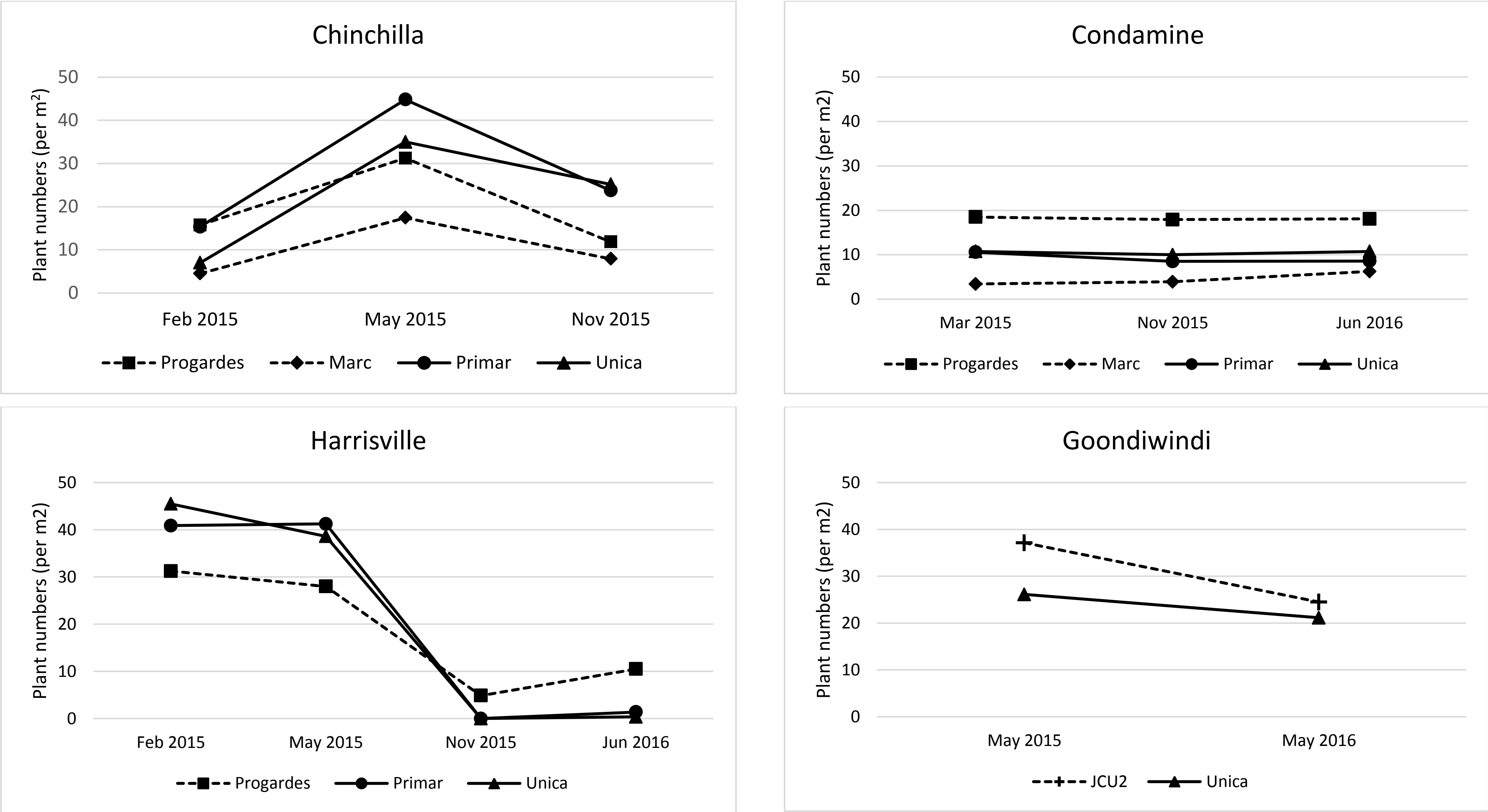


Fig. 11: Legume density over time at four trial sites in southern Queensland. The sites were sown at different times: Chinchilla and Condamine sites were sown in March 2014, Harrisville in December 2014 and Goondiwindi in February 2015.

3.4 Discussion

These trial sites provide useful additional sites for monitoring the long term persistence of commercially available desmanthus and Caatinga stylo varieties in more southerly latitudes. During the evaluation phase, all of the varieties were mainly tested in trial sites located in central and northern Queensland with very few trials established in southern Queensland. The trials that were in southern Queensland were located in the northern part of this region (i.e. Roma, Miles). There remains a gap in trial sites in more southerly, cooler locations to test the adaptation of these legume varieties. Graziers have reported that these varieties have not performed well on the Darling Downs.

Plant density has been measured for up to two summers, a period of time still considered to be within the establishment phase for permanent pastures. Despite the short term measurement, there are some important results that indicate that further work is required to better understand the adaptation of the commercial varieties. These trial results support the anecdotal reports from graziers that the commercial varieties of Caatinga stylo and perhaps desmanthus may struggle in districts with cooler and wetter winters:

- At Silverdale, Caatinga stylo completely died out at in the first winter when it experienced the dual stress of frost and waterlogging. Progardes desmanthus had a dramatic reduction in plant numbers in the same first winter but still had 5 plants/m^2 in spring. The fact that both legumes have failed in this environment suggests further work is required to determine the limits to adaptation for these commercially available varieties.
- At Amaroo, Caatinga stylo and Marc desmanthus plant numbers reduced dramatically in the first winter/spring period. The Caatinga stylo and Marc plots were sown with additional seeds and have subsequently supported high plant numbers.

These trial results combined with the gap in coverage of old trial sites described in Section 2 demonstrate the need for additional trials to be established to test the adaptation limits of the commercially available varieties of desmanthus and Caatinga stylo.

4 Legume productivity

4.1 Introduction:

A range of forage legumes are suitable for perennial pastures on clay soils, however there is limited data on long term productivity especially for the more recently released legumes desmanthus and Caatinga stylo. There is also very limited data available to compare different legume options that have been established the same way, sown side-by-side on the same soil type.

This activity measured dry matter production of perennial pasture legumes that were persisting across four old pasture trial sites in southern and central Queensland.
The aim of this work was to complement the measurements of persistence (described in Section 2) with measurements of pasture productivity of Caatinga stylo and desmanthus in the long term. While measuring the DM production of Caatinga stylo and desmanthus, other legumes were measured where they were persisting.

4.2 Methodology

Four old pasture evaluation trial sites located on private farms were selected across southern and central Queensland where both Caatinga stylo and desmanthus were persisting after being sown approximately 18 years previously. These sites were selected from the 44 old trial sites described in Section 2. All sites had a range of perennial legumes sown, at the sites were they were present both butterfly pea and leucaena were also measured. The locations of the trial sites are shown in Fig. 1. The town closest to the trials and soil types at the trial sites were:

- Roma (Grey Vertosol)
- Theodore – (Black Vertosol)
- Theodore – (Grey Vertosol)
- Capella – (Black Vertosol)

The Grey Vertosols both had Brigalow as the dominant native vegetation. The Black Vertosols were Queensland bluegrass vegetation.

Areas with good legume plant populations were marked and mechanically slashed to approximately 5cm above the ground in February 2013 and spelled from grazing. Plant regrowth was subsequently measured 3 months later, in May 2013. Legumes varied between sites with Caatinga stylo (cv. Prima and Unica) and desmanthus (cv Marc) at all sites, butterfly pea (cv. Milgarra) at 2 sites and leucaena (cv. Cunningham) at one site.

4.3 Results

The dry matter sampling of the legumes occurred in a relatively dry growing season (Table 5). The sites near Theodore and Capella all had approximately 200mm of rain, however the site near Roma had a very dry season receiving only 73mm.

Table 5: Rainfall received during the pasture regrowth period.

Site	Soil type	Rainfall 1 Feb to 1 May (mm)
Capella	Black Vertosol	218
Theodore 1	Black Vertosol	188
Theodore 2	Grey Vertosol	193
Roma	Grey Vertosol	73

Grass, legume and total (combined grass and legume) DM production are shown in Fig. 12. Grass made up the bulk of the dry matter measured at each site, however all legumes investigated showed that they can regrow after severe defoliation from slashing during a dry growing season.

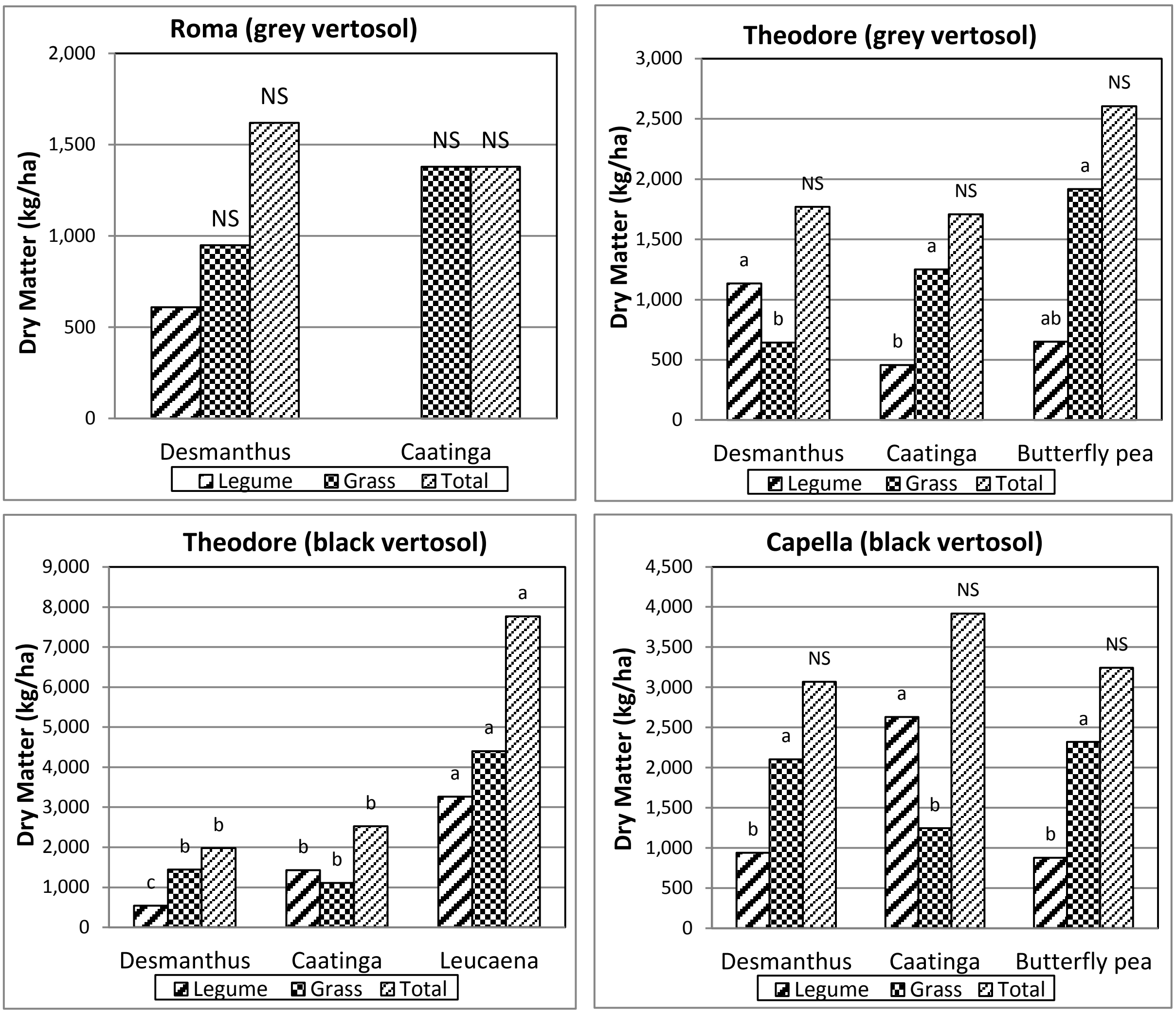


Fig. 12: Legume, grass and total dry matter yields (kg/ha), three months after slashing for 18 year old plots of desmanthus, Caatinga stylo, butterfly pea and leucaena harvested across four different properties in 2013. Letters denoting significance refer to the pasture component they are above (i.e. compare letters for legume fractions with other legume fractions only). NS = No significant difference.

Desmanthus and Caatinga stylo regrew from the slashing at all sites with the exception of Caatinga stylo at the Roma site. Drought conditions at Roma/Surat combined with slashing to approximately 5cm caused severe impacts to the Caatinga stylo and it did not regrow after slashing.

4.4 Discussion/conclusions

4.4.1 Legume dry matter production

The dry matter production at these trial sites demonstrates that all four legumes that were measured can be productive and persistent over the longer term (>15years).

Generally there was an inverse relationship between the legume and grass, that is where there was more legume produced there was less grass measured. This relationship resulted in similar total DM production.

4.4.1.1 Caatinga stylo and desmanthus

Dry matter production at these trial sites show that Caatinga stylo and desmanthus can have good productivity at >15 years after establishment. Across the four trial sites, these legumes were producing >25% of the total pasture yield (with the exception of Caatinga stylo at Roma which succumbed to the combined effects of short slashing and drought). These results combined with the persistence at a large percentage of old trial sites (Section 2) demonstrate that both of these legumes can be persistent and productive in long-term pastures on clay soils in the sub-tropics.

Caatinga stylo performed better on the Black Vertosol soils than desmanthus, desmanthus out performed Caatinga stylo on the Brigalow grey clay soils at Roma and Theodore; however they were both productive across both soil types. These results align with the results on legume persistence for desmanthus (described in Section 2) where it was not as persistent on Black Vertosols. Brigalow soils generally have higher sulphur, sodium and chloride levels, are more fertile and have more grass competition then the black cracking clays. Further work is required to determine if these factors contribute to desmanthus not performing as well on Black Vertosols or whether Caatinga stylo is intrinsically better adapted to black cracking clays.

4.4.1.2 Leucaena and butterfly pea

Leucaena was a solid performer at the one site it was sown and this supports it's well documented suitability to the central Queensland environment (Fig. 12), however site specific characteristics favoured its growth compared to the other legumes for a number of reasons. The Black Vertosol soil at Theodore where leucaena outperformed the other legumes had very high grass competition due to it being un-grazed in most years as it is in the corner of a cultivation paddock with a dense stand of purple pigeon grass. The very high grass competition at this site most likely impacted the lower growing legumes to a greater extent than the leucaena which being a tree that had been established for a long time before being cut back to a low height, had an existing large root system to support regrowth. Leucaena also favours, relatively fertile deeper ex-cropping soils without shallow sub soil constraints to rooting depth.

Butterfly pea produced good amounts of regrowth at the two sites it occurred. The good regrowth supports the suitability of this legume in the central Queensland environment on deeper better clay soils with grazing management that ensures it can recover from preferential grazing.

4.4.2 Limitations of the study

The trial designs were a low cost and efficient method of obtaining some information on the long term productivity of available legume varieties. The trial sites had been established under previous projects, the land owners maintained an interest in the trial results and therefore were keen to see the trials re-measured.

Three of the trial sites had been established as large plots (200m^2 plots), the fourth site consisted of small paddocks from a grazing demonstration. A valid comparison between the different legumes required finding areas within the old trial layout that had similar composition of grass and legume. Given the different growth characteristics between the legume species it was difficult to find areas with exactly the same composition to measure at some of the sites.

Another compromise at the sites was the slashing height. Given the different growth habits between the different species, slashing to the same height would probably be imposing a different level of impact and removal of growing points for the different species (e.g. the desmanthus has a virgate growth habit while Caatinga stylo often has an erect habit when competing with grass).

The leucaena was not slashed in the same way as the other species due to its woody nature. The leucaena had been allowed to grow above grazing height for many years. Prior to these trials it had been pushed over with a bulldozer blade, the project team then removed the shoots from pushed over leucaena as best as possible. Therefore the leucaena and companion grass had a different starting point to the other legumes.

4.4.3 Future R&D

There are very few trials that have compared the pasture productivity of different legume varieties in long term pastures. Central Queensland has a good coverage of old trial sites that tested legumes on clay soils from the "Legumes for clay soils project" (Clem and Jones, 1996). There has not been a similar project in southern Queensland that has compared the productivity of different legumes on clay soils in multiple districts. Trials should be established on the Darling Downs and Border Rivers districts to fill this gap (this gap is also identified in Section 2.5.2).

In addition to the gap identified in legume persistence and dry matter productivity, there is a gap in knowledge about the comparative animal production potential of the legumes that are available for clay soils in the sub-tropics.

5 Legume productivity grazing trials

5.1 Background

The long term productivity benefits of sowing the more recently released summer growing legumes Caatinga stylo and desmanthus with buffel grass has not previously been measured. Most trials measure productivity benefits from legumes for 3-5 years after establishment with relatively few measuring animal production benefits. This project activity aimed to measure the long-term benefits of the newer legumes desmanthus and Caatinga stylo to both pasture and cattle productivity. This activity had two separate trial sites that had two paddocks each; one paddock established with buffel grass pastures compared to buffel grass with a legume pastures approximately 15 years after establishment.

5.2 Methodology

Six old grazing trials were revisited as part of the activity measuring persistence at old trial sites (Section 2 of this report). Two of these old trial sites were suitable for re-measurement of animal performance because they had good legume content, fences were still in place and property owners were interested. Two of the other trial sites were ruled out due to fences being removed; the other two old trials were unsuitable as they still had low legume content due to poor establishment even after the passage of >15 years.

The two grazing trials that were remeasured were "Thisit" near Moura and "Kookaburra" near Wandoan (Fig. 13). At both sites the pastures were established into paddocks that had previously been cropped. Each trial has two 10ha paddocks; one paddock was sown to buffel grass while the other paddock was sown to buffel grass and either desmanthus (variety Jaribu) or Caatinga stylo (cv. Primar and Unica). The Moura site was sown with

Caatinga stylo early in 1997 with both *Biloela* and *Gayndah* buffel grass varieties. The Wandoan site was sown with desmanthus early in 1995 but differs from the Moura site in that only the *Biloela* variety of buffel grass was sown and a very small amount of creeping bluegrass *cv. Bissett* seed was also included.

Pasture and animal production was measured in the first few years after establishment with re-measurement as part of this project occurring in 2011-13. Some early results for the Wandoan site are available in an MLA final report (Clem and Jones, 1996). The Moura site was part of a Producer Demonstration Site (PDS) project. For both trials there was no animal or pasture production benefit from the legume in the first few years after establishment. These results are typical for newly established tropical grass pastures with good nitrogen availability from fallowing after a cropping phase.

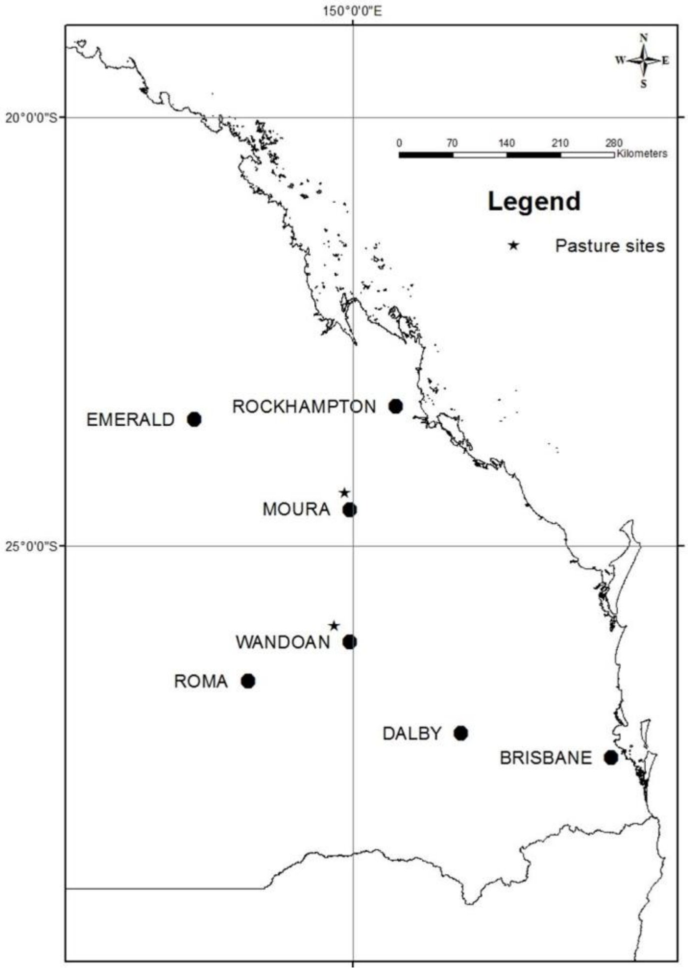


Fig. 13: Grazing trials established at Thisit property located near Moura and Kookaburra property located near Wandoan.

Pasture and animal measurements taken at both sites were:

- Botanals to measure pasture composition, standing dry matter and ground cover.
- Swiftsynds to measure pasture productivity and to allow GRASP modelling.
- Animal performance (live weight).
- Dung samples for NIRS analysis of feed quality and diet selection.
- Blood phosphorus levels.
- Grazing management for persistence trial.

- Phosphorus fertiliser trial. Both trial sites had very low plant available P levels in the soil, therefore a phosphorus fertiliser trial was conducted to measure the response of the pastures.

5.2.1 Soils and vegetation

The Thisit grazing trial site is typical of cleared brigalow / belah vegetation on cracking grey clays. Given the trials location, it most closely aligns to the Fitzroy Basin Brigalow softwood scrub land type (Whish 2011).

The remnant native vegetation remaining around the Kookaburra grazing trial included brigalow, red bauhinia, yarran and silver-leafed ironbark. The site was cleared with no regrowth present. The sites most closely align with Poplar box/Brigalow/bauhinia land type but on a grey clay soil (Whish 2011).

5.2.1.1 Soil nutrient levels

Soil samples were taken from a number of locations across the grazing trials to test for variability. Soil samples were analysed for a wide range of plant nutrients and soil constraints. Laboratory test results for the most commonly limiting nutrients in clay soils in this region are summarised in Section 7.2.1.

Both trial sites had very low plant available phosphorus levels:

- Thisit at Moura had a Colwell P level of 3-7 mg P/kg at 0-10cm depth and 2 mg P/kg at depth in 2010. Later soil test results taken in 2012 in a different part of the paddock when starting a P fertiliser trial had a Colwell P level of 1 mg/kg for the surface soil. The Caatinga stylo based pasture was subsequently shown to be responsive to applied P fertiliser (Section 7).
- Kookaburra had a Colwell P level of level of 3-5 mg/kg at 0-10cm and ≤1 mg/kg at depth for soil samples taken from three different sampling zones. The sampling zones were defined by contour banks (i.e. bottom of the slope, mid-slope, top of the slope. Subsequent soil sampling at the start of the P fertiliser trial in 2012 recorded a Colwell P level of <1 mg/kg for mid-slope soil. The desmanthus based pastures were subsequently shown to be responsive to applied P fertiliser and a fertiliser mix that supplied sulphur, potassium and zinc (i.e. it was responsive to S, K or Zn or a combination of these nutrients) (Section 7).

5.2.2 Botanals

Pasture composition, dry matter and species frequency were measured for both sites using the Botanal technique (Tothill *et al.*, 1992). The method was modified to also determine the density of legumes across the paddock (i.e. legume plants/m^2) by counting legume plants in each quadrat.

5.2.3 SWIFTsynd: Pasture productivity measurement

At each grazing trial, small exclosures (30mx30m) plots were established in the paddock sown to buffel and the paddock sown with legume. These were established at "Thisit" in November 2011 and "Kookaburra" October 2011. Detailed pasture production measurements were collected four times a year over the 2011-2013 period using the SWIFTsynd methodology (Day and Philp, 1997). The measurements taken at each site provide the minimum information required to determine pasture and soil parameters for the pasture growth model GRASP (McKeon *et al.*, 2000). Measurements obtained from the sites included:

- rainfall
- gravimetric soil moisture content

- pasture height
- pasture species composition
- green and dead plant cover
- dry matter yield of grass, legumes and forbs
- total % nitrogen in grass and legumes
- grass basal area

Preparation of the sites each year involved the removal of dead material and remaining litter before spring rains. At Thisit a rotary slasher was used to remove material to 5 cm at the beginning of the trial and again in the second year. At Wandoan the sites were mown to 5cm in year 1 using a lawn mower, but slashed in year 2 using the same rotary slasher as used at Thisit. Grass and legume samples collected over the two years were analysed for Total N. Accumulated rain gauges (capacity of 235 mm) located at the SWIFTSYND sites were emptied four times a year over the two years of data sampling.

5.2.4 GRASP: Pasture productivity modelling

Detailed data collected from SWIFTSYND sites over the 2011-2013 period was used to calibrate the GRASP pasture production model (McKeon et al. 2000). GRASP is a point-based model that uses daily climate inputs to simulate soil-water balance, above-ground grass growth and animal production. It has been widely used in the semi-arid tropical grazing lands of northern Australia to estimate safe carrying capacities and to evaluate the effects of grazing management practices on native pastures, livestock production and resource condition. In the summer rainfall environment of northern Australia, pasture growth is limited by moisture or soil fertility (primarily nitrogen). Standing pasture yield is the net result of the processes of pasture growth, death, detachment, consumption and trampling (McKeon et al. 2000).

The accumulated rainfall data from the SWIFTSYND sites and records from nearby locations were used to adjust the historic climate records accessed from Scientific Information for Land Owners (SILO) climate database (Jeffrey et al. 2001). The SILO records also contain temperature and other weather data. Particular care was taken to ensure the accumulated rainfall data for each site was correct. It was necessary to convert the accumulated rain data to a daily rainfall pattern that is required for the GRASP model. This was achieved by evenly distributing the difference between SILO and the measured accumulated rainfall for each collection period for every 1 mm or 5 mm SILO record. The supplemented historical climate data was then used to calibrate the sites using the GRASP model.

5.2.4.1 Simulations

Once calibrated, the grass only and grass and legume models for each location were reviewed to determine if and how the models differed, and whether the differences were due to site preparation approach, site-specific characteristics or location. Consideration of the appropriateness for the models to be extended over time, and the representativeness of the calibrated sites to a broader land system to allow for the extrapolation of results spatially was required.

The calibrated models were extended over time using historical climate data to determine the productivity of the grass only and grass and legume grazing systems for each location. Long-term simulation of these grazing systems were undertaken using the GRASP model (version g21_j7j6_for_test dated October 2010) and the following options:

- A 20-year simulation period (1995-2014) to capture productivity of the pastures since paddocks were sown with buffel and legumes.
- A three-year spinup to adjust soil water, cover and litter pools to more closely align with user defined parameters.

- Runoff model 1, which is a function of surface cover, rainfall intensity and soil-water deficit, was set for Kookaburra whilst these parameters were set to be free draining at Thisit.
- Soil loss (model 3) which is a function of surface cover and runoff at Kookaburra.
- Dynamic grass basal area model where changes in grass basal area are a function of total growth of current and previous growing seasons, with evapotranspiration and evapotranspiration use efficiency indicators of total growth.
- Pasture burning was turned off.
- Pastures were stocked with 2-year old steers (400kg LW)

Grazing strategies that dictated stocking rates were:

- Option 2 responsive stocking rate, where stocking rate is adjusted each year to eat a fixed proportion of the existing pasture yield (TSDM) on 1st June over the next year
- Date for resetting stocking rate was 1st June
- Annual live weight gain was calculated from % utilisation and percentage of days during the year where pasture growth index was above 0.05 threshold (model 9). The growth index is a product of soil water, solar radiation and temperature indices.
- Pasture utilisation was set at 30%, the recommended safe utilisation rate for the brigalow clay land types (e.g. Brigalow softwood scrub, Brigalow with melonholes, Brigalow with blackbutt) of Fitzroy GLM region (Whish, 2010).
- Pasture condition subroutine was turned on. The loss of desirable perennial grasses associated with heavy utilisation is simulated in GRASP by linking the percentage of desirable perennials to an annual time-scale. Percent perennial grass is used as an indicator of condition, with grazing pressure expressed as the percentage of total growth that is eaten as green material. Pasture condition can change up or down between excellent (90% perennial grass) and degraded (1% perennial grass) pastures in response to different utilisation rates.
- Pasture condition at both Thisit and Kookaburra commenced in A condition (88% perennial grasses). When 30% of total growth was consumed as green material there was no change in pasture condition, when less than 30% of green material was consumed there was an increase in pasture condition, and a decline in pasture condition occurred when utilisation was greater than 30%.
- Detachment rates for dead leaf and stem were set at 0. 0010 per day over growing season, and 0.0050 per day over the dry.

Adjustments to the annual live weight gain subroutine were made following a review of literature, grazing trial data and soil analyses. Simulation pasture and animal productivity outcomes were evaluated, and the suitability of calibrated models for use at other sites across the Brigalow Belt is discussed.

5.2.5 Animal production

Growing cattle were grazed at both sites, but unfortunately there were not cattle in the paddocks for the full period that pasture measurements were taken. The reasons for stock being taken out of the trials were:

- Thisit at Moura was for sale and eventually sold while we were taking measurements at the grazing trial. Livestock had been supplied by the landholder. The property was subsequently destocked while the property changed hands.
- The grazing trial at Kookaburra was destocked for a period due to very poor animal performance. The poor animal performance was subsequently attributed to phosphorus deficiency and animals were re-introduced to the paddocks with P supplements being offered.

The animal production measurements taken at the grazing trials were:
- Live-weight over the time periods that they were grazed.
- Dung samples for NIRS analysis of feed quality on approximately a monthly time step.

Blood samples were analysed for phosphorus at both grazing trials. Additionally, blood samples at Kookaburra were analysed for copper and sodium levels.

5.3 Results

5.3.1 Rainfall

Accumulated rainfall was measured at the trial sites, however rainfall gauges at both grazing trials over flowed during flood rain periods. The measured rainfall was compared to SILO records for nearby weather stations and property records to interpolate to daily rainfall and to fill in missing rainfall records. Rainfall during the SWIFTSynd measurement period were compared to interpolated 100 year SILO climate data.

Thisit experienced above average rainfall during the period of pasture measurement:
- 100 year average 661mm.
- 1179mm in 2010/11 (i.e. 178% of the long term average) in the year prior to this project taking measurements.
- Grass only received 809mm in 2011/12 (i.e. 122% of the long term average) and 862mm in 2012/13 (i.e. 130% of the long term average).
- Grass and legume paddock received 816mm in 2011/12 (i.e. 123% of the long term average) and 868mm in 2012/13 (i.e. 131% of the long term average).

Kookaburra experienced slightly below average rainfall during the period of pasture measurements but was preceded by an extraordinarily wet year:
- 100 year average annual rainfall 614mm.
- 1211mm 2010/11 (i.e. 197% of the long term average) in the year prior to this project taking measurements.
- 560mm July to June 2011/12 (i.e. 91% of the long term average).
- 569mm 2012/13 (i.e. 93% of the long term average).

5.3.2 Results at Thisit

5.3.2.1 Pasture composition across the paddocks

Pasture composition, dry matter yield and species frequency of the grass only (*Cenchrus ciliaris cvv.* Biloela and Gayndah) and grass and legume (Caatinga stylo *cvv. Primar* and *Unica*) paddocks were estimated in 2012 using the Botanal procedure (Table 6). The estimated total pasture yield in the grass and legume paddock (10 485 kg ha^{-1}) was double that of the grass only paddock (5 302 kg ha^{-1}), with stylo contributing 70% of the yield (7 430 kg ha^{-1}). In the grass only paddock, whilst both cultivars of buffel grass and Queensland bluegrass occurred in similar frequencies, total yield was dominated by buffel grass (Biloela 32%, Gayndah 22%) with Queensland bluegrass and Indian couch the next major contributors (~16% each). In the grass and legume paddock buffel cv. Biloela dominated the grasses, contributing almost a quarter of the yield (2 465 kg ha^{-1}).

Table 6: Pasture composition, dry matter yield and species frequency of grass only and grass and legume paddocks at Thisit estimated using the Botanal procedure in April 2012.

Species (contribute >1% to DM yield)	**Common name**	**DM yield**				**Species frequency**	
		kg ha^{-1}		**(%)**		**(%)**	
		Grass	**Grass + legume**	**Grass**	**Grass + legume**	**Grass**	**Grass + legume**
Cenchrus ciliaris	Buffel cv. Biloela	1687	2465	32	24	54	89
Cenchrus ciliaris	Buffel cv. Gayndah	1170	406	22	4	51	26
Dichanthium sericeum	Queensland bluegrass	868	30	16	0.3	51	2
Bothriochloa pertusa	Indian couch	819	35	16	0.3	30	4
Bothriochloa bladhii	Forest bluegrass	240	6	5	0.1	4	1
Stylosanthes seabrana	Caatinga stylo	144	7430	3	71	22	99
Chloris spp.	Windmill grass	121	8	2	0.1	21	2
Urochloa mosambicensis	Sabi grass	107	31	2	0.1	12	2
	Total	**5302**	**10,485**				

One of the symptoms of pasture rundown (i.e. reduced availability of nitrogen in the soil) is a change in pasture composition away from fertility demanding grasses like buffel grass, especially Biloela buffel grass, to species that are more tolerant of lower fertility conditions. At this trial site the grasses that are known to be tolerant of low fertility that are occurring as a much higher component of the pasture in the grass only paddock are (Table 6):

- Indian couch
- Forest bluegrass
- Queensland bluegrass
- Sabi grass
- Windmill grass

There is also an interesting change in the relative yield between the cultivars of Biloela and Gayndah buffel grass between the two paddocks. Biloela buffel grass contributed 2465 kg DM/ha in the grass + legume paddock but only produced 1687 kg DM/ha in the grass only paddock i.e. a much reduced DM production in the grass only paddock. Conversely, Gayndah buffel produced a lot more DM in the grass-only paddock (1170 kg DM/ha) compared to the grass + legume paddock (406 kg DM/ha). The most likely explanation is that the higher N availability, brought about by the inputs of the legume have allowed Biloela buffel grass to be more competitive which in turn to suppressed the Gayndah buffel.

Based on the pasture composition from the Botanal results (Table 6) both paddocks were in good condition at the start of the trial:

- Grass only paddock: If Sabi grass is considered a good pasture grass, 80% of the pasture composition is good pasture species and the paddock would therefore meet the criteria to be considered A condition (Aisthorpe *et al.*, 2004). Sabi grass continues to be sold as a sown pasture, however many producers have reported that it is not as productive as some other grasses in this environment. Given the broad categories and even with including Sabi grass included, only 80% of the yield is made up of better species; therefore it could be considered that the grass only paddock is at the good end of B condition.
- Grass with Caatinga stylo paddock: Good pasture species comprise 99% of the pasture yield, therefore this paddock is in A condition (Aisthorpe *et al.*, 2004).

5.3.2.2 Pasture growth in SWIFTSYND exclosures

Fenced SWIFTSYND exclosures (Day and Philp 1997) were established in the grass only and grass and legume paddocks in November 2011, with measurements continuing until 2013 (Fig. 14 & Fig. 15).

Legumes increased total pasture productivity by 23-35% over the 2 years of sampling (Table 7, Fig. 16). In the grass and legume SWIFTSYND site, buffel (49%) was the dominant contributor to total yield with both Queensland bluegrass (21%) and Caatinga stylo (25%) sub-dominant (Table 7). Buffel (39%) and Queensland bluegrass (37%) were the dominant contributors to total yield for the grass only SWIFTSYND site, although Indian couch and other species contributed 22% of the yield. Pasture species composition (% of total yield) in the grass only site and grass and legume site changed from buffel dominant (~45%, 66% respectively) and Queensland bluegrass and Indian couch sub-dominant (~28%) in the first year 2011-2012, to Queensland bluegrass (47%, 31% respectively) contributing more to total yield than buffel (32%, 31% respectively) in the second year (2012-2013) (Table 7). Queensland bluegrass was on average more dominant in the SWIFTSYND site (37%, 21%) than in the paddock (16%, 0%). It is possible that buffel grass was more sensitive than Queensland bluegrass to the slashing to 5-10cm approach used to “reset” the pasture each year to enable measurement of pasture growth. It is also possible that the erect, woody stemmed stylo was impacted by the height of “resetting” used, particularly in the first year.

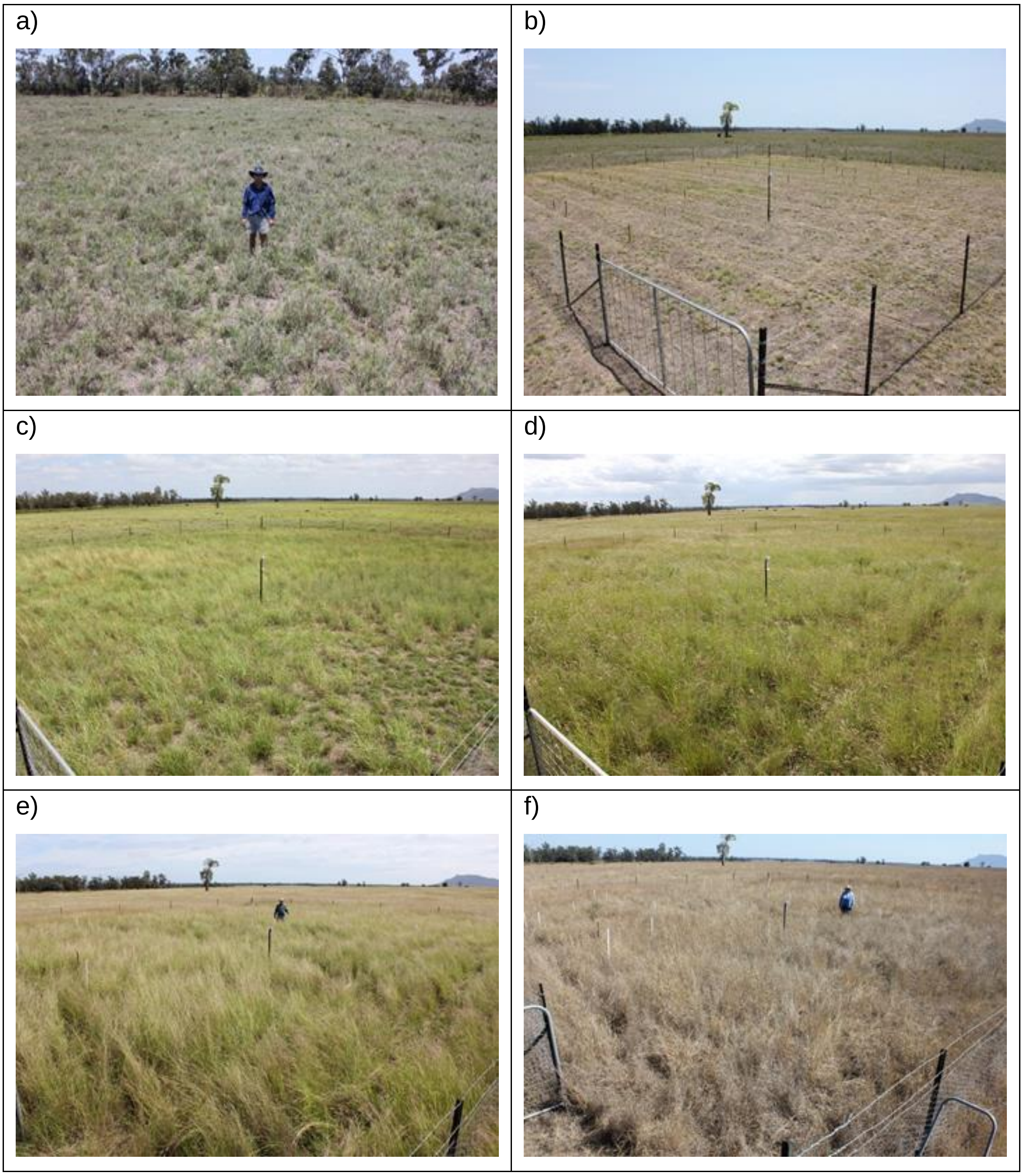
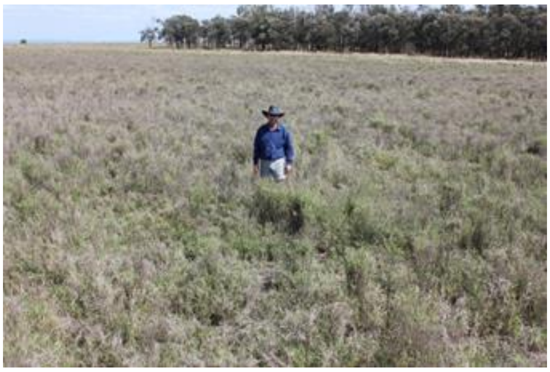


Fig. 14: Photographs of the grass only paddock and SWIFTSynd site at Thisit. a) paddock, and SWIFTSYND site b) establishment October 2011, c) year 1 harvest 1 February 2012, d) year 1 harvest 2 March 2012, e) year 2 harvest 3 April 2013, and f) year 2 harvest 4 September 2013.

a)



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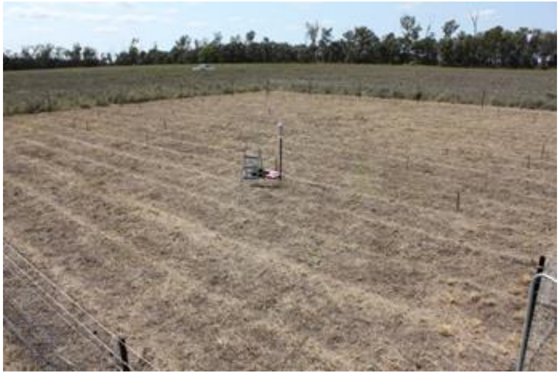

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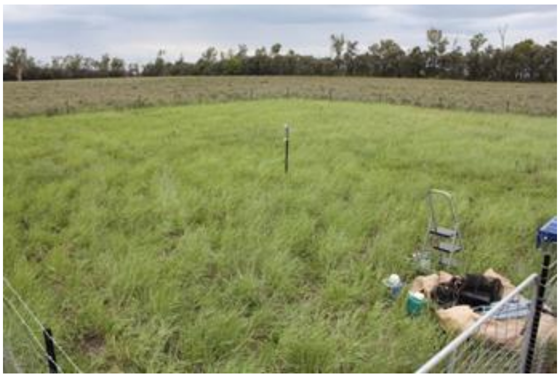

d)

e)

f)

Fig. 15: Photographs of the grass and Caatinga stylo paddock at Thisit. a) paddock, and SWIFTSYND site b) establishment October 2011, c) year 1 harvest 1 February 2012, d) year 1 harvest 2 March 2012, e) year 2 harvest 3 April 2013, and f) year 2 harvest 4 September 2013.

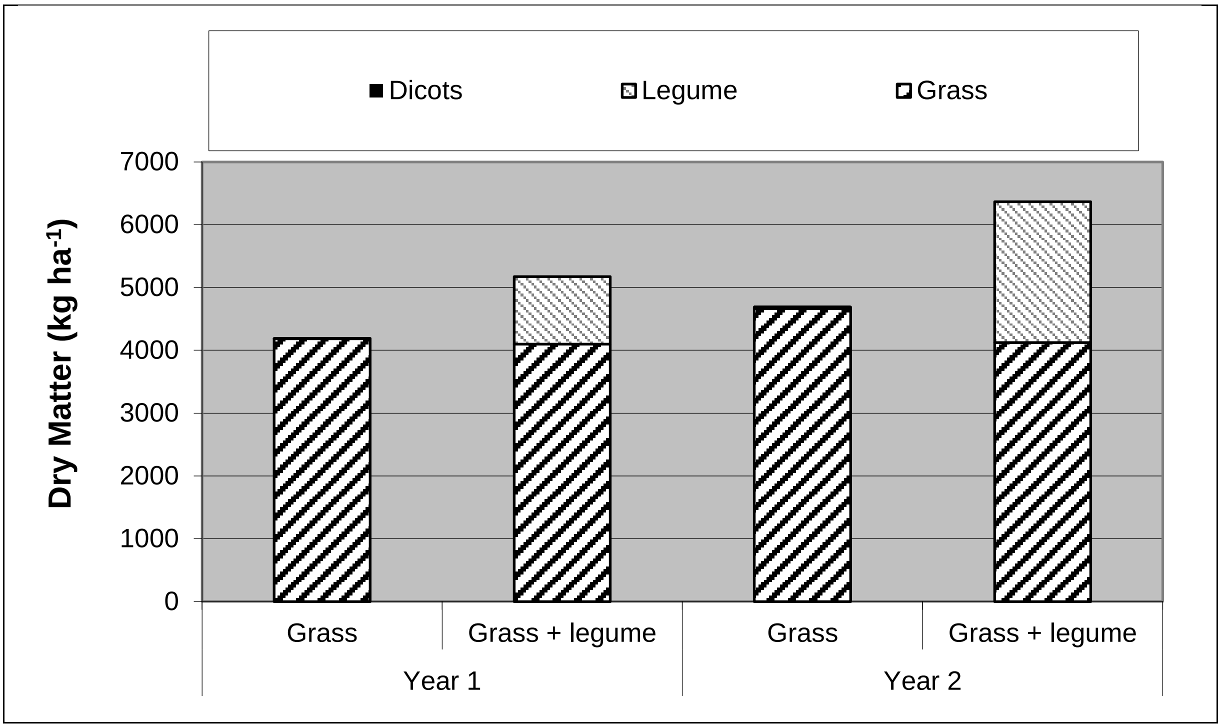

Fig. 16: Peak dry matter production (kg/ha) for each year of sampling between 2011-2013 for grass only and grass with legume pastures at Thisit sites.

Table 7: Pasture production (kg ha-1) and pasture species composition as a % of total yield estimated from grass only and grass and legume SWIFTSYND sites over two years from November 2011-September 2013.

Species	Common name	Year data collected	Total yield	
			(%)	(%)
			Grass	Grass + legume
Cenchrus ciliaris	Buffel grass	2011-2012	45	66
		2012-2013	32	31
		Average of 2 years	**39**	**49**
Dichanthium sericeum	Queensland bluegrass	2011-2012	28	11
		2012-2013	47	31
		Average of 2 years	**37**	**21**
Bothriochloa pertusa *Bothriochloa bladhii* *Chloris spp.*	Indian couch Forest bluegrass Windmill grass	2011-2012	26	4
		2012-2013	18	5
		Average of 2 years	**22**	**5**
Stylosanthes seabrana	Caatinga stylo	2011-2012	0	19
		2012-2013	0	32
		Average of 2 years	**0**	**25**
Total standing dry matter TSDM (kg ha^{-1})		2011-2012	4192	5173
		2012-2013	4711	6367
		Average of 2 years	**4452**	**5770**

5.3.2.3 Live weight gain

Live weight gain (LWG) of stock grazing the grass only and grass and legume paddocks were measured during the 2011/12 summer (Table 9). Live weight gain per animal was similar but a higher stocking rate on the grass and legume paddock (1 hd/ha) than the grass only paddock (0.5 hd/ha) resulted in almost double the LWG per hectare (79 kg/ha, 41 kg/ha respectively) during this period. These live weight gains were lower than what was considered likely for the time of year and pasture condition and Thisit soils had previously been tested and shown to be low in phosphorus levels (Colwell P 3 – 7 mg/kg at 0-10cm, 2 ppm at depth). Blood samples were taken and the stock were also shown to have marginal blood P levels.

Adjustments to the annual live weight gain subroutine were made following a review of literature (Table 8), grazing trial data (Table 9) and soil analyses. In GRASP, animal live weight gain is a function of the length of the growing season and pasture utilisation (the proportion of pasture growth which has been eaten). The estimated annual live weight gain regression parameters for the Thisit long-term simulations are shown in Table 10.

Table 8: Stocking rate (head/ha), live weight gain (LWG) (kg/head/day) and live weight gain (LWG) per hectare (kg/ha) of legume-based pastures compared with sown grass pastures, native pastures and buffel pastures in northern Australia.

	Region	**Stocking rate (ha/steer)**	**LWG per head (kg/hd/year)**	**LWG per hectare (kg/ha)**	**Literature source**
Native pasture	CQ	4	120	30	Noble *et al.* (2000)
Native pasture – stylo	CQ	3.5	155	44	Noble *et al.* (2000)
Buffel grass - new		2	180	90	Noble *et al.* (2000)
Buffel grass - rundown		3	145	48	Noble *et al.* (2000)
Benefit Caatinga stylo – grass pastures (4 years after establishment)	Central Qld & Southern Qld			20-40	Clem (2004)
Benefit Caatinga stylo – grass pastures (mean of 2 years, 5 years post establishment)	Central Qld & Southern Qld		112		Hill *et al.* (2009)
Benefit of seca stylo over-sown pastures	CQ		37		Burrows *et al.* (2010)
Benefit of Caribbean and shrubby stylo-grass pastures	Central & Northern Australia		30-60		Coates *et al.* (1997)
Very low phosphorus soil legume benefit			10	8.85 (76% increase)	Peck *et al.* (2015)
Low phosphorus soil legume benefit			30	36.7 (113% increase)	Peck *et al.* (2015)

Table 9: Stocking rate (head/ha), live weight gain (LWG) per head (kg/head/day) and live weight gain (LWG) per hectare (kg/ha) from 8 November 2011 till 14 March 2012 at Thisit grazing trials.

	Stocking rate (head/ha)	LWG per head (kg/hd/day)	LWG per hectare (kg/ha)
Grass only	0.5 (5 head)	0.65	41
Grass and legume	1.0 (10 head)	0.62	79

Table 10: Estimated annual live weight gain regression GRASP model parameters for grass only and grass and legume SWIFTSYND sites at Thisit.

Parameters	Grass only	Grass and legume
Co-efficient for % utilisation in annual LWG regression	-0.002061	-0.002061
Co-efficient for % green days in annual LWG regression	0.004883	0.004883
Intercept in annual LWG regression	0.1483	0.2103

5.3.2.4 Long-term productivity simulations

The calibrated grass only and grass and legume models were extended over time using historical climate data to determine the productivity of the grass only and grass and legume grazing systems.

Simulated long-term (1995-2014) pasture and animal productivity outcomes for grass only and grass and legume paddocks, and the difference between the paddock outcomes are shown in Table 11. The 20-year period had a few very wet years as indicated by a higher mean annual rainfall (625 mm) than the median annual rainfall (606 mm). The sites were sampled during the two above-average years (2011/12 - 647 mm and 2012/13 - 903 mm) which followed an extraordinary wet year (2010/11 - 1179 mm).

Both the buffel grass only and buffel grass and legume pastures were productive (average annual growth of 4166 DM kg/ha and 4799 DM kg/ha respectively) and an average pasture utilisation of 27% ensured pastures maintained their good condition (89% perennial grasses). The average stocking rate (2.9 ha/AE), live weight gain (LWG) per head (139 kg/head) and LWG per hectare (40 kg/ha) for buffel grass only pastures was comparable to those reported by Noble *et al*. (2000) for a rundown buffel pasture. The buffel pastures with legumes had a higher average stocking rate (2.5 ha/AE), LWG per head (166 kg/hd), and LWG per hectare (89 kg/ha) compared with the buffel grass pastures. The mean benefits of legume-based pasture compared with grass pasture included increases in stocking rate (15%, 0.38 ha/AE), LWG per head (20%, 27 kg/head), LWG per hectare (37%, 18 kg/ha) and nitrogen yield (68%, 23 kg N/ha). Simulated long-term benefits of annual LWG per head (27 kg/head) was comparable with the 35 kg/hd advantage of cattle grazing native pastures with stylo in central Queensland (Noble *et al.*, 2000), 37 kg/hd for seca stylo over-sown pastures in central Queensland (Burrows *et al.*, 2010), 30-60 kg/head for cattle grazing pastures that included Verano and / or Seca in north Queensland (Coates *et al.*, 1997), 45 kg/head on sown stylo grass pastures (Jones *et al*. 1990 cited in Hill *et al*. 2009), and the calculated benefit (37 kg/ha) of legume-based pasture on low phosphorus soil (Peck *et al.*, 2015). However, the results from this simulation were much lower than the mean annual LWG benefit of 112 kg/head for stylo/grass pastures on heavy textured cropping soils (Hill *et al.*, 2009). Simulated long-term benefits of annual LWG per hectare (18 kg/ha) were less than a stylo – native grass pasture of44 LWG kg/ha (Noble *et al.*, 2000) and less than Caatinga stylo –grass pastures four years post establishment of20-40 LWG kg/ha (Clem, 2004), and the calculated benefit (37 kg/ha) of legume-based pasture on low phosphorus soil (Peck *et al.*, 2015).

Table 11: Probability distribution of long-term (1995-2014) pasture and animal productivity outcomes for a) Thisit grass only, b) Thisit grass and legume and c) the difference between grass and legume and grass only. TSDM = Total standing dry matter. %util= pasture utilisation. LWG = live weight gain. % perennial grasses is an index of condition.

a)

Decile	Rain (mm)	TSDM kg/ha	Nitrogen Yield kg N /ha	Pasture growth kg/ha	%basal	Stocking rate hd/km2	Stocking rate ha/AE	%util	LWG/hd	LWG/ha	% perennial grasses
30%	505	2780	31.2	3317	4.94	26.6	3.76	21.9	122.5	36.3	88.7
50%	606	3766	35.3	4131	5.26	35.9	2.79	30.2	136.9	50.8	89.1
70%	694	4348	42.8	5364	5.83	43.7	2.29	35.9	167	54.7	89.7
Mean	**625**	**3519**	**34**	**4166**	**5.2**	**34.6**	**2.89**	**27.1**	**139**	**48.6**	**89**

b)

Decile	Rain (mm)	TSDM kg/ha	Nitrogen Yield kg N /ha	Pasture growth kg/ha	%basal	Stocking rate hd/km2	Stocking rate ha/AE	%util	LWG/hd	LWG/ha	% perennial grasses
30%	505	3306	53.4	3856	5.04	32.2	3.11	23	147.9	52.8	88.7
50%	606	4533	64.1	4963	5.49	43.1	2.32	29.3	163	72.2	88.9
70%	694	5002	67.6	5908	6.04	50.3	1.99	34.6	193.8	82.1	89.5
Mean	**626**	**4061**	**57**	**4799**	**5.4**	**39.8**	**2.51**	**27**	**166.3**	**66.8**	**88.9**

c)

Decile	Rain (mm)	TSDM kg/ha	Nitrogen Yield kg N /ha	Pasture growth kg/ha	%basal	Stocking rate hd/km2	Stocking rate ha/AE	%util	LWG/hd	LWG/ha	% perennial grasses
30%	505	526	22.2	539	0.1	5.6	0.65	1.1	25.4	16.5	0
50%	606	767	28.8	832	0.23	7.2	0.47	-0.9	26.1	21.4	-0.2
70%	694	654	24.8	544	0.21	6.6	0.30	-1.3	26.8	27.4	-0.2
Mean	**625**	**542**	**23**	**633**	**0.2**	**5.2**	**0.38**	**-0.1**	**27.3**	**18.2**	**-0.1**

5.3.3 Results at Kookaburra

5.3.3.1 Pasture composition across the paddocks

Pasture composition, dry matter yield and species frequency of the grass only and grass and legume paddocks were estimated in 2012 using the Botanal procedure (Table 12). The grass only paddock was planted with buffel grass *cv.* Biloela and a very small amount of creeping bluegrass *cv. Bissett;* the grass with legume paddock was planted with the same grasses and desmanthus *cvv. Marc, Bayamo* and *Uman*. Planting only Biloela buffel grass is unusual with most commercial pastures having been sown with seed mixes that include the shorter varieties of American and/or Gayndah. Planting only Biloela also contrasts to the pastures sown at Thisit which included the variety Gayndah.

There was 52% more pasture yield in the grass and legume paddock (4 461 kg ha^{-1}) than that estimated for the grass only paddock (2 941 kg ha^{-1}), with desmanthus contributing <10% of the yield (402 kg ha^{-1}). The dry matter yield for both the grass only and grass with legume pastures was dominated by Queensland bluegrass (59% and 54% respectively) with buffel grass contributing between 14% (mainly cv. Gayndah in grass only pasture) and 24% (mainly cv. Biloela in grass and legume) (Table 12).

The grass-only paddock containing more Gayndah than Biloela buffel is surprising given that only Biloela buffel was planted. The Gayndah buffel most likely came from surrounding paddocks or may have been a contaminant in the original seed. Even though Gayndah buffel was not sown, there was more Gayndah buffel (306kg/ha) in the grass only paddock than there was Biloela (120 kg/ha). In the grass with desmanthus paddock there was a similar amount of Gayndah (339 kg/ha) but six times more Biloela buffel (716 kg/ha). Gayndah buffel seems to tolerate low N availability better than Biloela.

One of the symptoms of pasture rundown (i.e. reduced availability of nitrogen in the soil) is a change in pasture composition away from fertility demanding grasses like buffel grass to species that are more tolerant of low fertility. At this trial site the grass that is dominating both paddocks is Queensland bluegrass which has been identified as a grass that is tolerant of low N availability and often increases as pastures rundown.

Based on the pasture composition from the Botanal results (Table 12) both paddocks were in good condition at the start of the trial.

- Grass only paddock: Good pasture species contributed 87% of the pasture composition, therefore this paddock met the criteria to be considered A condition (Aisthorpe *et al.*, 2004).
- Grass with desmanthus paddock: Good pasture species comprise 90% of the pasture yield, therefore this paddock was in A condition (Aisthorpe *et al.*, 2004).

Table 12: Pasture composition, dry matter yield and species frequency of Kookaburra grass only and grass and legume paddocks estimated using the Botanal procedure in April 2012.

Species (contribute 1% or more to DM Yield)	Common name	DM yield				Species frequency	
		kg ha^{-1}		(%)		(%)	
		Grass	Grass + legume	Grass	Grass + legume	Grass	Grass + legume
Dichanthium sericeum	Queensland bluegrass	1729	2412	59	54	90	79
Cenchrus ciliaris	Buffel cv. Gayndah	306	339	10	8	39	33
Bothriochloa bladhii	Forest bluegrass	242	0	8	0	7	0
Chloris spp.	Windmill grass	171	185	6	4	39	27
Chloris gayana	Rhodes grass	122	103	4	2	3	2
Cenchrus ciliaris	Buffel cv. Biloela	120	716	4	16	18	47
Stylosanthes seabrana	Caatinga Stylo	39	1	1	0	7	1
Sclerolaena spp.	Burrs	37	5	1	0	3	1
Desmanthus virgatus (early flowering)	Desmanthus cv. Marc	34	339	1	8	23	91
Aristida latifolia	Feathertop	32	109	1	2	2	9
Rhynchosia minima	Rhyncosia	19	8	1	0	28	4
Bothriochloa insculpta	Creeping bluegrass	11	57	0	1	1	2
Desmanthus virgatus (late flowering)	Desmanthus cv. Uman/Bayamo	1	63	0	1	1	13
Enneapogon spp.	Bottlewasher grass	0	36	0	1	1	5
	Total	2 941	4 460				

5.3.3.2 Pasture growth in SWIFTSYND exclosures

Fenced SWIFTSYND exclosures (Day and Philp 1997) were established in each of the paddocks in November 2011 (Fig. 17 and Fig. 18).

a)

b)

c)

d)

e)

f)

Fig. 17: The Kookaburra grass only a) paddock and SWIFTSYND site b) establishment October 2011, c) year 1 harvest 1 January 2012, d) year 1 harvest 2 March 2012, e) year 2 harvest 3 April 2013, and f) year 2 harvest 4 September 2013.

a)

b)

c)

d)

e)

f)

Fig. 18: The Kookaburra grass and legume a) paddock and SWIFTSYND site b) establishment October 2011, c) year 1 harvest 1 January 2012, d) year 1 harvest 2 March 2012, e) year 2 harvest 3 April 2013, and f) year 2 harvest 4 September 2013.

Legumes increased total pasture productivity by 113-170% over the 2 years of sampling at Kookaburra sites (Fig. 19, Table 13). However, over the two years of sampling total productivity of both sites decreased by 15-33%. As in the paddock, Queensland bluegrass was the dominant contributor to total yield for both the grass only (46%) and grass and legume (64%) SWIFTSYND sites, with buffel grass only contributing between 22-28% of the yield. At both the grass only and grass and legume sites, there was an increase in the proportion of Queensland bluegrass in the total yield between the first and second years of sampling (42 to 50%, 58% to 70% respectively). Corresponding to this increase in Queensland bluegrass was a decline in the contribution of buffel to total yield over the two years of sampling in the grass only (29% to 27%) grass and legume site (28% to 16%). Forest bluegrass and windmill grasses contributed about a fifth of the pasture yield of the grass only site, whilst desmanthus only contributed approximately 5% of total yield at the grass and legume site.

It is likely that pasture growth was adversely impacted by the “resetting” approach particularly as some pastures plants were mown below 5 cm. It is also possible that buffel grass was more sensitive than Queensland bluegrass to the mowing to 5cm with the contribution of buffel to yield decreasing over the two years of sampling.

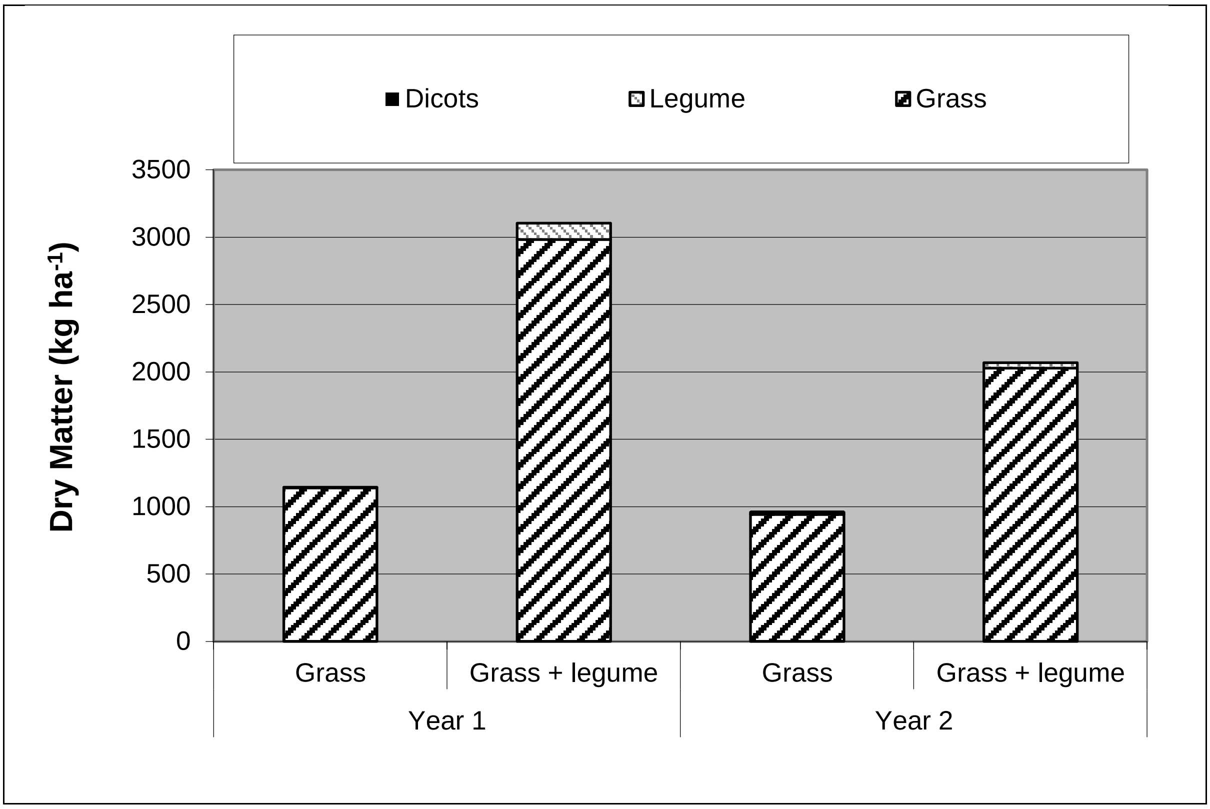

Fig. 19: Peak dry matter production (kg/ha) for each year of sampling between 2011-2013 for grass only and grass with legume pastures at Kookaburra sites.

Table 13: Total standing dry matter TSDM (kg ha-1) and pasture species composition as a % of total yield estimated from grass only and grass and legume SWIFTSYND sites at Kookaburra over two years from October 2011-September 2013.

Species	Common name	Year data collected	Total yield	
			(%)	(%)
			Grass	Grass + legume
Cenchrus ciliaris	Buffel grass	2011-2012	29	28
		2012-2013	27	16
		Average of 2 years	28	22
Dichanthium sericeum	Queensland bluegrass	2011-2012	42	58
		2012-2013	50	70
		Average of 2 years	46	64
Bothriochloa bladhii	Forest bluegrass	2011-2012	24	10
Chloris spp.	Windmill grass	2012-2013	20	9
		Average of 2 years	22	9
Desmanthus virgatus	Desmanthus	2011-2012	0	4
		2012-2013	0	5
		Average of 2 years	0	5
Total standing dry matter		2011-2012	1140	3105
TSDM (kg ha^{-1})		2012-2013	968	2068
		Average of 2 years	1054	2587

5.3.3.3 Live weight gain

Live weight gains for the 2011/12 and 2012/13 summer grazing periods are shown in Table 14. Cattle growth rates were extremely poor in the first year of the trial and blood samples were taken to try and diagnose the cause. Livestock tested as being deficient in phosphorus (P) and marginal for copper (Cu). Stock were offered a phosphorus (P) supplement and a rumen copper (Cu) pellet was administered during the 2013 grazing period which resulted in substantially better live weight gains than were measured during 2012 without supplementation.

Cattle grazing the legume with grass pasture gained an additional 0.16kg/day in 2012 and an extra 0.4kg/day relative to the grass only paddock over a grazing period of approximately 100 days (Table 14). The exceptional growth rates in the second year (>1.5 kg/hd/day) most likely reflect both the very good pasture quality and compensatory weight gain due to a dry start to the summer.

Table 14: Average live weight gain at Wandoan on a grass only compared to grass with desmanthus pasture. 2012 grazing period was from 31 December 2011 until 12 April. 2013 grazing period was from 10 February to 25 May with phosphorus and copper supplementation of stock.

Site and Treatment	Grass only[#]	Grass and desmanthus[#]
2012 Average gain per head (kg/hd/day)	0.02	0.18*
2013 Average gain per head (kg/hd/day)	1.5	1.9
2012 Gain per hectare (kg/ha)	0.8	11.2*
2013 Gain per hectare (kg/ha)	78	119

[#] Grass only paddock had 5 steers, grass with desmanthus paddocks had 6 steers.
* one animal excluded from average due to illness, per hectare live weight calculated assuming all 6 animals grew at average rate.

Cattle were left in the paddocks from February 2013 until June 2014. During this period the cattle in the grass-only paddock gained 0.4 kg/hd/day and the grass + legume paddock gained 0.45 kg/hd/day or 27 kg per head benefit from the legume over the full period. This measured live-weight gain difference is most likely under-estimating the benefit of the legume for the following reasons:

- The grass-only livestock were fed in a previously un-grazed paddock for a period by the land owner. Therefore, in effect the cattle in the grass only paddock grazed a larger area.
- Dry season protein supplements were offered to both paddocks. One of the benefits of legumes is to increase protein levels in the pasture, offering protein supplements would have reduced the advantage provided to stock via legume-derived protein within the grass-legume paddock.

5.3.3.4 Dung sample results

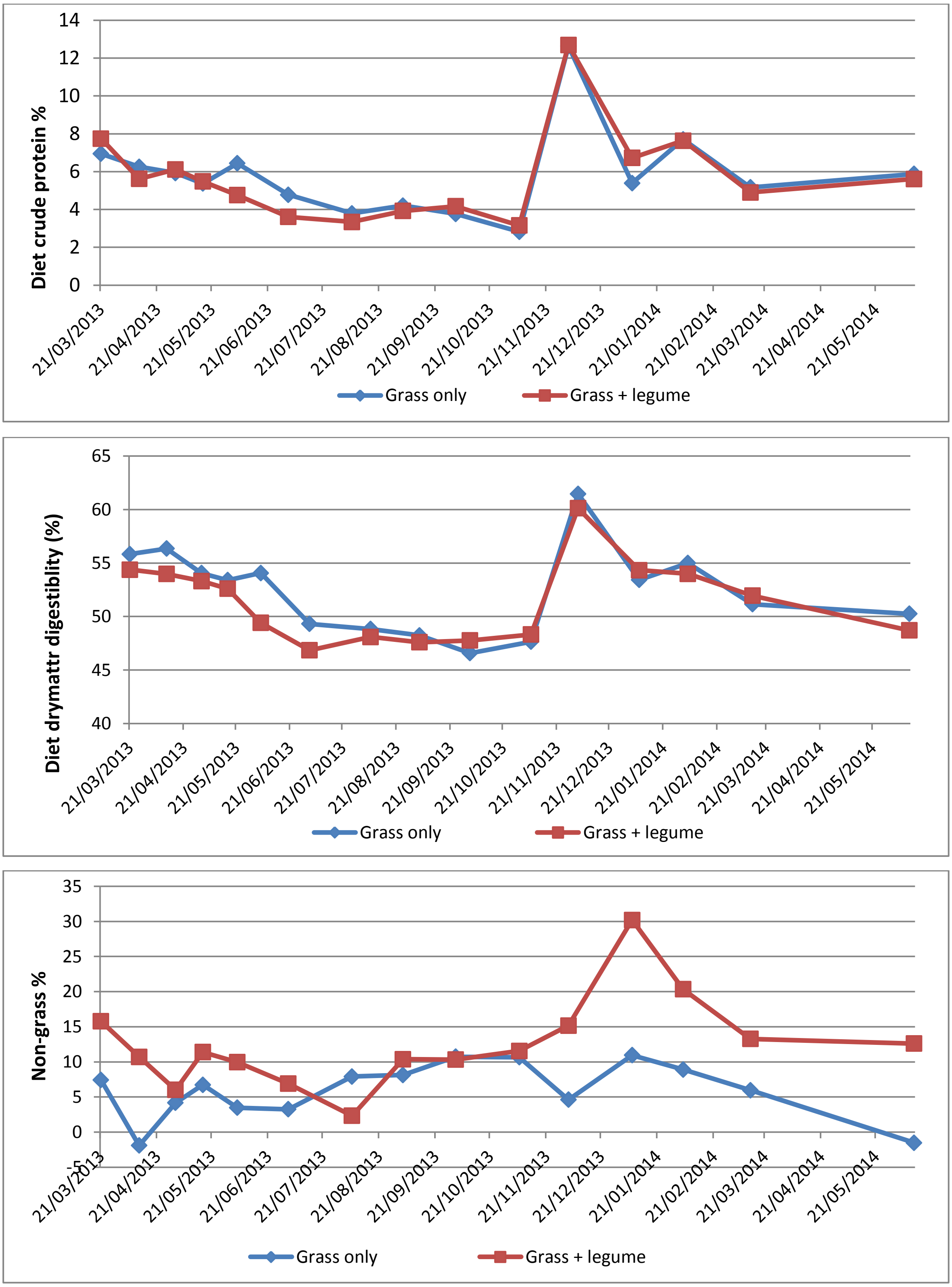

Fig. 20: Faecal analysis at Kookaburra. Graphs from top to bottom: Diet crude protein as determined from NIRS; Diet dry matter digestibility from NIRS; Non-grass intake determined from delta carbon 13 analysis.

Dung sample analysis results are shown in Fig. 20. Dung sample analysis results showed no difference in diet crude protein and dry matter digestibility between the two paddocks despite there being a difference in live weight gains (Section 5.3.3.3). This would suggest there may be a problem using the current algorithms when relating NIRS results to crude protein and digestibility for desmanthus based pastures.

Non-grass intake is shown in Fig. 20. For both of the paddocks, the main non-grass component on offer to the grazing animals is pasture legumes (Table 12). The amount of non-grass in the diet is similar between both paddocks for the winter/spring months of July-October; this is most likely due to the winter growing legumes, primarily burr medic. From late spring, through summer and autumn, there is a higher non-grass component in the diet in the desmanthus paddock. There is still some intake of non-grass in the grass-only paddock which likely resulted from there being a small component of legumes in the pasture (Table 12).

5.3.3.5 Long-term simulations

The calibrated grass only and grass and legume models were extended over a 20 year time period (1995-2014) using historical climate data to determine the productivity of the grass only and grass and legume grazing systems.

Simulated long-term (1995-2014) pasture and animal productivity outcomes for grass only and grass and legume paddocks, and the difference between the paddock outcomes are shown in Table 14. The 20-year period had a few very wet years as indicated by a higher mean annual rainfall (602 mm) than the median annual rainfall (577 mm). The sites were sampled during two below-average years (Jan-Dec 2012 - 550 mm and Jan – Dec 2013 - 483 mm) that were preceded by an extraordinarily wet year (2010/11 1211 mm).

On average over the 20-year period, both the grass only and grass and desmanthus pastures were of poor to moderate productivity (average annual growth of 1370 DM kg/ha and 2230 DM kg/ha respectively); however, the average pasture utilisation of 28-29% ensured pastures maintained their good condition (89% perennial grasses). The average stocking rate (8.4 ha/AE) for grass only pasture was lower than the expected carrying capacity for Brigalow and better scrubs (native grass) land systems (2-7 ha/AE) in the Maranoa Balonne (Paton *et al.*, 2011). Animal productivity from the Queensland bluegrass pastures (LWG per head 111 kg/hd, LWG per hectare 13.2 kg/ha) was also lower but comparable with the estimated values for stock on very low phosphorus soils (Peck *et al.*, 2015).

The Queensland bluegrass pastures with desmanthus had a higher average stocking rate (5.1 ha/AE), LWG per head (136 kg/hd), and LWG per hectare (27 kg/ha) compared with the Queensland bluegrass pastures. The mean benefits of legume-based pasture compared with grass pasture included increases in stocking rate (66%, 3.3 ha/AE), LWG per head (22%, 25 kg/head), LWG per hectare (105%, 13.8 kg/ha) and nitrogen yield (50%, 5 kg N/ha). Simulated long-term benefits of annual LWG per head (25 kg/head/year) was within the range of reported legume benefits from studies in central Queensland 22 & 35 kg/head (Burrows *et al.*, 2010) and the average of simulated legume benefits (26 kg, 20%) across five regions in Queensland (Ash *et al.*, 2015). The advantage of legume-based pastures compared to grass pastures found in this study was within range of previous results from south-east Queensland (25%) and those estimated for desmanthus pastures on low phosphorus soils (21%), although less than that found with Seca stylo pastures in central Queensland 32% (Burrows *et al.*, 2010) and at Brian Pastures Research Station in southern Queensland (27%). Simulated long-term benefits of annual LWG per hectare (13.8 kg/ha, 105%) were similar to the calculated benefit (9 kg/ha, 76%) of legume-based pasture on very low phosphorus soil (Peck *et al.*, 2015).

Table 15: Probability distribution of long-term (1995-2014) pasture and animal productivity outcomes for a) Kookaburra grass only, b) Kookaburra grass and legume and c) the difference between grass and legume and grass only outcomes. TSDM = Total standing dry matter. %util = pasture utilisation. LWG = live weight gain. % perennial grasses is an index of condition.

a)

Decile	Rain (mm)	TSDM kg/ha	Nitrogen Yield kg N /ha	Pasture growth kg/ha	%basal	Stocking rate hd/km2	Stocking rate ha/AE	%util	LWG/hd	LWG/ha	% perennial grasses
30%	491	1220	9.9	1324	3.0	12.4	8.1	26.3	96.6	11.6	88.7
50%	577	1248	10	1527	3.4	12.6	7.9	27.4	118.5	14.1	89
70%	656	1278	10	1531	3.7	12.9	7.8	28.6	129.5	16.7	89.3
Mean	602	1170	10	1370	3.4	11.9	8.4	27.9	111.3	13.2	88.9

b)

Decile	Rain (mm)	TSDM kg/ha	Nitrogen Yield kg N /ha	Pasture growth kg/ha	%basal	Stocking rate hd/km2	Stocking rate ha/AE	%util	LWG/hd	LWG/ha	% perennial grasses
30%	491	1591	12.2	1833	5.0	16.2	6.2	22.8	121.9	20.1	88.3
50%	577	1887	14.4	2218	5.7	19.0	5.3	28.8	140.1	24.2	88.9
70%	656	2207	16.8	2515	6.4	22.2	4.5	34.9	150.8	32.9	89
Mean	**602**	**1924**	**15**	**2230**	**5.6**	**19.7**	**5.1**	**28.7**	**136.3**	**27**	**88.6**

c)

Decile	Rain (mm)	TSDM kg/ha	Nitrogen Yield kg N /ha	Pasture growth kg/ha	%basal	Stocking rate hd/km2	Stocking rate ha/AE	%util	LWG/hd	LWG/ha	% perennial grasses
30%	491	371	2.3	509	2.0	3.8	1.9	-3.5	25.3	8.5	-0.4
50%	577	639	4.4	691	2.2	6.4	2.7	1.4	21.6	10.1	-0.1
70%	656	929	6.8	984	2.7	9.3	3.2	6.3	21.3	16.2	-0.3
Mean	**602**	**754**	**5**	**860**	**2.2**	**7.8**	**3.3**	**0.8**	**25**	**13.8**	**-0.3**

5.4 Discussion

Both of the grazing trials demonstrated an ongoing clear benefit of including legumes approximately 15 years after sowing pastures in the Brigalow Belt bio-region. In the years the trials were measured there were large positives in pasture composition, pasture growth and animal production. The measured pasture growth was used to populate the GRASP pasture growth model. The model predicted large production benefits from including legumes.

Unfortunately, both of these grazing trials were conducted on very low P soils. It is likely that the long term production benefits of well managed grass with either Caatinga stylo or desmanthus pastures in non P limited conditions are greater than what these trials have measured.

5.4.1 Measured pasture and animal production

Measurements conducted as part of the grazing trial demonstrate a clear benefit from including legumes in the long term when planting sown pastures. Both trials reported no benefit from the legume in the first few years after sowing compared to planting grass only pastures. The land owners reported that they noticed clear production benefits from the legume paddocks from about 5 years after establishment (i.e. shortly after measurements of the original trials ceased). The measurements at the trial sites as part of this project were conducted approximately 15 years after establishment and show clear production benefits.

The production benefits from using persistent pasture legumes 15 years after sowing at these trial sites were:

- Better pasture composition
- More total standing dry matter
- Higher dry matter production
- Higher animal live-weight gain
- Higher long-term productivity

5.4.1.1 Pasture composition and Total Standing Dry Matter

At Thisit the Botanal measurement revealed there was almost double the pasture biomass in the grass with Caatinga stylo paddock as in the grass-only paddock. The grass only paddock had 5300 kg DM/ha; while in the grass with Caatinga stylo paddock there was 10,500 kg DM/ha.

In the Caatinga stylo paddock; 99% of the pasture biomass was made up of good pasture species which means the paddock is in A condition. The grass only paddock had 80% of its pasture biomass consisting of good pasture species, therefore it is also in A condition but is on the cut-off for being considered B condition. In the legume paddock there was 10,400 kg/ha of good pasture species while in the grass only paddock there was 4240 kg/ha of good pasture species. Including the legume has resulted in approximately double the amount of good pasture per hectare.

At Kookaburra the Botanal recorded approximately 50% more pasture biomass in the desmanthus paddock compared to the grass only paddock. The grass only paddock had 2941 kg DM/ha, compared to the desmanthus with grass paddock which had 4460 kg DM/ha. Both paddocks were in A condition with 87% of pasture biomass in the grass only paddock being good pasture species and 90% in the desmanthus with grass paddock.

Biloela buffel seems to have a higher N requirement than Gayndah buffel as it occurred as a much higher contributor to biomass in the legume paddocks than in the grass only paddocks at both sites. At Kookaburra, only Biloela buffel grass was sown which is not typical of most commercial pastures. Even though Gayndah buffel was not sown, there was more Gayndah buffel (306kg/ha) in the grass only paddock than there was Biloela (120 kg/ha). In the grass with desmanthus paddock there was a similar amount of Gayndah (339 kg/ha) but six times more Biloela buffel (716 kg/ha). At Thisit, there was 46% more Biloela buffel biomass in the legume paddock than the grass only paddock. These results support the perception that Biloela is not very tolerant of lower N availability.

5.4.1.2 Higher dry matter production and animal growth rates

At Thisit, there was 23% more DM/ha grown in year 1 in the legume paddock than in the grass only paddock. In year 2 of measurement there was 35% more DM/ha grown in the legume with grass paddock than the grass only paddock. At Kookaburra the results were even more impressive with 113% more DM/ha grown in year 1; and 170% more DM/ha grown in year 2 in the desmanthus with grass paddocks than in the grass-only paddocks.

At both trial sites, the legume paddocks recorded higher live weight gains. At Thisit, there was a higher live weight gain per hectare but not a higher individual animal gain. However the legume paddock had twice as many cattle. Unfortunately the cattle were only kept in their separate paddocks early in the trial, subsequently the trial was completely de-stocked as the property was sold.

At Kookaburra, the trial recorded higher per animal and per hectare growth rates. The live weight gains in year 1 were retarded by P deficiency. The growth rates in year 2 were dramatically better when the animals had a copper pellet inserted into their rumen and were offered a P supplement. Over a full year, the animals in the desmanthus paddock had a 25kg/head higher growth rate; however this is an underestimate of the benefit of the legume because a dry season protein supplement was offered and the grass only steers were grazed in an adjacent paddock for a period. Therefore the benefit of the legume is >25kg/hd/year.

The fertiliser trials conducted at these grazing trials suggest that P fertiliser could increase DM production of legume based pastures by approximately 50% (Section 7). The effect this would have on animal productivity for these pastures has not been tested.

5.4.2 Simulated pasture and animal production

The two trial sites described in the methodology were used to evaluate the productivity benefits of sowing legumes with buffel grass pastures approximately 15 years post establishment. Site data collected from both of these locations between 2011 and 2013 was used to calibrate the GRASP pasture and animal growth model and to simulate long-term (1995-2014) productivity benefits of sowing legumes with buffel pastures.

At both Moura and Wandoan, over 20 years when stocked conservatively (30% utilisation of available forage at the end of May), legumes improved pasture productivity (kg / ha) by 15% and 63% respectively, animal productivity (LWG / ha) by 37% and 105% respectively, and nitrogen yield (kg N / ha /by 68% and 50% respectively. Animal productivity was reflective of legume persistence, increased pasture yield, and better pasture quality, but also the limitation of low soil phosphorus at Moura and very low soil phosphorus at Wandoan.

Data collected from the grass only and grass and legume sites at Moura and Wandoan provided appropriate soil and pasture data for calibration of the GRASP pasture production model. Key biological and physical pasture processes were fairly well represented in the GRASP model at both locations. However, generally these key processes were best represented in the Moura calibrated models, and between predicted data and measured standing dry matter (R^2 0.92, R^2 0.98 at Moura; R^2 0.78, R^2 0.89 at Wandoan) than green cover (R^2 0.64, R^2 0.63 at Moura; R^2 0.20, R^2 0.62 at Wandoan), N yield of total standing dry matter (R^2 0.60, R^2 0.66 at Moura; R^2 0.78, R^2 0.46 at Wandoan) and %N yield of total standing dry matter (R^2 0.57, R^2 0.54 at Moura; R^2 0.30, R^2 0.14 at Wandoan). The calibrated relationships between measured soil water and predicted data were best at the Moura and Wandoan grass and legume sites (0-10 cm R^2 0.98, R^2 0.82; 10-50cm R^2 0.48, R^2 0.87; 50-100 cm R^2 0.99, R^2 0.46 respectively), whilst these relationships were poorer with increasing soil depth at Moura and Wandoan grass only sites (0-10 cm R^2 0.82, R^2 0.76; 10-50cm R^2 0.57, R^2 0.01; 50-100 cm R^2 0.00, R^2 0.11 respectively).

Discrepancies between measured and predicted values could be due to sampling error, the impact of “resetting” approach on plants and / or site-specific characteristics. The appropriateness of the calibrated model to be extrapolated temporally using historic climate data requires consideration of the impact of the “resetting” approach on pasture composition and productivity. At both Moura and Wandoan grass only and grass and legumes sites, there was a decline in buffel, and a corresponding increase in Queensland bluegrass, as a proportion of total productivity over the two years of sampling. Additionally, at Wandoan total productivity in first year of sampling was between 15 and 33% higher than total productivity in the second year of sampling. Rainfall received in the second year of sampling at Wandoan was 10% lower than rainfall received in the first year of sampling, whilst at Moura rainfall was 23% higher in the second year compared to the first. It is highly likely that buffel grass was more sensitive than Queensland bluegrass to the slashing/mowing approach used to “reset” the pasture each year, and the reduction of plants to ~ 5cm in height most likely impeded the ability of plants to regrow particularly when plants were water-stressed.

Spatial extrapolation of the calibrated models is only appropriate if the sites are considered to adequately represent the buffel and sown legumes pastures on brigalow clays established more than 15 years previously. The buffel dominant pastures at Moura were a mix of taller (Biloela) buffel that is suited to heavier soils and higher rainfall, and medium height varieties (American, Gayndah) that are low-fertility tolerant and more suited to lighter soils and lower rainfall; this mix of Buffel grass varieties is typical of commercial pastures. Although calibrated relationships between measured soil water and predicted data were only average particularly at the grass only site, without any obvious site-specific impediments, it was assumed that the soil waters were representative of the spatial heterogeneity of the cracking Brigalow clay soils.

Wandoan pastures were dominated by Queensland bluegrass with buffel only contributing <25% to yield. The calibrated relationships between measured soil water and predicted data were only average to poor particularly at the grass only site. The presence of chloride, sodium and other salts in the Wandoan soils are likely to cause some soil structure issues and root penetration difficulties, with effective root depth estimated at 60-90 cm. These site-specific soil characteristics may have resulted in unused water in 50-100cm layer and impeded grass growth, particularly buffel that can be sensitive to water-logging and salintiy. The Wandoan sites are Queensland bluegrass dominant pastures, where productivity is likely to be have impeded by the “reset” approach and site-specific soil characteristics. The Wandoan pastures are representative of sown grass pastures that have been colonised by native bluegrass and sown legume pastures on the lower productivity Brigalow associated landtypes such as the Poplar box/Brigalow/Bauhinia landtype (Whish, 2010) that these paddocks most closely align with. Native grasses have colonised large areas of sown grass pastures, especially when planted with higher N requiring grasses like green panic or Rhodes grass.

5.4.3 Limitations and extrapolation to other farms

The Kookaburra site is unusual because only the large Biloela buffel grass variety was sown. Most buffel grass pastures in Queensland have more Gayndah and American buffel grass varieties than Biloela. Graziers report Biloela as being less persistent or less dominant long term than the shorter varieties. At Kookaburra the trial site is now dominated by Queensland bluegrass which may not have occurred to the same extent if the varieties Gayndah or American had been planted. Many graziers have reported an increase in Queensland bluegrass as their buffel grass pastures age and nitrogen availability decreases (i.e. one of the symptoms of "pasture rundown"). Pasture composition does change over time, Kookaburra does have more Queensland bluegrass than many "buffel" grass pastures, however it is still similar to many commercial paddocks especially those sown with either green panic or Rhodes grass.

Both of the grazing trials were conducted on very low phosphorus clay soils. Fertiliser trials that were conducted within the grazing trials demonstrated that these pastures responded strongly to applied P. When extrapolating these trial results, the low P status needs to be taken into account; that is the production benefits from incorporating a legume are likely to be larger than what was measured at these sites as demonstrated by the higher pasture productivity when fertiliser was applied. The higher productivity that is possible from fertiliser application is described in Section 7.

Both of the trial sites had multiple soil samples taken at different times with slightly different P levels, however they should both be considered to have Colwell P of <6 kg P/ha. Peck *et al.* (2015) reviewed three soils databases that reported that 20-50% of clay soils in the Brigalow Belt had Colwell P levels of <10mg P/kg. The incidence of low P soils where pasture legumes will respond to fertiliser is likely to be a lot more common on Brigalow clay soils than is generally appreciated by the beef industry. Peck *et al.* (2015) reported that there are >3.51M of sown pasture in the Brigalow Belt with a Colwell P <10 mg P/kg. By contrast the same report identified 4.76M ha having Colwell P levels of 10-25mg P/ha and 4.76M ha having >25mg P/ha. Therefore these trial sites are representative of quite large areas of the Brigalow Belt (27% of sown pastures), albeit the lower fertility soils.

6 Grazing management for persistence

6.1 Background

Where legumes have established, a lack of understanding of grazing management requirements to maintain grass/legume balance can lead to poor legume performance and persistence. Grazing management systems that will maintain effective legume content of pastures need to be defined. An understanding of when cattle select for a particular legume relative to the grass combined with an understanding of when the legume is most sensitive to grazing could improve grazing and spelling recommendations for maintaining both the grass and legume component in pastures.

As part of the grazing trials described in Section 5 there was an effort to try and determine the dietary selection of the legumes desmanthus and Caatinga stylo relative to grass. Mini-paddocks were constructed in part of the grass with legume paddock that could be closed to grazing at different times of the year to measure the impact of spelling on pasture composition. The aim of the study was to develop grazing recommendations for legume persistence for Caatinga stylo and desmanthus from measurements of: (a) seasonal diet selection patterns and (b) response of the pasture to seasonal rest from grazing.

6.2 Methodology

A spelling trial was established at each of the two grazing trials ("Thisit" near Moura and "Kookaburra" near Wandoan) to assess the impact of spelling at different times of the year on pasture composition and legume persistence. This involved fencing an area of 150m x 20m into 15 individual sections (20m x 10m) where gates could be opened and shut at different times of the year so stock could either be permitted to graze or excluded from grazing. The trial layout is shown in Fig. 21.

A dry matter assessment and legume density were measured on individual treatment areas at both sites before livestock were given access to the paddocks.

Fig. 21: Plan of the layout indicating the months when stock were excluded from the treatments.

Rep 1						Rep 2						Rep 3		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Nov - Jan	Mar - May	Apr - May	Feb - May	Control	Feb - Apr	Feb - Apr	Control	Nov - Jan	Mar - May	Apr - May	Feb - May	Nov - Jan	Control	Mar - May

6.3 Results and discussion

6.3.1 Diet selection

The diet selection of the cattle grazing at the Kookaburra trial is shown in Fig. 22. The main non-grass component in the grass + legume paddock during summer was desmanthus and made up approximately 10% of the pasture or 400 kg DM/ha (Table 11). In the grass only paddock the non-grass component was mainly desmanthus and other legumes but as a much lower percentage of the pasture (approximately 3% combined or 100 kg DM/ha). The cattle consumed higher amounts of desmanthus in the grass + legume paddock in line with its higher availability. The cattle consumed desmanthus throughout the year with the highest consumption recorded in the summer growing season.

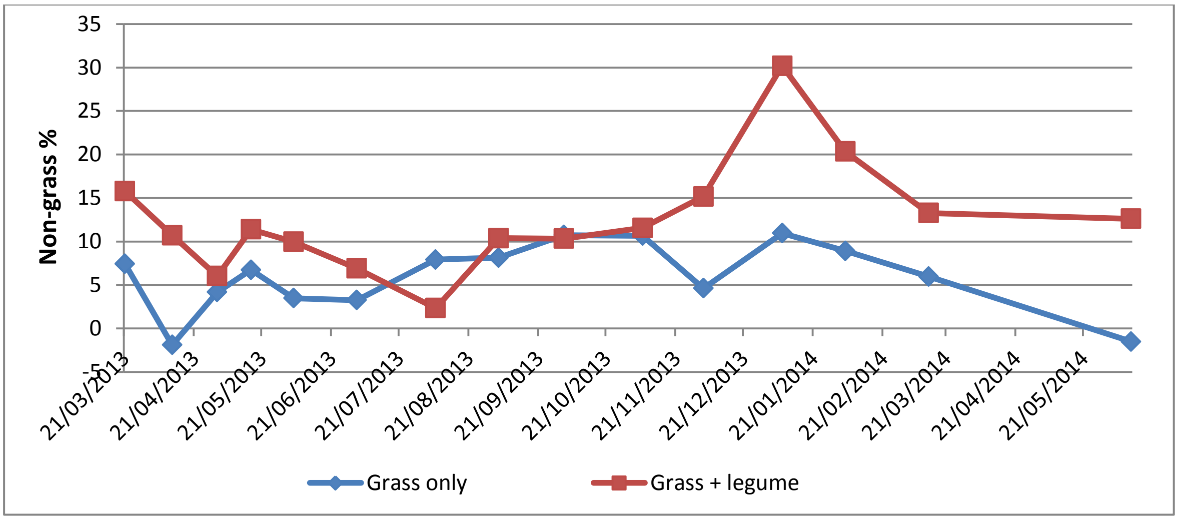

Fig. 22: Faecal analysis at Kookaburra for diet selection. Non-grass intake determined from delta carbon 13 analysis.

6.3.2 Pasture spelling

The pasture spelling trial layout was designed to permit the livestock to graze through the open fenced areas while being excluded from the closed off areas when stock were in the paddock. Unfortunately, the trial did not provide the expected outcome. 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. As a result no meaningful data on the effect of spelling on pasture composition was collected from the spelling exclosures.

6.3.3 Recommendations for future R&D

If research on spelling requirements were considered a high priority in the future there are a number of issues learnt from this unsuccessful exercise that could provide recommendation towards the design of a new experiment:

1. Consider slashing as a means of resetting the pasture at the beginning of the experiment and making the pasture more attractive to the grazing livestock. When the mini-paddocks are open the trial design requires the cattle to be actively grazing that area, reshooting pasture would hopefully attract the livestock to preferentially graze the area.
2. Imposing fewer treatments with longer spelling periods would take better account of seasonal differences between rainfall timing and hopefully cause pasture compositional changes to manifest more readily. The main treatments that need to be tested are the grazing/spelling of new growth early in the growing season which would likely put more pressure on reshooting grass and allow more space for the legume compared to spelling late in the season when cattle are more likely to be selecting for the legume in their diet.
3. Reduce the number of treatments and increase the replication, as changes in pasture composition often occur in a patchy way.
4. Use larger mini paddocks so livestock graze more freely into the fenced off areas.
5. It would be essential to provide year round grazing with quiet cattle therefore a large paddock with good legume content would be required.
6. Select cooperative producers who are prepared to set stock the area for the whole year.

The project team now consider grazing management R&D for Caatinga stylo and desmanthus a lower priority than other knowledge gaps with these legumes. There is sufficient evidence for thinking desmanthus and Caatinga stylo are tolerant of grazing and therefore seem tolerant of a wide range of grazing management practices. Evidence for grazing management to improve persistence being considered a lower research priority include:

- Both of these species have shown to have good persistence under grazing as measured at the 44 odd old trial sites (reported in Section Legume persistence2 in this final report).
- At these old trial sites neither of these legumes persisted in high numbers where no grazing pressure was applied. This occurred only where the trial areas remained fenced which excluded stock.
- Spelling requirements are likely to be a higher priority for highly palatable legumes that are sensitive to grazing at key times of their growth cycle. Both desmanthus and Caatinga stylo can reshoot from ground level and seed frequently during the growing season; therefore they are likely to get opportunities to grow and seed under commercial grazing practices.

7 Caatinga stylo and desmanthus respond to phosphorus fertiliser

7.1 Introduction

Persistent and productive legumes can significantly boost animal diet quality and supply nitrogen for companion grasses. To biologically fix large amounts of nitrogen, legumes need to produce large amount of dry matter which requires good nutrition. Legumes require adequate amounts of plant nutrients to grow well with the most commonly limiting nutrients being phosphorus (P) and or sulphur (S) (Peck *et al.*, 2015).

The grazing trials near Wandoan and Moura described in Section 5 both had low plant available P levels in the soil. The low soil P levels provided an opportunity to test the ability of desmanthus and Caatinga stylo to respond to P fertiliser. These trials were originally established as on-farm research sites, however the responsiveness of these legumes to applied fertiliser P has not been reported in the literature. The lack of previous research trials means these trials are of greater importance for analysis and have had a greater effort in measurement than was originally planned.

7.2 Methods

Two fully fenced trials were set up in existing long-term grass-legume pastures on low P status soils:

- Site 1 near Moura with buffel grass (*Cenchrus ciliaris*) and Caatinga stylo (*Stylosanthes seabrana*);
- Site 2 near Wandoan with buffel grass (*Cenchrus ciliaris*) and desmanthus (*Desmanthus spp.*).

At both sites, five rates of P (0, 10, 20, 50 and 100 kg P/ha) were applied during September 2012 and replicated four times. These treatments also received a basal rate of potassium (K), sulfur (S) and zinc (Zn) to eliminate other potential soil nutrient deficiencies. A sixth treatment of 100 kg P/ha without K, S, Zn was applied to investigate the responses without these nutrients and therefore whether these other nutrients were limiting growth at these trial sites.

The fertiliser was drilled into the soil behind tines that were approximately 30cm apart. The fertiliser was applied shortly after rain at Moura to a depth of 7.5-10cm. The soil was drier and harder at Wandoan resulting in the fertiliser being applied to a shallow depth of 2.5-5cm.

Pasture biomass (grass, legume, and total) was measured annually. After each biomass assessment, both trials were reset (by slashing) during winter when the pasture was dormant to allow measurement of the following summer growth season. The trials were harvested on the following dates:

- Wandoan
    - Year1: 19/04/13
    - Year 2: 30/04/14
    - Year 3: 11/03/15
    - Year 4: 15/02/16
- Moura
    - Year 1: 15/04/13
    - Year 2: No 2014 harvest due to cattle breaking the fence and heavily grazing the trial.
    - Year 3: 10/03/15
    - Year 4: 14/03/16

7.2.1 Soil nutrient status

Both grazing trial sites had very low plant available phosphorus levels. Soil tests have been taken at multiple locations and times across the two trial sites with the following results:

- Thisit at Moura had a Colwell P level of 3-7 mg P/kg at 0-10cm depth and 2 mg P/kg at depth in 2010.
- Kookaburra had a Colwell P level of level of 3-5 mg/kg at 0-10cm and ≤1 mg/kg at depth for soil samples taken from three different sampling zones. The sampling zones were defined by contour banks (i.e. bottom of the slope, mid-slope, top of the slope.

The P fertiliser response trials were established in a slightly different part of the paddock to where the previous soil samples were taken. Soil samples taken immediately prior to the fertiliser being applied on the trial site returned even lower soil nutrient levels. Soil nutrient levels are shown in Table 16.

Table 16: Soil nutrient levels at the phosphorus fertiliser trial sites prior to fertiliser application.

Soil test	Thisit			Kookaburra		
	0-10cm	10-30cm	30-60cm	0-10cm	10-30cm	30-60cm
Colwell P (mg/kg)	1	<1	<1	<1	<1	<1
BSES P (mg/kg)	10	8	9	9	10	15
Phosphorus Buffer Index	49.7	66.5	53.5	48.4	91.7	87.5
Sulphur (mg/kg)	2.4	2.6	36.5	2.8	3.3	550.2
Potassium (mg/kg)	156	108	95	138	116	123
Zinc (mg/kg)	0.4	0.2	0.2	0.3	0.4	0.4

7.3 Results

Large increases in pasture biomass with increasing P rates have been recorded at both trial sites in some years (Fig. 23 and Fig. 24). The responses were measured in two out of four years at Wandoan and two out of three years at Moura. There was wide variation in the relative responses between the treatments for the years measured, with this difference most likely being due to harvests occurring at different stages of plant growth. In some years the plants were green, lush and actively growing whereas in other years they were wilting and had already dropped leaf by the time the trials were harvested.

The increased yields from fertiliser peaked at about 50kg P/ha in the years that the pasture showed responses. Pasture dry matter (grass and legume) increases of up to 20 – 50 % were recorded. Fertiliser increased legume DM production at Wandoan by between 250 and 800% from a very low baseline productivity. At Moura, legume productivity increased by up to 100%.

Legume biomass increased with applied fertiliser by approximately four fold at Wandoan and two fold at Moura in the first year. At Moura, the high legume growth in the early years has resulted in greater grass growth in year three but this has not yet been measured at Wandoan. Pasture biomass was higher with K, S and Zn at Wandoan, but no response was recorded at Moura.

The fertiliser was applied only once at the beginning of the trial. The pastures are still responding four years after application at Wandoan. There was also a visual response early in the fourth growing season at Moura. Across the sites and years of recordings, total dry matter yield was increased by up to 50%.

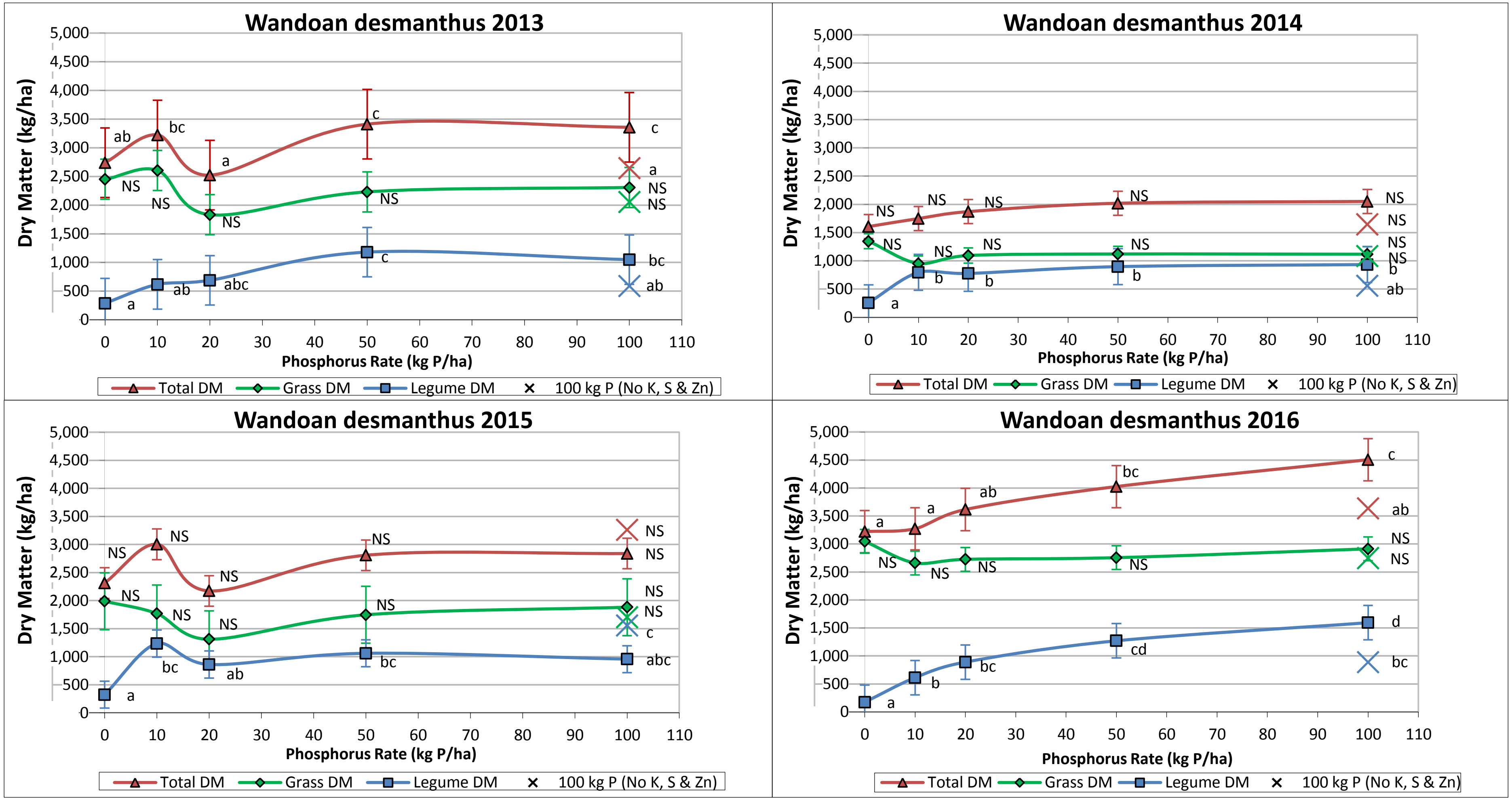

Fig. 23: Dry matter (kg/ha) responses (legume, grass and total yield) to applied phosphorus for desmanthus at Wandoan in 2013, 2014, 2015 and 2016 respectively. Phosphorus was applied to existing legume-grass pastures on low P soils at rates of 0, 10, 20, 30, 50 and 100kg P/ha. All treatments were provided basal fertiliser of potassium, sulfur and zinc. A sixth treatment of 100kg/ha was applied without these additional nutrients. Significance notation relates to comparisons between rates, <u>within</u> dry matter components of the pasture. NS = No significant difference.

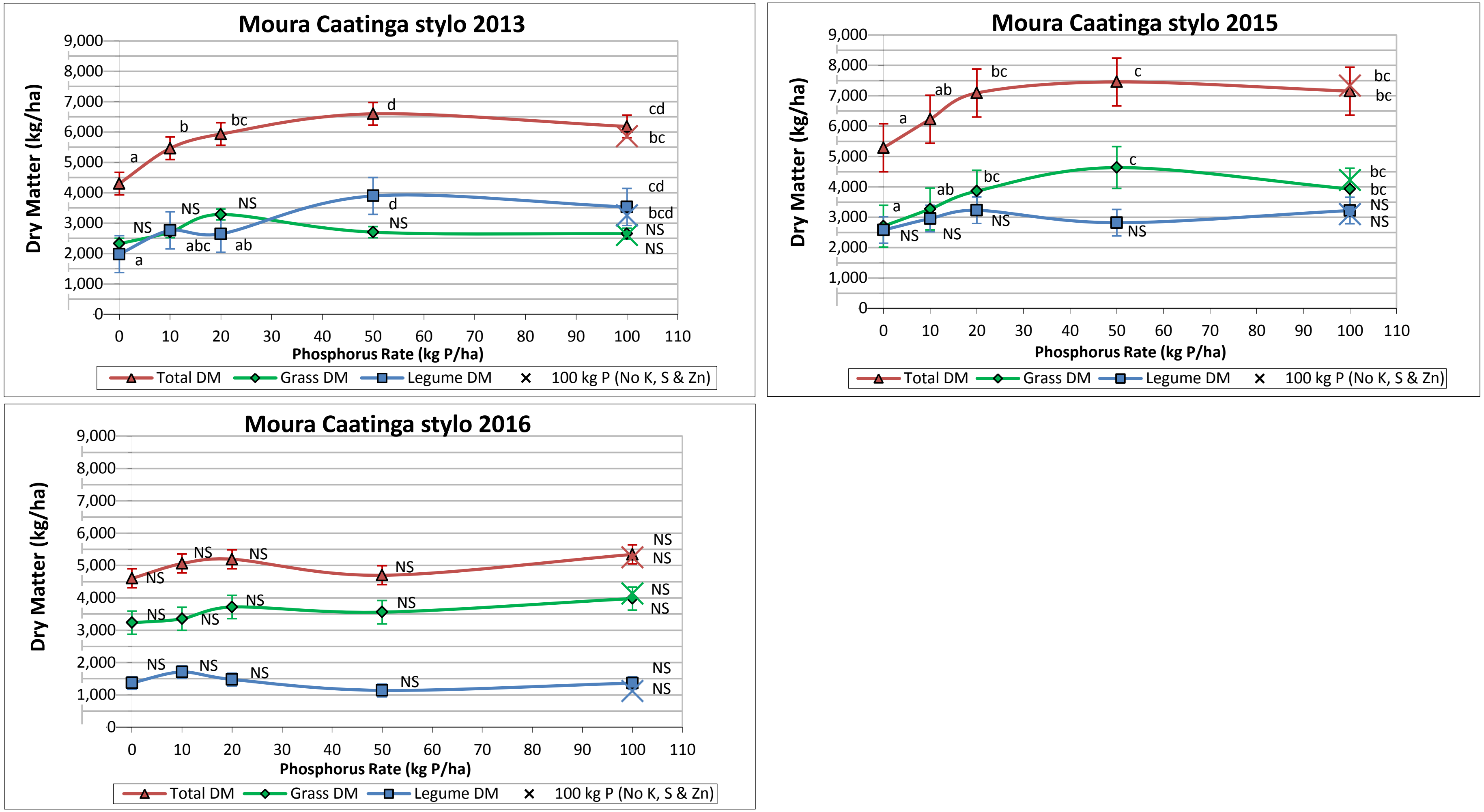

Fig. 24: Dry matter (kg/ha) responses (legume, grass and total yield) to applied phosphorus for desmanthus at Moura in 2013, 2015 and 2016 respectively. Phosphorus was applied to existing legume-grass pastures on low P soils at rates of 0, 10, 20, 30, 50 and 100kg P/ha. All treatments were provided basal fertiliser of potassium, sulphur and zinc. A sixth treatment of 100kg/ha was applied without these additional nutrients. Significance notation relates to comparisons between rates, <u>within</u> dry matter components of the pasture. NS = No significant difference.

7.4 Discussion

The results from these trials demonstrate that both desmanthus and Caatinga stylo are responsive to P fertiliser on soils with low P availability resulting in higher total pasture productivity. Higher short term legume yield from fertiliser in year one resulted in increased N supply, which in turn boosted grass yield at Moura in year three. A similar response has been observed but not measured at Wandoan with a change in composition towards buffel grass cv. Biloela (which was originally sown) that has become apparent after the last harvest (Fig. 25).

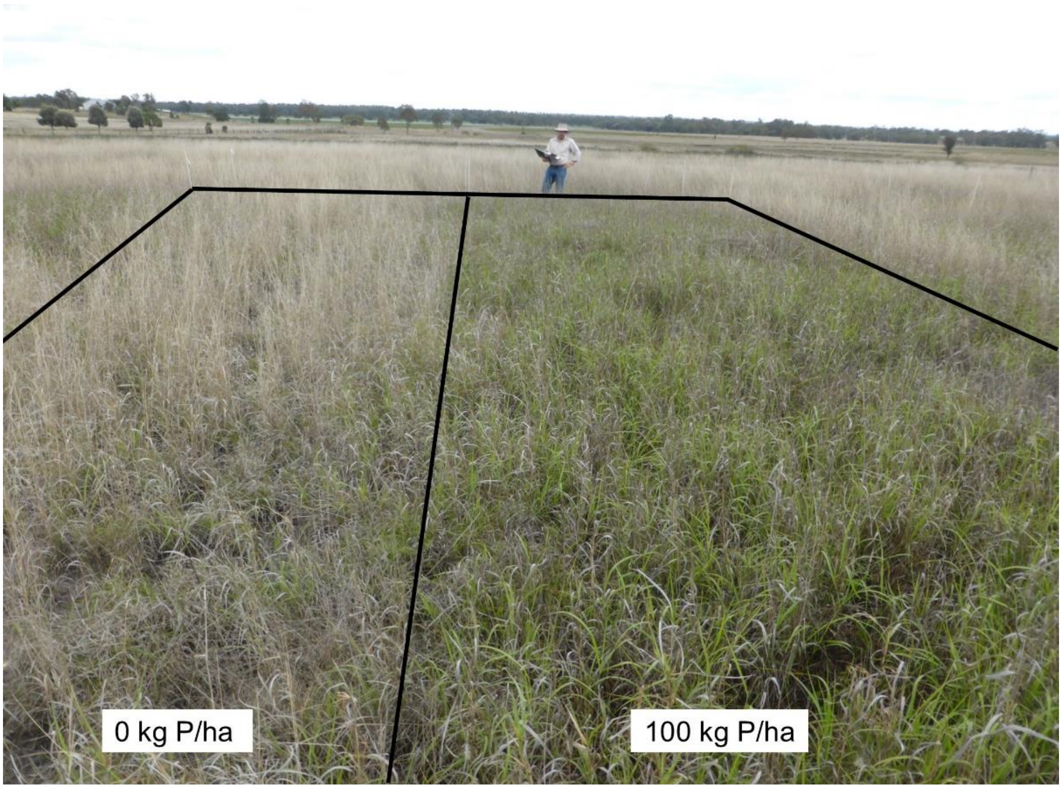

Fig. 25: Pasture composition change at Wandoan four years after phosphorus fertiliser application. The plot on the right hand side of the photo had 100kg P/ha applied and the pasture has become Biloela buffel dominant, the plot on the left hand side had no fertiliser applied and has remained native grasses dominated.

Phosphorus fertiliser increased dry matter yield at both sites in some years, but not every year despite the pasture showing a visual response to fertiliser each year. The most likely reason for this is that the pastures were harvested once a year and too late in the pasture growth cycle in some years. In effect our trial design of harvesting once later in the growing season is measuring the accumulated growth of the whole season, not the growth potential of multiple grazing's and the regrowth that could occur under regular grazing. This is especially the case for the higher fertiliser rate treatments.

The one harvest approach reduces workload but is likely to have underestimated the benefit of fertilising legume based pastures with P fertiliser. The faster growing treatments with higher fertiliser rates would achieve higher leaf areas, reach maturity and extract soil water sooner than slower growing treatments which would lead to senescence sooner. Therefore in some harvests at both sites the pastures were already dropping leaf and senescing by the time the trials were harvested which would contribute to reducing the measured dry matter yield differences between treatments. The other reason for reduced differences between treatments due to harvesting methodology is that the slower growing, low fertiliser rate treatments continue to accumulate biomass after the faster growing treatments have reached the point of slowing or stopping growth due to shading and lodging. The impact of slower growing treatments continuing to grow after the faster treatments have stopped, combined with the faster growing treatments dropping leaf and losing biomass, explains why visual improvements in growth early in the growing season did not always translate to higher DM yield at harvest.

Further research is required to identify the critical P requirement for the two legumes, how often P fertiliser should be applied to maintain pasture responses, and to determine whether fertiliser should be broadcast on the surface; or drilled or banded into the soil:

- The trial has not determined the critical P requirement of these legume species due to difficulty in soil sampling. Fertiliser was been applied behind tynes on approximately 30cm spacing which has made it difficult to determine plant available P levels in the soil.
- The trials have shown pasture responses out to the fourth growing season. Additional measurement is required to determine how long the pastures will continue to respond to the single application of fertiliser.
- The fertiliser was drilled into the soil behind tynes to the depth that the machine could work (approximately 7.5-10cm at Moura; 2.5-5cm at Wandoan) to maximise the chance of measuring a growth response in the year of application. Further work is required to see if a similar response could be achieved with surface applications of fertiliser.

Determining critical P requirements for legumes is required to provide fertiliser recommendations to graziers. Gaps in this information exist not only for these two species of legume, but for several other legumes of commercial importance within the sub-tropics. In order to address these issues, a systematic R&D effort is required.

7.5 Conclusions about fertilising legumes

Legume productivity can be dramatically increased through applying phosphorus fertiliser on low P soils. At the Wandoan trial site with desmanthus, the legume DM production was up to 3 – 6 times higher with P fertiliser. Legume DM production is directly related to biological nitrogen fixation, therefore N fixation was increased by up to 3 – 6 times in three out of four years with 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 3.

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. Economic analysis suggests good returns from the use of P fertiliser on legumes based sown pastures in the Brigalow Belt bio-region and elsewhere (Peck *et al.*, 2015). It is likely to require a major change in attitude across industry for graziers to start using fertiliser on pastures, however some leucaena growers are currently conducting an MLA supported Producer Demonstration Sites project to investigate the animal production benefits from fertilising leucaena with grass pastures.

8 Conclusions

8.1 Adequacy of available legumes

Pasture legumes have been identified by research trials and some graziers as the best option to improve long term productivity of sown grass pastures. A lot of graziers have tried using legumes on clay soils in the sub-tropics of Queensland, but there are very few productive pastures with high legume content in the Brigalow Belt bio-region. The low successful adoption rates of pasture legumes means there is a huge opportunity to increase beef production through the better adoption of pasture legumes in sown pastures, and thereby provide significantly higher economic returns for decades to come.

Achieving the high production gains demonstrated from legumes in research trials requires well adapted legumes with good management and nutrition. Desmanthus and Caatinga stylo were released as commercial varieties in 1995 and 1997 respectively; both showed promise for clay soils in the sub-tropics and tropics. Since their release, commercial results for desmanthus and Caatinga stylo have been mixed with some notable successes but many failures. Wider adoption of Caatinga stylo and desmanthus have been hindered by technical issues such as poor quality of commercial seed, specific rhizobia requirements, reliable establishment methodologies, and management practices to promote persistence and production. Several people in the seed industry, graziers and researchers have suggested that because of these technical issues (especially specific rhizobia requirements) that desmanthus and Caatinga stylo are doomed to fail as legumes for wide scale adoption in northern Australia (Peck *et al.*, 2011; Bell *et al.*, 2016). Conversely, other graziers and researchers have concluded that as a generalisation, industry needs to improve the management of legumes, especially during establishment, if <u>any</u> of them are to be reliably productive.

Due to the mixed, often poor commercial results from desmanthus and Caatinga stylo; industry and research agencies have questioned whether the commercial varieties are adequate which led to the research trials in this project. Trials in this project have demonstrated that Caatinga stylo and desmanthus are:

- Persistent over a wide geographic area and a range of soils.
- Productive and provide large benefits over grass only pastures.
- Worthy of further R,D&E investment, particular regarding establishment methods, plant nutrition and adoption.

8.1.1 Persistence of desmanthus and Caatinga stylo

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

Both legumes have persisted on low phosphorus soils and Caatinga stylo can also persist on lighter soils. Both of these legumes persisted at a higher percentage of old (10 - >30 years since establishment) pasture evaluation trials than other legumes including leucaena which is considered to be highly persistent by industry.

The adaptation limits of desmanthus and Caatinga stylo are 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 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.

8.1.2 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 at >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 (3-19% more of the biomass was from good pasture species).
- **More total standing dry matter.** There was 50% and 100% more pasture biomass with the legume-grass paddock 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 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.
- **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).

8.2 Improving reliability and productivity of legumes

The large production benefits from Caatinga stylo and desmanthus that have been demonstrated at 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 are likely to dramatically improve the reliability and productivity of these legumes in commercial paddocks. High priorities for further research and development are:

1. Improving reliability of establishing small seeded legumes into existing, competitive sown grass pastures.
2. Improved nutrition of legumes.
3. Improved reliability of establishing rhizobia of summer growing legumes when sown onto hot soils.
4. Better varieties.
5. Better quality seed.

8.2.1 Improved legume establishment

Poor establishment is the most common reason for desmanthus and Caatinga stylo failing when sown into existing sown grass pastures in the sub-tropics. Research has been conducted on establishment and is described in Volume 4 of this project report.

8.2.2 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. A review by Peck *et al.* (2015) suggests good economic returns and identified RD&E priorities. Research priorities were to:

- Demonstrate the animal production and economic response of P fertiliser applied at the paddock scale.
- Detailed pot and field trials for key legume species to determine the critical P requirements and response rates to applied fertiliser and the frequency that fertiliser needs to be reapplied.
- Field trials to test effectiveness of application techniques, for example surface broadcasting compared to drilling or banding. This is likely to be particularly important for leucaena due to it being a tree planted in a hedgerow, to determine if a band of fertiliser drilled into the soil close to the leucaena rows is more or less effective than surface broadcasting or other application techniques.
- Determine critical requirements for other nutrients, especially potassium and sulphur, for key legume varieties.

8.2.3 Improved rhizobia establishment

Both desmanthus and Caatinga stylo have specific rhizobia requirements. 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 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. Delivery methods are likely to require the rhizobia to be placed at depth into moist soil.

8.2.4 Better legume 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.

Although there is a high probability of finding better varieties of legumes for clay soils in the sub-tropics, industry has a poor track record of marketing and adopting new varieties. Even if new varieties were discovered, improved establishment and management will still be required for both existing and any new varieties. Given the large historic investment in releasing the commercial varieties of these species and the modest adoption by industry, there are probably greater gains to be made from RD&E investment towards the better use of existing varieties, than investment in evaluation or the breeding of new varieties (Quirk, 2011; Walker *et al.*, 1997).

8.2.5 Better seed quality

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. Coated seed has been regularly of poor quality. Caatinga stylo seed has only been supplied as coated seed in recent years which poses a problem for rhizobia survival until sowing time. 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. There are exceptions to these generalisations with some seed lots being of better quality and some companies supplying better quality seed.

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10 Appendix: GRASP model

Improving productivity of rundown sown grass pastures B.NBP.0639

Modelling long-term productivity benefits of sowing legumes with buffel grass in central Queensland

Prepared by Giselle Whish

September 2016

10.1 Introduction

Two grazing trials were established to evaluate the long-term pasture and animal productivity benefits of sowing legumes with buffel grass pastures. The GRASP pasture simulation model was used to extend trial results in both time and space. Detailed pasture production measurements collected from SWIFTSYND sites established at the grazing trials were used to calibrate the GRASP pasture model to enable simulation of the productivity of grass only and grass with legume pastures that were established approximately 15 years previously.

This report describes the modelling approaches used to calibrate GRASP model and to extend the trial results over time. The calibration and modelled outcomes for two locations on clays soils of the brigalow belt region, and the implications of the long-term productivity benefits of sowing legumes with buffel grass in central Queensland are discussed.

10.2 Methods

10.2.1 Grazing trials

Grazing trials at “Thisit” near Moura and “Kookaburra” near Wandoan were established into paddocks that had a history of cropping (Figure 1). Each trial had 10 ha sown to buffel grass and 10 ha sown to buffel grass plus a legume. The Moura site was sown with caatinga stylo (cv. Primar and Unica) early in 1997 and the Wandoan site was sown with desmanthus early in 1995.

A wide range of measurements and samples were collected at the grazing trials to assess pasture productivity (SWIFTSYND sites, Botanal paddock assessments) and animal performance (animal liveweight, blood samples – analysed for phosphorus at both sites, additionally for copper and sodium at Kookaburra, monthly dung samples for feed quality NIRS analysis), and delta carbon technique for C4 grass intake.

10.2.1.1 Thisit property

The FORAGE report (State of Queensland 2016) for the Thisit Lot Plan 3FN198 indicated the property was comprised of the following grazing land types (Whish 2011):

- 869 ha (73%) of brigalow blackbutt (FT04)
- 286 ha (24%) of box flats (FT03)
- 32 ha (3%) brigalow melonholes (FT05)

The FORAGE report provided a summary of annual rainfall and simulated pasture growth for the period 1960 to 2015. Average annual rainfall for Thisit property was 625 mm and average pasture growth was 3841 kg/ha. Average pasture growth for the major land types was 3607 kg/ha for brigalow blackbutt, 4338 kg/ha for box flats and 5761 kg/ha for brigalow melonholes.

10.2.1.2 Kookaburra property

The FORAGE report (State of Queensland 2016) for the Kookaburra Lot Plan 42FT505 indicated the property was comprised of the following grazing land types (Whish 2011):

- 285 ha (58%) of Brigalow with softwood scrub species (FT06)

- 204 ha (42%) of Poplar box with shrubby understorey (FT24)

The FORAGE report indicated that average annual rainfall for Kookaburra property was 589 mm and average pasture growth was 4039 kg/ha for the period 1960 to 2015. Average pasture growth for the major land types was 5532 kg/ha for brigalow with softwood scrub species and 1956 kg/ha for poplar box with shrubby understorey.

10.2.2 SWIFTSYND sites

At each grazing trial, fenced small (30m x 30m) plots were established in the paddock sown to buffel and the paddock sown with legume. The SWIFTSYND sites (see Figure 2 for layout) were established at "Thisit" in November 2011 and "Kookaburra" October 2011. Detailed pasture production measurements were collected four times a year over the 2011-2013 period using methodology of Day and Philp (1997). The measurements taken at each site provide the minimum information required to determine pasture and soil parameters for pasture growth model GRASP. Measurements obtained from sites included:

- rainfall,
- gravimetric soil moisture content,
- pasture height,
- pasture species composition,
- green and dead plant cover,
- dry matter yield of grass, legumes and forbs,
- total % nitrogen in grass and legumes
- grass basal area

Preparation of the sites each year involved the removal of dead material and remaining litter before spring rains. At Thisit a rotary slasher was used to remove material to 5 cm, and at Wandoan the sites were mown to 5cm using lawn mowers when the site was established and a rotary slasher in the second year. Grass and legume samples collected over the two years were analysed for Total N. Accumulated rain gauges (capacity of 235 mm) located at the SWIFTSYND sites were emptied four times a year over the two years of data sampling.

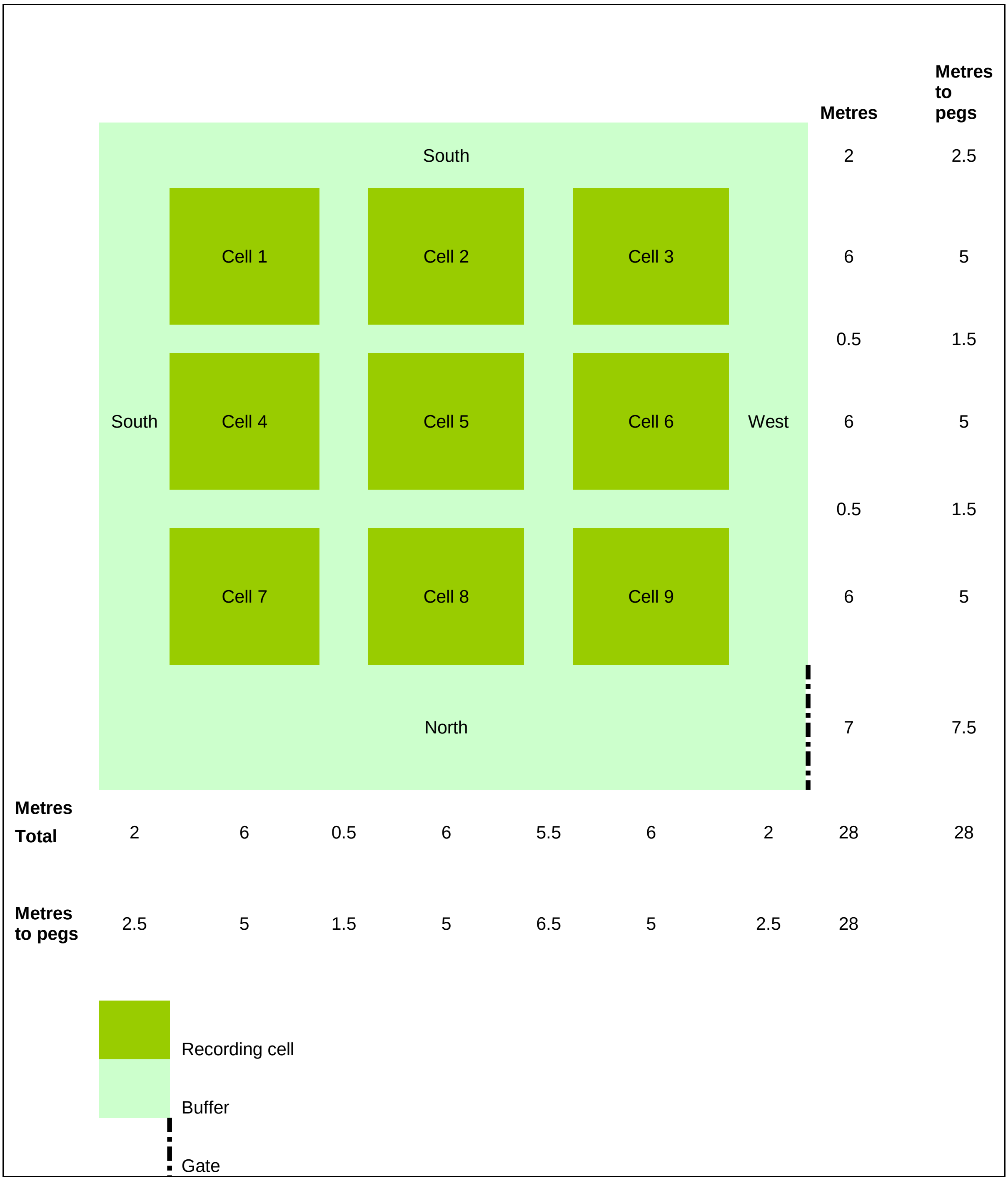


Figure 2 – Example layout of SWIFTSYND sites.

10.2.3 GRASP model

Detailed data collected from SWIFTSYND sites over the 2011-2013 period was used to calibrate the GRASP pasture production model (McKeon *et al*. 2000). GRASP is a point-based model that uses daily climate inputs to simulate soil-water balance, above-ground grass growth and animal production. It has been widely used in the semi-arid tropical grazing lands of northern Australia to estimate safe carrying capacities and to evaluate the effects of grazing management practices on native pastures, livestock production and resource condition. In the summer dominant rainfall environment of northern Australia pasture growth is limited by moisture or soil fertility (primarily nitrogen). Standing pasture yield is the net result of the processes of pasture growth, senescence, detachment, consumption and trampling (McKeon *et al*. 2000).

The accumulated rainfall data from the SWIFTSYND sites and records from nearby locations were used to adjust the historic climate records accessed from Scientific Information for Land Owners (SILO) climate database (Jeffrey *et al*. 2001). The SILO records also contain temperature and other weather data. Particular care was taken to ensure the accumulated rainfall data for each site was correct. It was necessary to convert the accumulated rain data to a daily rainfall pattern that is required for the GRASP model. This was achieved by evenly distributing the difference between SILO and the measured accumulated rainfall for each collection period for every 1 mm or 5 mm SILO record. The supplemented historical climate data was then used to calibrate the sites using the GRASP model.

10.2.3.1 Calibration

A systematic approach for model calibration (Scanlan *et al*. 2008) was employed to ensure key biological and physical pasture processes were well represented in the GRASP model. Calibration of the SWIFTSYND site models was undertaken using CEDAR GRASP (version 1.1.45 2011) and GRASP Calibrator (version 1.31 Build 4328) software. As GRASP is an empirical model there are many calibrated parameters values. A few of these parameters relate to location and characteristics of the site, a number of them can be estimated initially from field data, and some parameters can only be adjusted by examining the model output compared with observations. Time-series graphs of predicted data and observed values, and the linear regression statistics (R-squared, root mean square error (RSME) and sum (x-y)) are provided.

Collation, checking and organisation of field measurements was required to enable model calibration. Data collected in the field was checked and entered into pasture and soil spreadsheets and rechecked for errors (soil water measurements, dates of collection, sward composition, missing data) before being extracted into a site by date format appropriate for use in GRASP model.

The systematic approach used to calibrate GRASP involved the following five steps:

1. Set parameter values based on literature, location and site data
2. Use field observations to calculate and set soil water parameters
3. Use field observations to calculate and set pasture production parameters
4. Adjust soil and plant parameters using visual ‘best fit’ and statistics
5. Review calibration results in relation to other sites and findings

Average native pasture parameters and the supplemented historic SILO climate file were used to commence the calibration process. A number of “general” parameters that relate to the location and site description were set to represent the following:

- no grazing nor any grazing utilisation
- no burning
- no tree basal area
- grass basal area was set to the dynamic evapotranspiration subroutine
- runoff for free draining soils at the relatively flat Thisit sites
- runoff as a function of pasture yield for the sloped sites at Kookaburra
- rainfall intensity co-efficients that are a function of latitude and season were set to Brian Pastures
- plant temperature index parameters were aligned with C4 plants
- soil evaporation for cracking soil set at 0.7 mm/day
- starting values for grass basal area parameters were set using measured value from July 2014
- nitrogen reset date was beginning of October

A review of pasture and soil data provided initial values for upper and lower soil water parameters, dilution of nitrgoen in pasture and minimum nitrogen concentration. Other parameters that relate to the available soil water, transpiration efficiency, the level of dilution of nitrogen in the pasture, soil fertility with its influence on potential regrowth rate, availability of soil nitrogen for N uptake, and rate of detachment during summer and winter were calibrated from measured data.

10.2.3.2 Simulations

Once calibrated, the grass only and grass and legume models for each location were reviewed to determine if and how the models differed, and whether the differences were due to site preparation approach, site-specific characteristics or location. Consideration of the appropriateness for the models to be extended over time, and the representativeness of the calibrated sites to a broader land system to allow for the extrapolation of results spatially was required.

The calibrated models were extended over time using historical climate data to determine the productivity of the grass only and grass and legume grazing systems for each location. Long-term simulation of these grazing systems were undertaken using the GRASP model (version g21_j7j6_for_test dated October 2010) and the following options:

- A 20-year simulation period (1995-2014) to capture productivity of the pastures since paddocks were sown with buffel and legumes.

- A three-year spinup to adjust soil water, cover and litter pools to more closely align with user defined parameters.

- Runoff model 1, which is a function of surface cover, rainfall intensity and soil-water deficit, was set for Kookaburra whilst these parameters were set to be free draining at Thisit.

- Soil loss (model 3) which is a function of surface cover and runoff at Kookaburra.

- Dynamic grass basal area model where changes in grass basal area are a function of total growth of current and previous growing seasons, with evapotranspiration and evapotranspiration use efficiency indicators of total growth.

- Pasture burning was turned off.

- Pastures were stocked with 2-year old steers (400kg LW)

- Grazing strategies that dictated stocking rates were:
  - Option 2 responsive stocking rate, where stocking rate is adjusted each year to eat a fixed proportion of the existing pasture yield (TSDM) on 1st June over the next year
  - Date for resetting stocking rate was 1st June
- Annual live weight gain was calculated from % utilisation and percentage of days during the year where pasture growth index was above 0.05 threshold (model 9). The growth index is a product of soil water, solar radiation and temperature indices.
- Pasture utilisation was set at 30%, the recommended safe utilisation rate for the brigalow clay land types (e.g Brigalow softwood scrub, Brigalow with melonholes, Brigalow with blackbutt) of Fitzroy GLM region (Whish 2011).
- Pasture condition subroutine was turned on. The loss of desirable perennial grasses associated with heavy utilisation is simulated in GRASP by linking the percentage of desirable perennials to an annual time-scale. Percent perennial grass is used as an indicator of condition, with grazing pressure expressed as the percentage of total growth that is eaten as green material. Pasture condition can change up or down between excellent (90% perennial grass) and degraded (1% perennial grass) pastures in response to different utilisation rates.
- Pasture condition at both Thisit and Kookaburra commenced in A condition (88% perennial grasses). When 30% of total growth was consumed as green material there was no change in pasture condition, when less than 30% of green material was consumed there was an increase in pasture condition, and a decline in pasture condition occurred when utilisation was greater than 30%.
- Detachment rates for dead leaf and stem were set at 0. 0010 per day over growing season, and 0.0050 per day over the dry.

Adjustments to the annual live weight gain subroutine were made following a review of literature, grazing trial data and soil analyses. Simulation pasture and animal productivity outcomes were evaluated, and the suitability of calibrated models for use at other sites across the Brigalow Belt is discussed.

10.3 Results

10.3.1 Thisit property

10.3.1.1 Grass only and grass and legume SWIFTSYND sites

Fenced SWIFTSYND exclosures (Day and Philp 1997) were established in the grass only and grass and legume paddocks in November 2011 (Fig. 3 & 4). The Thisit sites were described by Department of Agriculture and Fisheries (DAF) project staff as typical brigalow / belah vegetation on brigalow grey clays, although the actual sites were treeless. The sites most closely align with Brigalow softwood scrub land type (Whish 2011). It was estimated by field operators that both sites were in A condition, as desirable species (buffel, Queensland bluegrass, forest bluegrass, sabi grass, stylo) contributed over 80% of the pasture yield, and would grow approximately 4500 kg/ha. However, the grass only paddock only just met this condition benchmark.

Legumes increased total pasture productivity by 23-35% over the 2 years of sampling (Fig. 5, Table 2). In the grass and legume SWIFTSYND site, buffel (49%) was the dominant contributor to total yield with both Queensland bluegrass (21%) and Caatinga stylo (25%) sub-dominant (Table2). Buffel (39%) and Queensland bluegrass (37%) were the dominant contributors to total yield for the grass only SWIFTSYND site, although Indian couch and other species contributed 22% of the yield. In the grass only paddock, Indian couch contributed to ~ 16% to total pasture yield but its contribution to yield in the grass and legume paddock was negligible (~0.3% to total yield). Pasture species composition (% of total yield) in the grass only and grass and legume SWIFTSYND sites changed from buffel dominant (~45%, 66% respectively) and Queensland bluegrass and Indian couch sub-dominant (~28%) in the first year 2011-2012, to Queensland bluegrass (47%, 31% respectively) contributing more to total yield than buffel (32%, 31% respectively) in the second year (2012-2013) (Table 2). Queensland bluegrass was on average more dominant in the SWIFTSYND site (37%, 21%) than in the paddock (16%, 0%). It is possible that buffel grass was more sensitive than Queensland bluegrass to the slashing to 5-10cm approach used to “reset” the pasture each year to enable measurement of pasture growth. It is also possible that the erect, woody stemmed stylo was impacted by the height of “resetting” used, particularly in the first year.

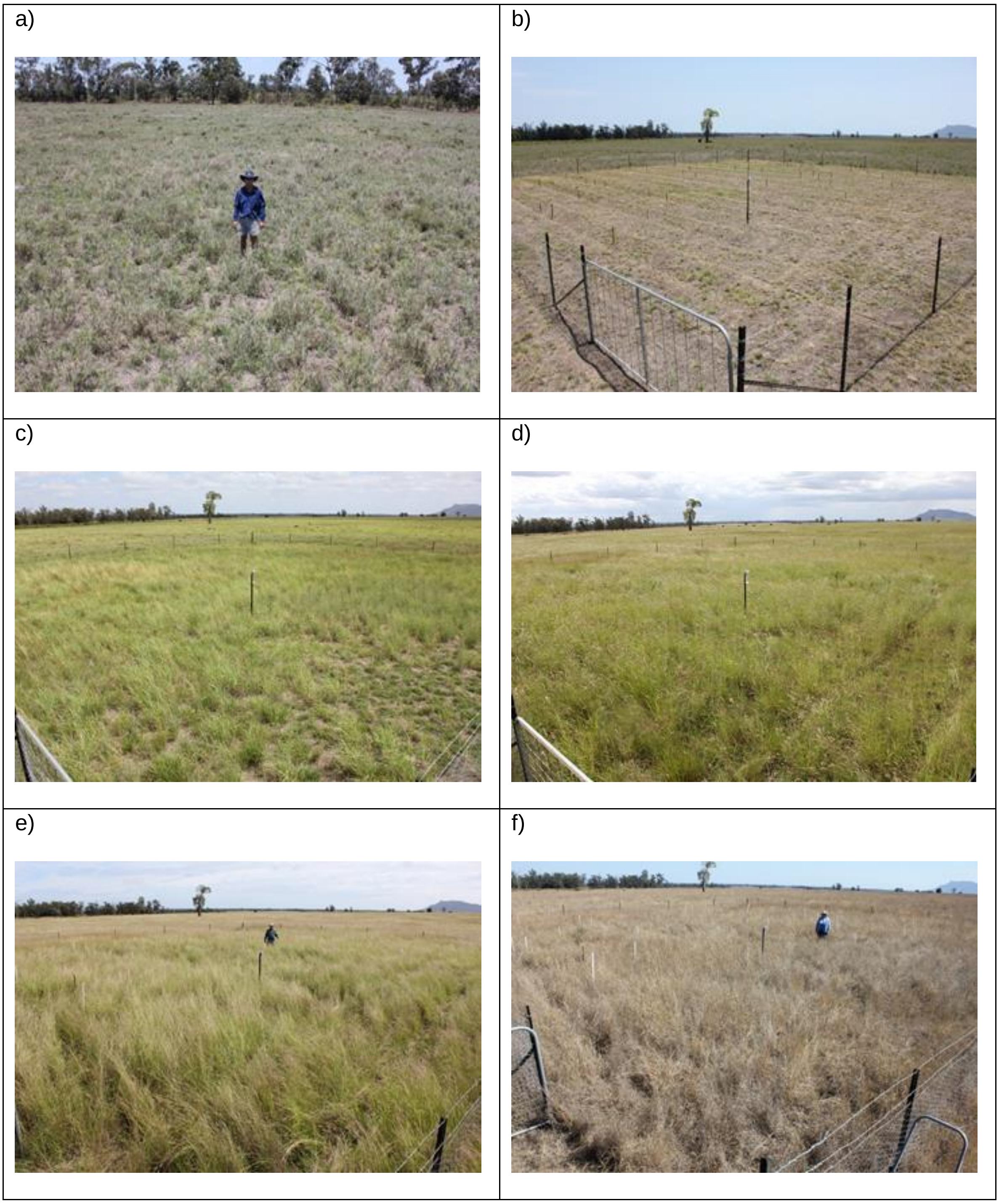
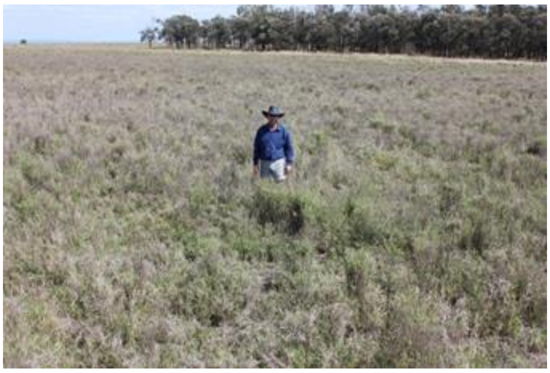


Figure 3 - The Thisit grass only a) paddock, and SWIFTSYND site b) establishment October 2011, c) year 1 harvest 1 February 2012, d) year 1 harvest 2 March 2012, e) year 2 harvest 3 April 2013, and f) year 2 harvest 4 September 2013.

a)



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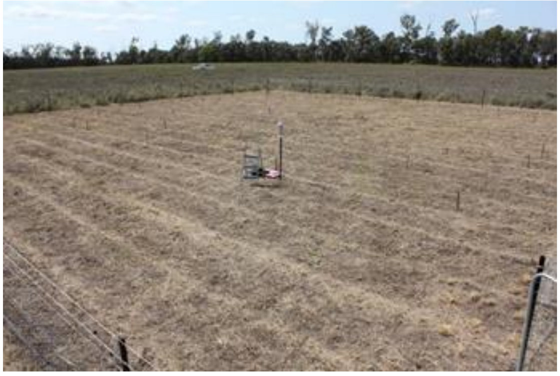

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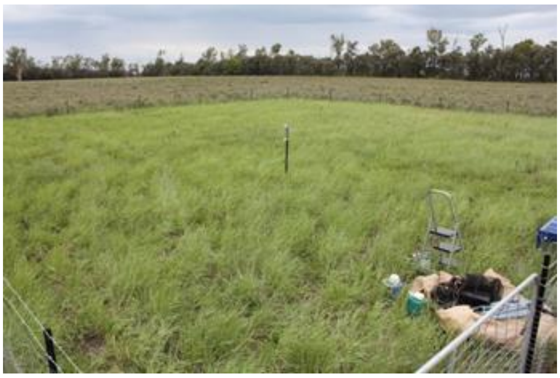

e)

f)

g)

Figure 4 - The Thisit grass and legume a) paddock, and SWIFTSYND site b) establishment October 2011, c) year 1 harvest 1 February 2012, d) year 1 harvest 2 March 2012, e) year 2 harvest 3 April 2013, and f) year 2 harvest 4 September 2013.

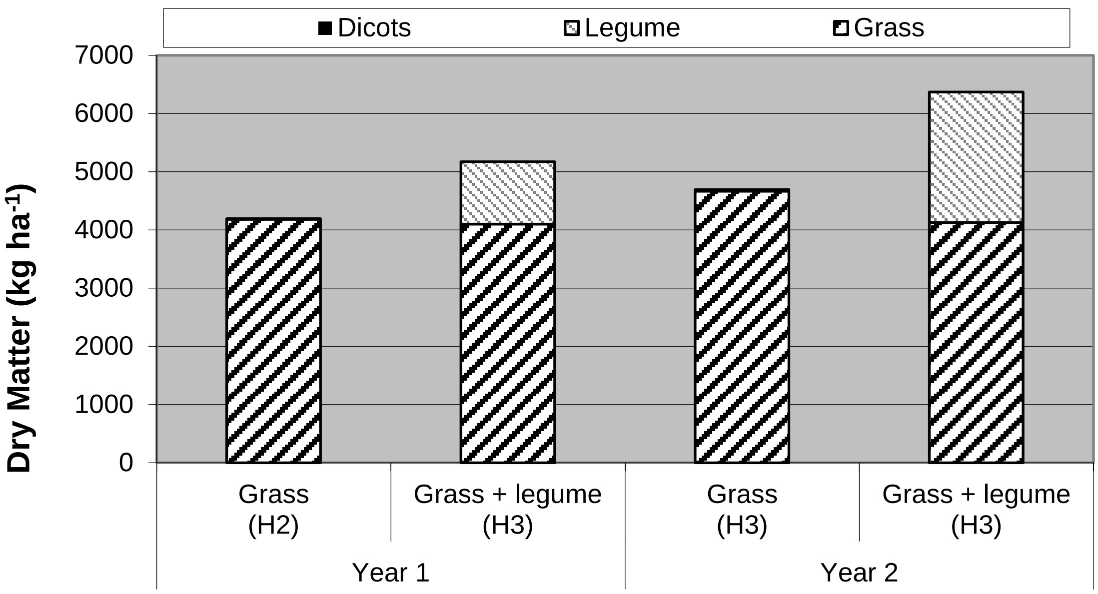

Figure 5 – Measured peak dry matter production (kg/ha) for each year of sampling between 2011-2013 for grass only and grass with legume Thisit SWIFTSYND sites. Harvest (H) number for peak production is indicated.

Table 2 – Total standing dry matter TSDM (kg ha^{-1}) and pasture species composition as a % of total yield estimated from grass only and grass and legume SWIFTSYND sites over two years from November 2011-September 2013.

Species	Common name	Year data collected	Total yield	
			(%)	(%)
			Grass	Grass + legume
Cenchrus ciliaris	Buffel grass	2011-2012	45	66
		2012-2013	32	31
		Average of 2 years	**39**	**49**
Dichanthium sericeum	Queensland bluegrass	2011-2012	28	11
		2012-2013	47	31
		Average of 2 years	**37**	**21**
Bothriochloa pertusa	Indian couch	2011-2012	26	4
Bothriochloa bladhii	Forest bluegrass	2012-2013	18	5
Chloris spp.	Windmill grass	Average of 2 years	**22**	**5**
Stylosanthes seabrana	Caatinga stylo	2011-2012	0	19
		2012-2013	0	32
		Average of 2 years	**0**	**25**
Total standing dry matter TSDM (kg ha^{-1})		2011-2012	4192	5173
		2012-2013	4711	6367
		Average of 2 years	**4452**	**5770**

10.3.1.2 Rainfall

Rainfall measured at the grass only and grass and legume sites was compared to SILO records for Thisit property and nearby weather stations (Biloela and Baralaba). There were three periods where site accumulated measurements differed from SILO records by more than 100 mm. For two of the "missing data" periods, during the summer of 2011-2012 when there was flooding in Queensland and in late January 2013 with the occurrence of a cyclone, it is likely that the rain gauge had overflowed. The third "missing data" period between 18/9/2013- 12/2/2014, rainfall measured at the sites was ~120 mm (grass only) and 109 mm (grass and legume) less than the 300-350 mm for Thisit and nearby locations SILO records. For these three periods only SILO records for Thisit property were used. Other than the three missing data periods, rainfall measured at the sites was 100.8 mm (grass only) and 113.3 mm (grass and legume) more than that interpolated from SILO over the 2 years (November 2011 – February 2014).

Site accumulated rainfall measurements were included in the interpolated 100 year climate data by evenly distributing the difference between SILO and the measured rainfall to every 1 mm or 5 mm SILO record for each collection period. As such, supplemented climate data was created for both SWIFTSYND sites for use in the calibration process.

The total annual rainfall after adjustments for two years of sampling (2011-2012, 2012-2013) at grass only site (809, 862 mm respectively) and grass and legume site (816, 868 mm respectively) was 22-31% higher than the 100 year annual average for Thisit (661 mm).

10.3.1.3 Calibration of model

Model calibration of the Thisit grass only and grass and legume SWIFTSYND sites was undertaken using the systematic approach of Scanlan *et al*. (2008). Calibration commenced using the parameters for average native pastures and the supplemented historical climate data. A detailed account of the calibration process, derivation of model parameters from measured data, estimation of parameters by examining model output compared with observation data and the associated linear regression statistics is provided in Appendix A. Summary of the calibration outcomes is provided below.

Soil water

Measured soil water at the grass and legume SWIFTSYND site was between 9 and 56 mm more than the grass only site over the two years samples were collected. In particular, the measured soil water at 50 -100 cm depth (layer 3) at the grass and legume site was consistently greater (4-48 mm) than measurements for the same depth at the grass only site.

The calibrated relationships between observed (measured soil water) and GRASP predicted soil water were best at the grass and legume site (0-10 cm R^2 0.98, 10-50cm R^2 0.48, 50-100 cm R^2 0.99) whilst at the grass only site these relationships were poorer with increasing soil depth (0-10 cm R^2 0.82, 10-50cm R^2 0.57, 50-100 cm R^2 0.00). Discrepancies between observed and predicted values at the grass only site could be due to errors in measured data, errors in the estimated rainfall distribution, or due to a site specific impediment. Less likely, the generally higher measured soil water at the grass and legume site may be a result of slightly higher cover (86% cf. 82%) and better infiltration less runoff than the grass only site. Whilst gilgais were present in both paddocks and due care was taken to avoid hollows when SWIFTSYND sites were established. Without any obvious site specific impediments, it was assumed that the soil waters can be representative of the spatial heterogeneity of the cracking clay brigalow soils.

o Pasture production

GRASP uses two ways to estimate pasture growth: one cover-independent method is based on grass basal area (GBA) and growth per unit basal area; and the other cover-dependent is transpiration by transpiration use efficiency. GRASP selects the maximum of the two estimates.

Perennial grass basal area was initially estimated from measurements obtained in July 2014. Grass basal area for grass only (4.7%) and the grass and legume (4%) sites were within the range for perennial native pastures (3-6%). Potential regrowth rate kg/ha DM grown / day / unit basal area was estimated from days since start of the growing season. It was considered that the start of growing season occurred after 50 mm of rain fell over a two week period.

Pasture growth is calculated under both transpiration limiting (low soil water) and radiation limiting conditions for each day, with the most limiting factor estimating growth. The green yield to green cover relationship allowed determination of green yield at which both transpiration and radiation interception is 50%. The estimated value of 1663 kg/ha for green yield at 50% green cover was used for the grass only site (R^2 0.62) and the grass with legume site (R^2 0.79). A similar height yield relationship was measured at both SWIFTSYND sites. The height yield relationship is a measurement of the plant structure, influencing pasture growth through the impact of vapour pressure deficit.

Nitrogen is a key determinant of growth in many native pastures in northern Australia, particularly in areas above about 650mm rainfall. GRASP has a simple calculation of nitrogen limitation so both limitations of climate and soil fertility can be represented in simulations of pasture growth. The simple nitrogen-limitation sub-model is based on a constant potential N uptake and minimum nitrogen concentration being determined for each site. Hence, potential annual growth is a constant. Values for a number of key nitrogen related parameters are shown in Table 4. These key parameters include: the initial pulse of nitrogen present in dry matter that occurs during the first growth period of the growing season; the rate of N uptake per 100 mm of grass transpiration which is related to the rate of N mineralisation; maximum N uptake which is an indicator of the fertility of the site; % N at zero growth; and maximum N% in pasture where values higher than the default value of 2.5% have been measured for fertilised sown pastures.

The calibrated grass only and grass and legume models produced reasonable agreement between the predicted data and observed values of green cover (R^2 0.64, R^2 0.63 respectively), N yield of total standing dry matter (R^2 0.60, R^2 0.66 respectively) and %N yield of total standing dry matter (R^2 0.57, R^2 0.54 respectively). There was a very good relationship between predicted data and observed values of standing dry matter for the calibrated grass only and grass and legume models (R^2 0.92, R^2 0.98 respectively).

Table 3. Calibrated key pasture production GRASP model parameters for typical native pastures, and grass only and grass and legume SWIFTSYND sites at Thisit.

Parameter description	Parameter value		
	Typical value for native pastures	Grass only	Grass and legume
Potential daily regrowth rate (kg/ha/day/%basal area)	5.0	7.2	8.0
Initial plant density (%basal area)	4.0	4.7	4.0
Transpiration efficiency (kg/ha/mm of transpired at vpd 20 kpa)	13.5	17.2	19.5
N uptake (kg/ha) at zero transpiration	2-5, up to 10	7	5
N uptake (kg/ha) per 100 mm GRASS transpiration	5-6 south, 10 in north	15	27
Maximum N uptake (kg/ha)	10-25, very fertile 40	43	68
% N at zero growth	0.45 (C4), 0.7 (forbs), 0.91 (C3 &C4 with forbs)	0.78	1.15
Maximum % N in growth	2.5 default	2.5	3.0

10.3.1.4 Long-term simulations

The calibrated grass only and grass and legume models were extended over time using historical climate data to determine the productivity of the grass only and grass and legume grazing systems.

Adjustments to the annual live weight gain subroutine were made following a review of literature (Table 4), grazing trial data (Table 5) and soil analyses. Thisit soils had low phosphorus levels (Colwell P 5 ppm at 0-10cm, 2 ppm at depth), whilst stock were also shown to have marginal blood P levels. Live weight gain (LWG) of stock grazing the grass only and grass and legume paddocks were measured during the 2011/12 summer (Table 5). A higher stocking rate on the grass and legume paddock (1 hd/ha) than the grass only paddock (0.5 hd/ha) resulted in almost double the LWG per hectare (79 kg/ha, 41 kg/ha respectively) during this period.

In GRASP, animal live weight gain is a function of the length of the growing season and pasture utilisation (the proportion of pasture growth which has been eaten). The estimated annual live weight gain regression parameters for the Thisit long-term simulations are shown in Table 6.

Table 4: Stocking rate (head/ha), live weight gain (LWG) per head (kg/head/day) and live weight gain (LWG) per hectare (kg/ha) of legume-based pastures compared with sown grass pastures, native pastures and buffel pastures in northern Australia.

	Region	Stocking rate (ha/steer)	LWG per head (kg/hd/year)	LWG per hectare (kg/ha)	Literature source
Native pasture	CQ	4	120	30	Noble *et al*. 2000
Native pasture – stylo	CQ	3.5	155	44	Noble *et al*. 2000
Buffel grass - new		2	180	90	Noble *et al*. 2000
Buffel grass - rundown		3	145	48	Noble *et al*. 2000
Benefit Caatinga stylo – grass pastures (4 years after establishment)	Central Qld & Southern Qld			20-40	Clem 2004
Benefit Caatinga stylo – grass pastures (mean of 2 years, 5 years post establishment)	Central Qld & Southern Qld		112		Hill *et al*. 2009
Benefit of seca stylo over-sown pastures	CQ		37		Orr 2005
Benefit of grass + stylo pastures Average over 4 years	Southern Qld			0.07 LWG /ha/day (13)% increase) 17	Clem 2004
Benefit of carribean and shrubby stylo-grass pastures	Central & Northern Australia		30-60		Coats *et al*. 1997
Very low phosphorus soil legume benefit			10	8.85 (76% increase)	Peck *et al.*, 2015
Low phosphorus soil legume benefit			30	36.7 (113% increase)	Peck *et al.*, 2015

Table 5: Average stocking rate (head/ha), live weight gain (LWG) per head (kg/head/day) and live weight gain (LWG) per hectare (kg/ha) from 8 November till 14 March at Thisit grazing trials.

	Stocking rate (head/ha)	LWG per head (kg/hd/day)	LWG per hectare (kg/ha)
Grass only	0.5 (5 head)	0.65	41
Grass and legume	1.0 (10 head)	0.62	79

Table 6: Estimated annual live weight gain regression GRASP model parameters for grass only and grass and legume SWIFTSYND sites at Thisit.

Parameters	Grass only	Grass and legume
Co-efficient for % utilisation in annual LWG regression	-0.002061	-0.002061
Co-efficient for % green days in annual LWG regression	0.004883	0.004883
Intercept in annual LWG regression	0.1483	0.2103

Simulated long-term (1995-2014) pasture and animal productivity outcomes for grass only and grass and legume paddocks, and the difference between the paddock outcomes are shown in Table 7. The 20-year period had a few very wet years as indicated by a higher mean annual rainfall (625 mm) than the median annual rainfall (606 mm). The sites were sampled during the two above-average years (2011/12 - 647 mm and 2012/13 - 903 mm) which followed an extraordinary wet year (2010/11 - 1179 mm).

Both the buffel grass only and buffel grass and legume pastures were productive (average annual growth of 4166 DM kg/ha and 4799 DM kg/ha respectively) and an average pasture utilisation of 27% ensured pastures maintained their good condition (89% perennial grasses). The average stocking rate (2.9 ha/AE), live weight gain (LWG) per head (139 kg/head) and LWG per hectare (40 kg/ha) for buffel grass only pastures was comparable to those reported by Noble *et al*. (2000) for a rundown buffel pasture. The buffel pastures with legumes had a higher average stocking rate (2.5 ha/AE), LWG per head (166 kg/hd), and LWG per hectare (89 kg/ha) compared with the buffel grass pastures. The mean benefits of legume-based pasture compared with grass pasture included increases in stocking rate (15%, 0.38 ha/AE), LWG per head (20%, 27 kg/head), LWG per hectare (37%, 18 kg/ha) and nitrogen yield (68%, 23 kg N/ha). Simulated long-term benefits of annual LWG per head (27 kg/head) was comparable with the 35 kg/hd advantage of cattle grazing native pastures with stylo in central Queensland (Noble *et a*l. 2000), 37 kg/hd for seca stylo over-sown pastures in central Queensland (Orr 2005), 30-60 kg/head for cattle grazing pastures that included Verano and / or Seca in north Queensland (Coates *et al*. 1997), 45 kg/head on sown stylo grass pastures (Jones *et al*. 1990 cited in Hill *et al*. 2009), and the calculated benefit (37 kg/ha) of legume-based pasture on low phosphorus soil (Peck *et al.* 2015). However, the results from this simulation were much lower than the mean annual LWG benefit of 112 kg/head for stylo/grass pastures on heavy textured cropping soils (Hill *et al*. 2009). Simulated long-term benefits of annual LWG per hectare (18 kg/ha) were comparable with caatinga stylo –grass pastures four years post establishment (17 LWG kg/ha Clem 2004), but less than a stylo – native grass pasture (44 LWG kg/ha Noble *et al*. 2000) and the calculated benefit (37 kg/ha) of legume-based pasture on low phosphorus soil (Peck *et al.* 2015).

Table 7: Probability distribution of long-term (1995-2014) pasture and animal productivity outcomes for a) Thisit grass only, b) Thisit grass and legume and c) the difference between grass and legume and grass only. TSDM = Total standing dry matter. %util= pasture utilisation. LWG = live weight gain. % perennial grasses is an index of condition.

a)

Decile	Rain (mm)	TSDM kg/ha	Nitrogen Yield kg N /ha	Pasture growth kg/ha	%basal	Stocking rate hd/km2	Stocking rate ha/AE	%util	LWG/hd	LWG/ha	% perennial grasses
30%	505	2780	31.2	3317	4.94	26.6	3.76	21.9	122.5	36.3	88.7
50%	606	3766	35.3	4131	5.26	35.9	2.79	30.2	136.9	50.8	89.1
70%	694	4348	42.8	5364	5.83	43.7	2.29	35.9	167	54.7	89.7
Mean	625	3519	34	4166	5.2	34.6	2.89	27.1	139	48.6	89

b)

Decile	Rain (mm)	TSDM kg/ha	Nitrogen Yield kg N /ha	Pasture growth kg/ha	%basal	Stocking rate hd/km2	Stocking rate ha/AE	%util	LWG/hd	LWG/ha	% perennial grasses
30%	505	3306	53.4	3856	5.04	32.2	3.11	23	147.9	52.8	88.7
50%	606	4533	64.1	4963	5.49	43.1	2.32	29.3	163	72.2	88.9
70%	694	5002	67.6	5908	6.04	50.3	1.99	34.6	193.8	82.1	89.5
Mean	626	4061	57	4799	5.4	39.8	2.51	27	166.3	66.8	88.9

c)

Decile	Rain (mm)	TSDM kg/ha	Nitrogen Yield kg N /ha	Pasture growth kg/ha	%basal	Stocking rate hd/km2	Stocking rate ha/AE	%util	LWG/hd	LWG/ha	% perennial grasses
30%	505	526	22.2	539	0.1	5.6	0.65	1.1	25.4	16.5	0
50%	606	767	28.8	832	0.23	7.2	0.47	-0.9	26.1	21.4	-0.2
70%	694	654	24.8	544	0.21	6.6	0.30	-1.3	26.8	27.4	-0.2
Mean	625	542	23	633	0.2	5.2	0.38	-0.1	27.3	18.2	-0.1

10.3.2 Kookaburra property

10.3.2.1 Grass only and grass and legume SWIFTSYND sites

Fenced SWIFTSYND exclosures (Day and Philp 1997) were established in each of the paddocks in November 2011 (Fig. 6 & 7). The Kookaburra sites were brigalow / bauhinia / yarran vegetation on slopes of brigalow grey clays, although the actual sites were treeless.

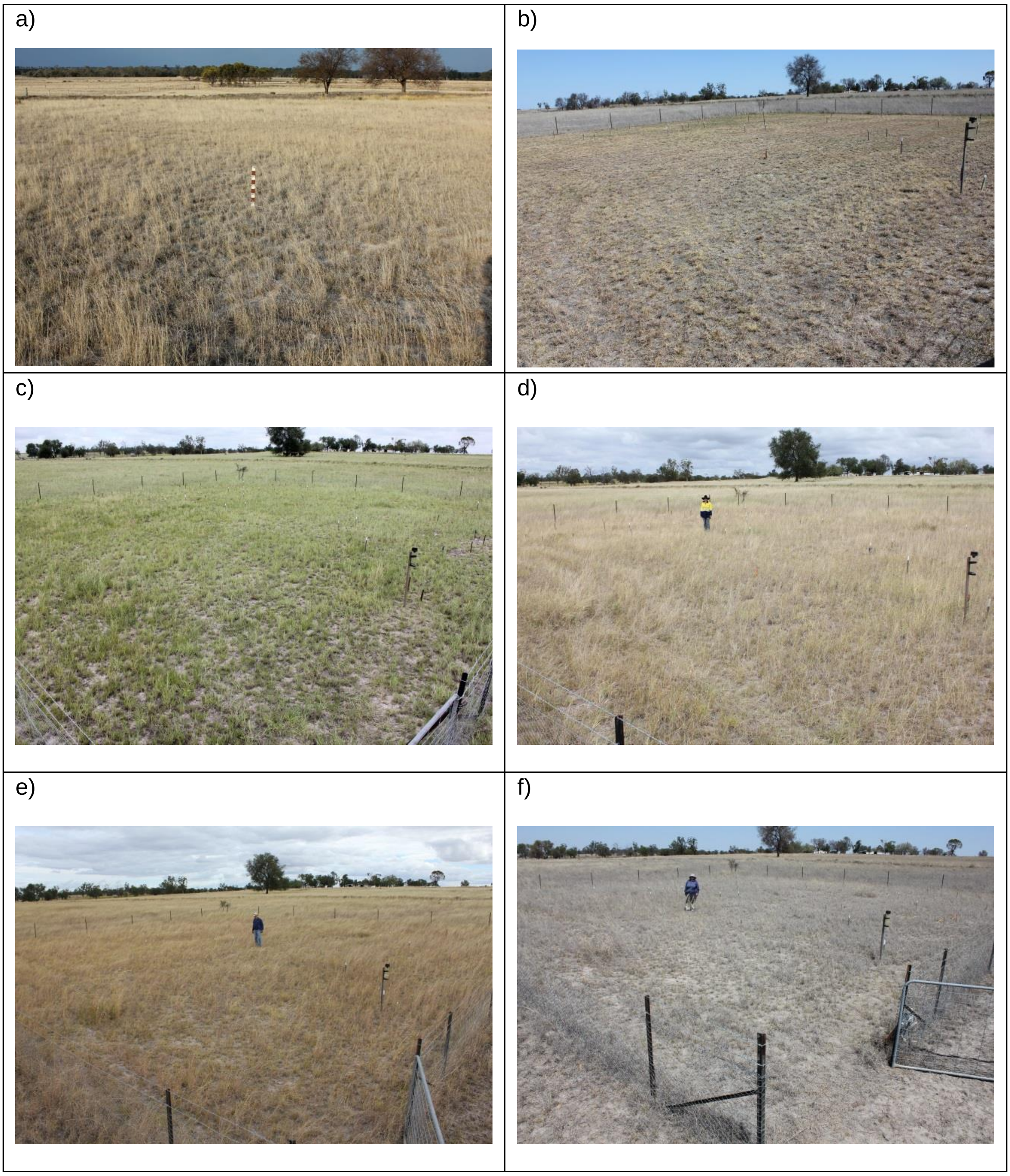

Figure 6 - The Kookaburra grass only a) paddock and SWIFTSYND site b) establishment October 2011, c) year 1 harvest 1 January 2012, d) year 1 harvest 2 March 2012, e) year 2 harvest 3 April 2013, and f) year 2 harvest 4 September 2013.

a) 	b) 
c) 	e) 
f) 	g) 

Figure 7 - The Kookaburra grass and legume only a) paddock and SWIFTSYND site b) establishment October 2011, c) year 1 harvest 1 January 2012, d) year 1 harvest 2 March 2012, e) year 2 harvest 3 April 2013, and f) year 2 harvest 4 September 2013.

The sites most closely align with brigalow softwood scrub land type (Whish 2011). It was estimated by field operators that both sites were in A condition, as desirable species (Queensland bluegrass, buffel, forest bluegrass, Rhodes grass, desmanthus) contributed over 80% of the pasture yield.

Legumes increased total pasture productivity by 113-170% over the 2 years of sampling at Kookaburra sites (Fig. 8, Table 9). However, over the two years of sampling total productivity of both sites decreased by 15-33% (Fig. 8, Table 9). As in the paddock, Queensland bluegrass was the dominant contributor to total yield for both the grass only (46%) and grass and legume (64%) SWIFTSYND sites, with buffel grass only contributing between 22-28% of the yield Only the Biloela variety of buffel was sown in these paddocks. Biloela buffel appears to have a higher N requirement than Gayndah and American varieties and tends to die out as the pasture N availability decreases with increasing time since sowing. At both the grass only and grass and legume sites, there was an increase in the proportion of Queensland bluegrass in the total yield between the first and second years of sampling (42 to 50%, 58% to 70% respectively). Corresponding to this increase in Queensland bluegrass was a decline in the contribution of buffel to total yield over the two years of sampling in the grass only (29% to 27%) grass and legume site (28% to 16%). Forest bluegrass and windmill grasses contributed about a fifth of the pasture yield of the grass only site, whilst desmanthus only contributed approximately 5% of total yield at the grass and legume site.

It is likely that pasture growth was adversely impacted by the “resetting” approach particularly as some pastures plants were mown below 5 cm. It is also possible that buffel grass was more sensitive than Queensland bluegrass to the mowing to 5cm with the contribution of buffel to yield decreasing over the two years of sampling.

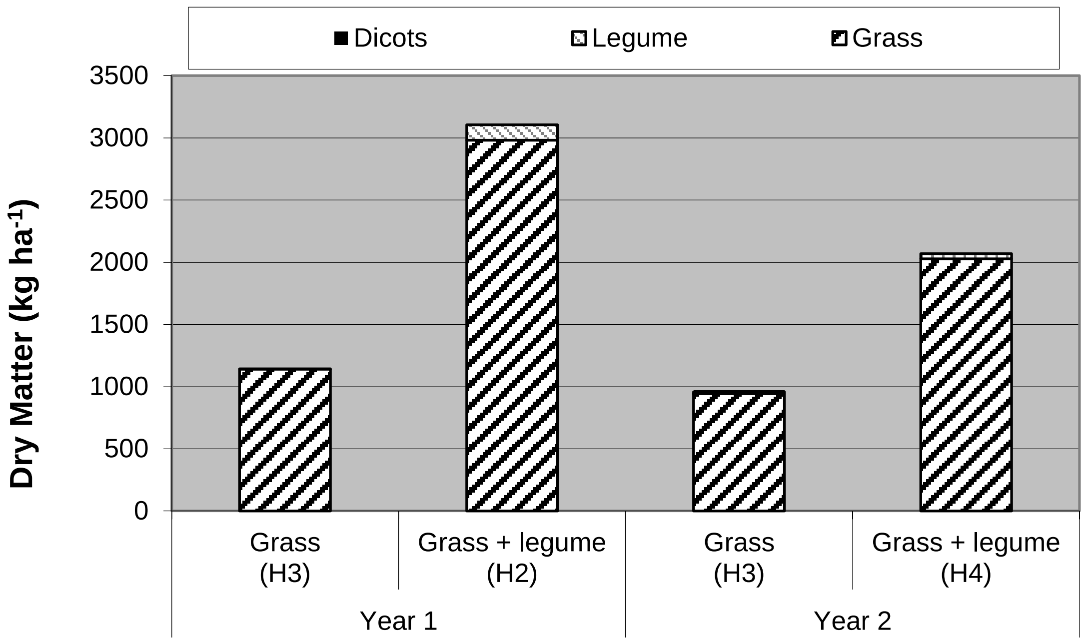

Figure 8 – Measured peak dry matter production (kg/ha) for each year of sampling between 2011-2013 for grass only and grass with legume pastures at Kookaburra sites. Harvest (H) number for peak production is indicated.

Table 9 – Total standing dry matter TSDM (kg ha^{-1}) and pasture species composition as a % of total yield estimated from grass only and grass and legume SWIFTSYND sites at Kookaburra over two years from October 2011-September 2013.

Species	Common name	Year data collected	Total yield	
			(%)	(%)
			Grass	Grass + legume
Cenchrus ciliaris	Buffel grass	2011-2012	29	28
		2012-2013	27	16
		Average of 2 years	**28**	**22**
Dichanthium sericeum	Queensland bluegrass	2011-2012	42	58
		2012-2013	50	70
		Average of 2 years	**46**	**64**
Bothriochloa bladhii *Chloris spp.*	Forest bluegrass Windmill grass	2011-2012	24	10
		2012-2013	20	9
		Average of 2 years	**22**	**9**
Desmanthus virgatus	Desmanthus	2011-2012	0	4
		2012-2013	0	5
		Average of 2 years	**0**	**5**
Total standing dry matter TSDM (kg ha^{-1})		2011-2012	1140	3105
		2012-2013	968	2068
		Average of 2 years	**1054**	**2587**

10.3.2.2 Rainfall

There was only one accumulative 2.35 L capacity rain gauge located at the grass only SWIFTSYND site at Kookaburra. Rainfall measured at the site was compared to SILO records for Kookaburra property and the neighbouring property (Ekullem) located approximately 800m away. Total rainfall measured at SWIFTSYND site, SILO records and neighbouring property for the two years (14/10/2011 to 19/09/2013) was 906 mm, 949 mm and 1074 mm respectively. There was one period (15/5/12 to 12/12/12) where site accumulated measurements differed from both neighbouring property and SILO records by more than 100 mm. For this period, with the occurrence of flooding in Queensland, it was assumed that the rain gauge had overflowed and 142 mm of rainfall was added to climate file. Other than this period, site accumulated rainfall measurements were included in the interpolated 100 year climate data by evenly distributing the difference between SILO and the measured rainfall to every 1 mm or 5 mm SILO record for each collection period.

The total rainfall after adjustments (1087 mm) was 182 mm more than that measured at the site. The adjusted annual rainfall for the two years of sampling (550 mm 2012, 483 mm 2013) was 10-21% less than the 100 year annual average for Kookaburra (614 mm).

10.3.2.3 Calibration of model

Model calibration of the Kookaburra grass only and grass and legume SWIFTSYND sites was undertaken using the systematic approach of Scanlan *et al*. (2008). Calibration commenced using the parameters for average native pastures and the supplemented historical climate data. A detailed account of the calibration process, derivation of model parameters from measured data, estimation of parameters by examining model output compared with observation data and the associated linear regression statistics is provided in Appendix B. Summary of the calibration outcomes is provided below.

Soil water

The total (0 – 100 cm) measured soil water at the grass and legume SWIFTSYND site was between 24 and 80 mm more than the grass only site over the two years samples were collected, with the largest differences occurring in the first year of sampling. The greatest differences (between 16 and 51 mm) in soil water between the sites occurred at L2 10-50cm, although measured soil water at 50 - 100 cm depth (L3) at the grass and legume site was also greater (4-24 mm) than measurements for same depth at the grass only site. The measured soil waters differed from estimated field capacity for loam or clay textured soil, particularly for L2 (10-50 cm) and L3 (50-100 cm). Measured soil water were a quarter or less of the expected field capacity for L2 at grass only site and L3 at grass and legume site.

It is difficult to assess whether the unexpected measured soil waters (both minimum and maximums) reflect sampling difficulties (particularly grass only L2 maximum) or reflect specific site characteristics. Soil chemical analyses at the sites indicate that the presence of chloride, sodium and other salts in the soils were causing some soil structure issues and root penetration difficulties, with effective root depth 60-90 cm. The greater amount of measured soil water at the grass and legume site compared with the grass only site is most likely due to higher ground cover (average over two years 76% compared with 58% respectively) resulting in better infiltration and less runoff.

The calibrated relationships between observed (measured soil water) and GRASP predicted soil water were best at the grass and legume site (0-10 cm R^2 0.82, 10-50cm R^2 0.87, 50-100 cm R^2 0.46) although the relationship for L3 was poor. At the grass only site these relationships were poor particularly at depth (0-10 cm R^2 0.76, 10-50cm R^2 0.01, 50-100 cm R^2 0.11). Discrepancies between observed and predicted values could be due to site-specific root penetration problems resulting in unused water in L3 and or errors in the estimated rainfall distribution. These site specific soil characteristics need to be taken into consideration when determining whether the sites are representative of the spatial heterogeneity of the grey clay brigalow soils.

Pasture production

Perennial grass basal area was initially estimated from measurements obtained in July 2014. Grass basal area for grass only (3.7%) and the grass and legume (6.7%) sites were within the range for perennial native pastures (3-6%). Potential regrowth rate kg/ha DM grown / day / unit basal area was estimated from days since start of the growing season (50 mm of rain over 2 week period). Calibration of the potential regrowth rate of the grass only site to “unusual” soil and pasture measurements resulted in very low, constrained pasture growth rate (Table 10). Conversely, the potential regrowth rate of the grass and legume site was a similar value to that commonly used for a healthy and productive native pasture.

Pasture growth is calculated under both transpiration limiting (low soil water) and radiation limiting conditions for each day, with the most limiting factor estimating growth. The green yield to green cover relationship allowed determination of green yield at which both transpiration and radiation interception is 50%. The green yield to green cover relationship for both sites was only fair (R^2 0.38

grass only, R^2 0.48 grass and legume), with green cover not estimated to be more than 50% at the grass only site. The estimated value for green yield at 50% green cover for grass only site was 575 kg/ha (R^2 0.38) and 1183 kg/ha for grass and legume site (R^2 0.48). Height yield relationship, a measurement of the plant structure, of 1000 kg/ha yield was 16.7 cm for the grass only site and 11.8 cm for the grass and legume pasture. These measurements are likely to be reflecting the contribution (~20% of total yield) of the taller *Bothriochloa bladhii* pasture (120cm) at the grass only site compared with the *Dichanthium sericeum* (70cm) dominated pasture at the grass and legume site.

Values for a number of key nitrogen related parameters are shown in Table 10. These key parameters include: the initial pulse of nitrogen present in dry matter that occurs during the first growth period of the growing season; the rate of N uptake per 100 mm of grass transpiration which is related to the rate of N mineralisation; maximum N uptake which is an indicator of the fertility of the site; % N at zero growth; and maximum N% in pasture where values higher than the default value of 2.5% have been measured for fertilised sown pastures.

The relationship between the predicted data and observed values of green cover was only poor (R^2 0.20) for grass only site, but there was reasonable agreement (R^2 0.62) between the predicted data and observed values of green cover at the grass and legume site The calibrated grass only and grass and legume models achieved the best possible fit for N yield of TSDM (R^2 0.78, R^2 0.46 respectively) and TSDM (R^2 0.78, R^2 0.89 respectively) although at both sites the resulting % N TSDM relationships were poor (R^2 0.30, R^2 0.14 respectively).

Table 10. Calibrated key pasture production GRASP model parameters for typical native pastures, and grass only and grass and legume SWIFTSYND sites at Kookaburra.

Parameter description	Parameter value		
	Typical value for native pastures	Grass only	Grass and legume
Potential daily regrowth rate (kg/ha/day/%basal area)	5.0	1.3	4.5
Initial plant density (%basal area)	4.0	2.3	5.0
Transpiration efficiency (kg/ha/mm of transpired at vpd 20 kpa)	13.5	13.5	13.5
N uptake (kg/ha) at zero transpiration	2-5, up to 10	4.5	3.7
N uptake (kg/ha) per 100 mm GRASS transpiration	5-6 south, 10 in north	5	5.7
Maximum N uptake (kg/ha)	10-25, very fertile 40	10	25
% N at zero growth	0.45 (C4), 0.7 (forbs), 0.91 (C3 &C4 with forbs)	0.65	0.65
Maximum % N in growth	2.5 default	2.5	2.5

10.3.2.4 Long-term simulations

The calibrated grass only and grass and legume models were extended over time using historical climate data to determine the productivity of the grass only and grass and legume grazing systems.

Adjustments to the annual live weight gain subroutine were made following a review of literature (Table 4), grazing trial data (Table 11) and soil analyses. Kookaburra soils had very low phosphorus levels (Colwell P 4 ppm at 0-10cm, 1 ppm or lower at depth) and stock were deficient in P and copper and marginal for sodium. Live weight gain (LWG) of stock grazing the grass only and grass and legume paddocks were measured during the summer of 2011/12 and 2013 (Table 11). Stock were supplemented with phosphorus and copper during the 2013 grazing period. Animal productivity increased substantially (tenfold to hundredfold) when stock were supplemented. For both non-supplemented and supplemented stock, LWG per head on the grass and legume paddock (0.18, 11.2 kg/hd respectively) was higher than the grass only paddock (0.02, 0.8 kg/hd respectively). Over the 13 months steers in the grass only paddock gained 0.3 kg/day whilst stock in the desmanthus paddock gained 0.4 kg/day.

In GRASP, animal live weight gain is a function of the length of the growing season and pasture utilisation (the proportion of pasture growth which has been eaten). Annual live weight gain regression parameters for the Kookaburra long-term simulations were estimated assuming stock had no mineral deficiencies (Table 12).

Table 11: Average stocking rate (head/ha), live weight gain (LWG) per head (kg/head/day) and live weight gain (LWG) per hectare (kg/ha) from 31 December 2011 until 12 April 2012 and 10 February to 25 May 2013 at Kookaburra grazing trials. # 2013 grazing period stock were supplemented with phosphorus and copper.

	Stocking rate (head/ha)	LWG per head Yr1 (kg/hd/day)	LWG per head Yr2 (kg/hd/day) #	LWG per hectare Yr1 (kg/ha)	LWG per hectare Yr2 (kg/ha) #
Grass only	0.5 (5 head)	0.02	1.5	0.8	78
Grass and legume	0.6 (6 head)	0.18	1.9	11.2	119

Table 12: Estimated annual live weight gain regression GRASP model parameters for grass only and grass and legume SWIFTSYND sites at Kookaburra

Parameters	Grass only	Grass and legume
Co-efficient for % utilisation in annual LWG regression	-0.002061	-0.002061
Co-efficient for % green days in annual LWG regression	0.004883	0.004883
Intercept in annual LWG regression	0.0603	0.1353

Simulated long-term (1995-2014) pasture and animal productivity outcomes for grass only and grass and legume paddocks, and the difference between the paddock outcomes are shown in Table 13.

Table 13: Probability distribution of long-term (1995-2014) pasture and animal productivity outcomes for a) Kookaburra grass only, b) Kookaburra grass and legume and c) the difference between grass and legume and grass only outcomes. TSDM = Total standing dry matter. %util= pasture utilisation. LWG = live weight gain. % perennial grasses is an index of condition.

a)

Decile	Rain (mm)	TSDM kg/ha	Nitrogen Yield kg N /ha	Pasture growth kg/ha	%basal	Stocking rate hd/km2	Stocking rate ha/AE	%util	LWG/hd	LWG/ha	% perennial grasses
30%	491	1220	9.9	1324	3.0	12.4	8.1	26.3	96.6	11.6	88.7
50%	577	1248	10	1527	3.4	12.6	7.9	27.4	118.5	14.1	89
70%	656	1278	10	1531	3.7	12.9	7.8	28.6	129.5	16.7	89.3
Mean	602	1170	10	1370	3.4	11.9	8.4	27.9	111.3	13.2	88.9

b)

Decile	Rain (mm)	TSDM kg/ha	Nitrogen Yield kg N /ha	Pasture growth kg/ha	%basal	Stocking rate hd/km2	Stocking rate ha/AE	%util	LWG/hd	LWG/ha	% perennial grasses
30%	491	1591	12.2	1833	5.0	16.2	6.2	22.8	121.9	20.1	88.3
50%	577	1887	14.4	2218	5.7	19.0	5.3	28.8	140.1	24.2	88.9
70%	656	2207	16.8	2515	6.4	22.2	4.5	34.9	150.8	32.9	89
Mean	602	1924	15	2230	5.6	19.7	5.1	28.7	136.3	27	88.6

c)

Decile	Rain (mm)	TSDM kg/ha	Nitrogen Yield kg N /ha	Pasture growth kg/ha	%basal	Stocking rate hd/km2	Stocking rate ha/AE	%util	LWG/hd	LWG/ha	% perennial grasses
30%	491	371	2.3	509	2.0	3.8	1.9	-3.5	25.3	8.5	-0.4
50%	577	639	4.4	691	2.2	6.4	2.7	1.4	21.6	10.1	-0.1
70%	656	929	6.8	984	2.7	9.3	3.2	6.3	21.3	16.2	-0.3
Mean	602	754	5	860	2.2	7.8	3.3	0.8	25	13.8	-0.3

The 20-year period had a few very wet years as indicated by a higher mean annual rainfall (602 mm) than the median annual rainfall (577 mm). The sites were sampled during two below-average years (Jan-Dec 2012 - 550 mm and Jan – Dec 2013 - 483 mm) that were preceded by an extraordinary wet year (2010/11 1211 mm).

On average over the 20-year period, both the grass only and grass and desmanthus pastures were of poor to moderate productivity (average annual growth of 1370 DM kg/ha and 2230 DM kg/ha respectively); however, the average pasture utilisation of 28-29% ensured pastures maintained their good condition (89% perennial grasses). The average stocking rate (8.4 ha/AE) for grass only pasture was lower than the expected carrying capacity for brigalow and better scrubs (native grass) land systems (2-7 ha/AE) in the Maranoa Balonne (Paton *et al* 2011). Animal productivity from the Queensland bluegrass pastures (LWG per head 111 kg/hd, LWG per hectare 13.2 kg/ha) was also lower but comparable with the estimated values for stock on pastures on very low phosphorus soils (Peck *et al.*, 2015).

The Queensland bluegrass pastures with desmanthus had a higher average stocking rate (5.1 ha/AE), LWG per head (136 kg/hd), and LWG per hectare (27 kg/ha) compared with the Queensland bluegrass pastures. The mean benefits of legume-based pasture compared with grass pasture included Increases in stocking rate (66%, 3.3 ha/AE), LWG per head (22%, 25 kg/head), LWG per hectare (105%, 13.8 kg/ha) and nitrogen yield (50%, 5 kg N/ha). Simulated long-term benefits of annual LWG per head (25 kg/head) was within range of reported legume benefits from studies in central Queensland (22 & 35 kg/head, Orr 2005) and the average of simulated legume benefits (26 kg, 20%) across five regions in Queensland (Hunt *et al*. 2014). The LWG/AE advantage of legume-based pastures compared to grass pastures found in this study was within range of those estimated for desmanthus pastures on low phosphorus soils (21% Peck *et al.*, 2015), although less than that found with seca stylo pastures in central Queensland (32%, Orr 2005). Simulated long-term benefits of annual LWG per hectare (13.8 kg/ha, 105%) were similar to the calculated benefit (9 kg/ha, 76%) of legume-based pasture on very low phosphorus soil (Peck *et al.*, 2015) but less than that found for caatinga stylo pastures at Brian Pastures Research Station in southern Queensland (17 kg/ha Clem 2004).

10.4 Discussion

Two locations in the brigalow belt bioregion of central Queensland were used to evaluate the productivity benefits of sowing legumes with buffel grass pastures that were established approximately 15 years previously. Site data collected from these locations between 2011 and 2013 was used to calibrate the GRASP pasture and animal growth model and to simulate long-term (1995-2014) productivity benefits of sowing legumes with buffel pastures.

Long-term productivity benefits of sowing legumes with buffel grass on brigalow clay soils were predicted for two locations in central Queensland. At both Moura and Wandoan, over 20 years when stocked conservatively (30% utilisation of available forage at the end of May), legumes improved pasture productivity (kg/ha) by 15% and 63% respectively, animal productivity (LWG/ha) by 37% and 105% respectively, and nitrogen yield (kg N/ha /by 68% and 50% respectively. Animal productivity were reflective of legume persistence, increased pasture yield, and better pasture quality, but also the limitation of low phosphorus at Moura and very low phosphorus at Wandoan.

Data collected from the grass only and grass and legume sites at Moura and Wandoan provided appropriate soil and pasture data for calibration of the GRASP pasture production model. Key biological and physical pasture processes were fairly well represented in the GRASP model at both locations. However, generally these key processes were best represented in the Moura calibrated models, and between predicted data and measured standing dry matter (R^2 0.92, R^2 0.98 at Moura; R^2 0.78, R^2 0.89 at Wandoan) than green cover (R^2 0.64, R^2 0.63 at Moura; R^2 0.20, R^2 0.62 at Wandoan), N yield of total standing dry matter (R^2 0.60, R^2 0.66 at Moura; R^2 0.78, R^2 0.46 at Wandoan) and %N yield of total standing dry matter (R^2 0.57, R^2 0.54 at Moura; R^2 0.30, R^2 0.14 at Wandoan). The calibrated relationships between measured soil water and predicted data were best at both the Moura and Wandoan grass and legume sites (0-10 cm R^2 0.98, R^2 0.82; 10-50cm R^2 0.48, R^2 0.87; 50-100 cm R^2 0.99, R^2 0.46 respectively), whilst these relationships were poorer with increasing soil depth at Moura and Wandoan grass only sites (0-10 cm R^2 0.82, R^2 0.76; 10-50cm R^2 0.57, R^2 0.01; 50-100 cm R^2 0.00, R^2 0.11 respectively).

Discrepancies between measured and predicted values could be due to sampling error, the impact of “resetting” approach on plants and / or site-specific characteristics. The appropriateness of the calibrated model to be extrapolated temporally using historic climate data requires consideration of the impact of the “resetting” approach on pasture composition and productivity. At both Moura and Wandoan grass only and grass and legumes sites, there was a decline in buffel, and a corresponding increase in Queensland bluegrass, as a proportion of total productivity over the two years of sampling. Additionally, at Wandoan total productivity in first year of sampling was between 15 and 33% higher than total productivity in the second year of sampling. Rainfall received in the second year of sampling at Wandoan was 10% lower than rainfall received in the first year of sampling, whilst at Moura rainfall was 23% higher in the second year compared to the first. It is highly likely that buffel grass was more sensitive than Queensland bluegrass to the slashing/mowing approach used to “reset” the pasture each year, and the reduction of plants to ~ 5cm most likely impeded the ability of plants to regrow particularly when plants are water-stressed.

Spatial extrapolation of the calibrated models is only appropriate if the sites are considered to adequately represent the buffel and sown legumes pastures on brigalow clays established more than 15 years previously. The buffel dominant pastures at Moura were a mix of taller (Biloela) buffel that is suited to heavier soils and higher rainfall, and medium height varieties (American, Gayndah) that are low-fertility tolerant and more suited to lighter soils and lower rainfall. Although calibrated relationships between measured soil water and predicted data were only average particularly at the grass only site, without any obvious site-specific impediments, it was assumed that the soil waters were representative of the spatial heterogeneity of the cracking brigalow soils.

Wandoan pastures were dominated by Queensland bluegrass with buffel (Biloela) only contributing <25% to yield. It is likely that Biloela buffel, a variety that is N demanding, died out as the level of N available to pastures decreased as time since sowing increased, Calibrated relationships between measured soil water and predicted data were only average to poor particularly at the grass only site. The presence of chloride, sodium and other salts in the Wandoan soils are likely to cause some soil structure issues and root penetration difficulties, with effective root depth estimated at 60-90 cm. These site-specific soil characteristics may have resulted in unused water in 50-100cm layer and impeded grass growth, particularly buffel that can be sensitive to water-logging. The Wandoan sites are Queensland bluegrass dominant pastures, where productivity is likely to be have impeded by the “reset” approach and site-specific soil characteristics. The Wandoan pastures are different to most commercial buffel grass pastures on brigalow clay soils that include both Biloela and Gayndah varieties. However, there are some commercial rundown sown grass pastures on poorer soils where native grasses have re-invaded and displaced the sown grass pastures, especially where more nitrogen demanding grasses like green panic have been sown.

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10.6 Appendix A: Calibration of SWIFTSYND sites at Thisit property

A systematic approach for model calibration was undertaken to ensure key biological and physical pasture processes were well represented in the GRASP model. Calibration of SWIFTSYND model was undertaken using CEDAR GRASP (version 1.1.45 2011) and GRASP Calibrator (version 1.31 Build 4328) software.

The systematic approach used to calibrate GRASP involved the following five steps:

6. Set parameter values based on literature, location and site data
7. Use field observations to calculate and set soil water parameters
8. Use field observations to calculate and set pasture production parameters
9. Adjust soil and plant parameters using visual ‘best fit’ and statistics
10. Review calibration results in relation to other sites and findings

This calibration procedure was undertaken using data collected from the grass only and grass and legume SWIFTSYND sites located at Thisit property. Once calibrated, the models can be extended over time since pasture establishment and across similar soil types and pastures in central Queensland.

Calibration commenced using the parameters for average native pastures, location and the supplemented historical climate data.

10.6.1 Soil water

Volumetric soil water was calculated for the SWIFTSYND sites for seven of the eight harvest periods for which the data was available. Soil water measurements for the grass only site and grass and legume site (Table 1) were used to calibrate air dry, wilting point, and field capacity to estimate available water range of the three soil water layers available for pastures. As it is often difficult to access sites when they are wet and to obtain measurements at depth in very dry soils, the minimum and maximum field measurements may underestimate field capacity and wilting point.

Table 1 – Minimum and maximum soil water (mm) for L1 (0-10 cm), L2 (10-50 cm) and from L3 (50-100cm) collected from grass only and grass and legume SWIFTSYND sites over 2 years from November 2011-September 2013.

	Grass only site		Grass and legume site	
Soil water layer	Minimum (mm)	Maximum (mm)	Minimum (mm)	Maximum (mm)
L1 (0-10 cm)	9.8	31.2	10.9	32.2
L2 (10-50 cm)	72.9	128.8	72.2	120.2
L3 (50-100 cm)	106.9	130.6	125.7	155.1

It was assumed that there was deep soil evaporation from the cracking clay soils, and, as such, the minimum soil moisture measured at the site provided estimates of air dry soil moisture for the three soil layers. Air dry is the minimum possible soil water due to the removal of water by plants and evaporation. Wilting point was estimated to be a few mm greater than air dry. Field capacity was estimated from the maximum soil moistures measured at the site (often an under-estimate) and the relationship between field capacity and wilting point derived from calibration of sites in Queensland for all soil types.

The total soil water (0 -100 cm) measured from the grass and legume site was between 9 and 56 mm more than the grass only site over the two years samples were collected (Table 2). The measured soil water at 50 -100 cm depth (layer 3) at the grass and legume site was consistently greater (4-48 mm) than measurements for same depth at the grass only site (Table 2). It is difficult to assess whether the differences in soil water between the two sites is an artefact of the grass only SWIFTSYND (e.g. salt, hardpan or sampling of melonholes) or can be representative of the spatial heterogeneity of the cracking clay brigalow soils.

Plant available soil water for the calibrated grass and legume and grass only SWIFTSYND sites (Table 1) were similar to soils with clay texture in top 10cm (18, 19 mm respectively); soils with loamy sand texture in L2 (49, 44 mm respectively); and soils with sand texture in L3 (30, 20 mm respectively). Of note is the loss of 0.7 mm/day of soil water from cracking clays in the calibrated model may be close approximation of the soil water loss to through drainage of the sandier profiles at these sites.

Table 2 – Difference between measured soil water from grass and legume SWIFTSYND site and grass only SWIFTSYND site over the two years (March 2012 – September 2013) samples were collected.

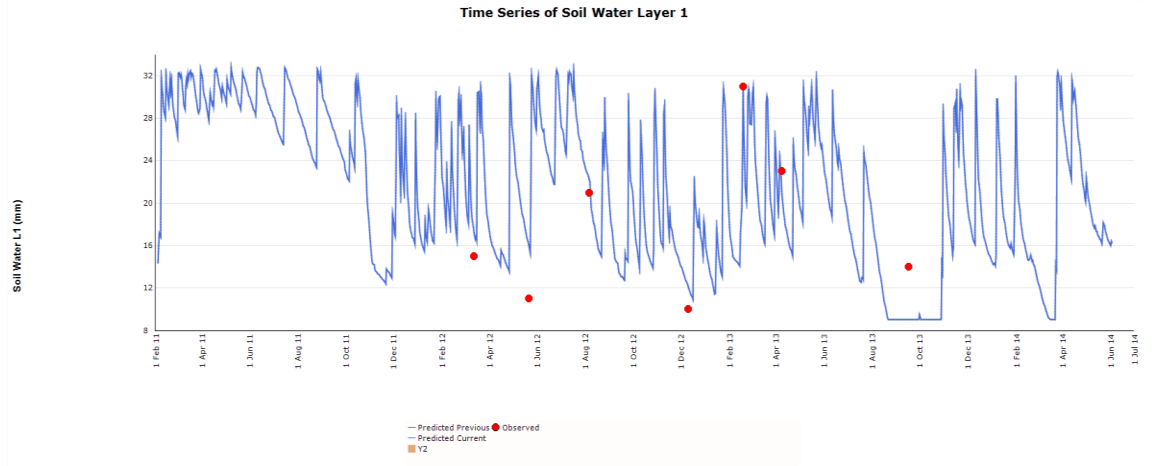
	Year 1 sampling			Year 2 sampling			
Soil water layer	Mar 2012	May 2012	Aug 2012	Dec 2012	Feb 2013	April 2013	Sep 2013
L1 (0-10 cm)	2	3	4	1	1	-3	-2
L2 (10-50 cm)	14	-9	-9	-1	7	5	2
L3 (50-100 cm)	32	4	14	21	48	25	16
Total (0-100 cm)	49	-1	9	22	56	27	16

The calibrated relationships between observed (measured soil water) and GRASP predicted soil water were best at the grass and legume site, whilst at the grass only site these relationships were poorer with increasing soil depth (Fig. 1 & 2).

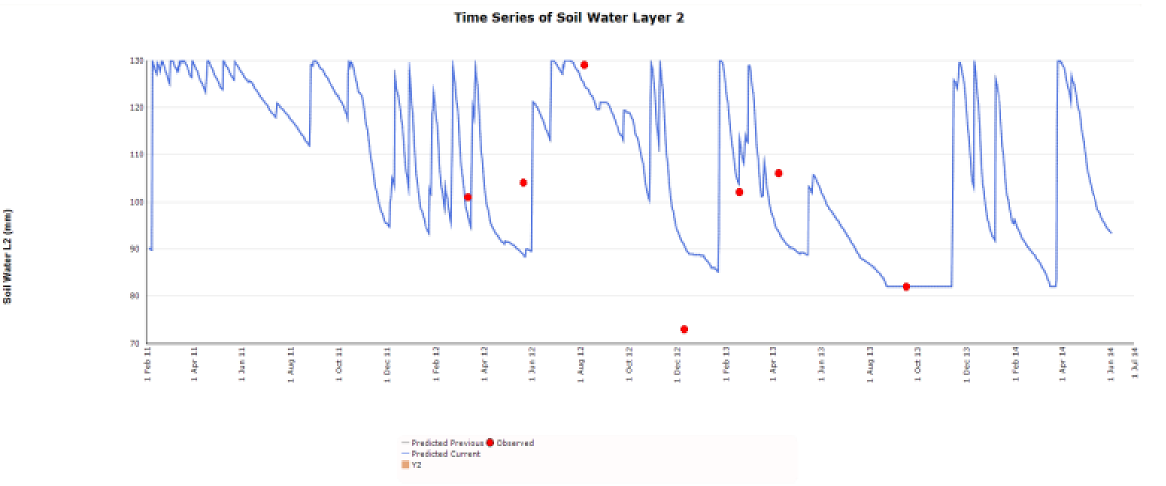
Calibrating the grass only model to measured soil waters was difficult, with the greatest differences between measured and predicted values for the three soil layers (Fig. 1) as follows:

- Predicted soil water for the top 10cm (L1) did not reach the measured minimum values of 11 and 10 mm on 22/5/12 and **11/12/12** respectively
- Predicted soil water for L1 was **much lower (9 mm)** than the observed 14 mm on **18/9/13**
- Predicted soil water for L2 (10-50cm) when calibrated to observed soil water (82 mm) for **18/9/13** did not reach the low measured value of 73 mm on **11/12/12**
- Predicted soil water for L3 (50-100 cm) did not reach the high observed soil water for 131 mm **22/5/12** - this measurement was despite also having a very low L1 measurement for same period

a) RSME = 3.05, ∑(x-y) = -3.32, R-squared = 0.82



b) RSME = 11.1, ∑(x-y) = 6.77, R-squared = 0.57



c) RSME = 10.6, ∑(x-y) = 16.2, R-squared = 0.00

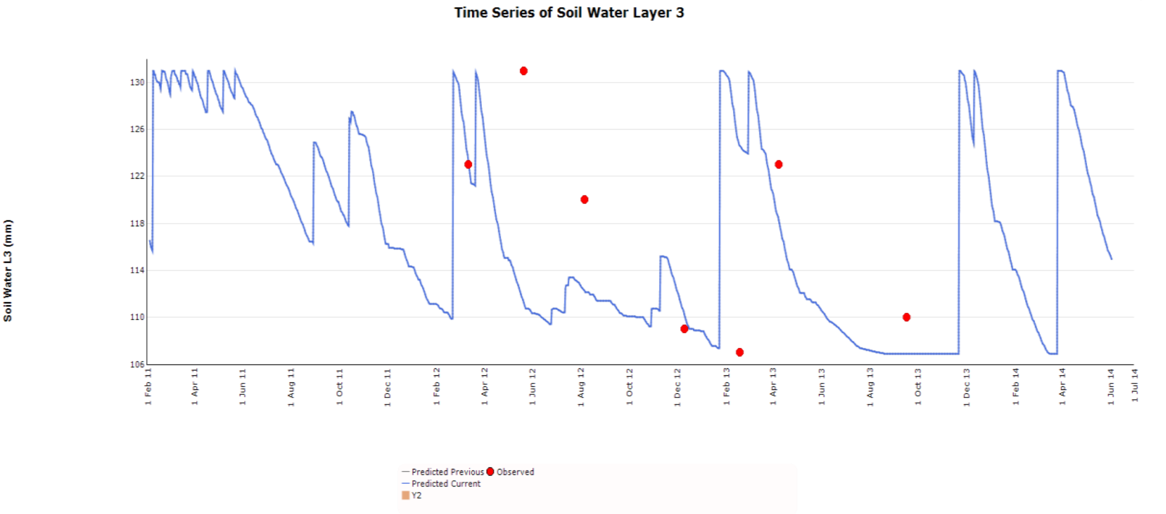


Figure 1 – Time series for calibrated grass only SWIFTSYND site soil water (observed red circles and predicted blue line) for a) L1 (0-10 cm), b) L2 (10-50 cm), c) L3 (50-100 cm). X axis December 2010 to July 2014. Y axis soil water mm. Linear regression statistics (R-squared, root mean square error (RSME) and ∑ (x-y)) are provided.

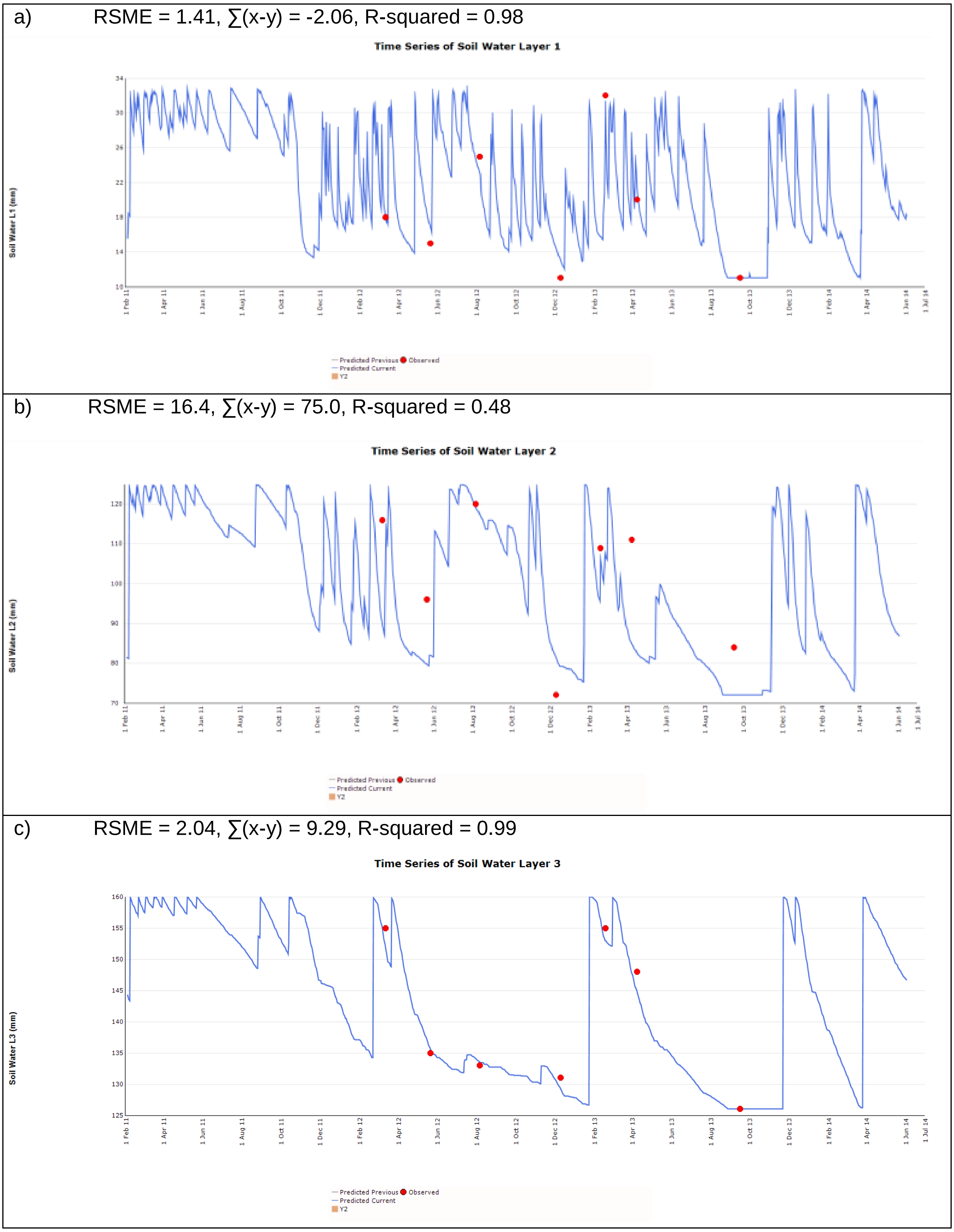


Figure 2 – Time series for calibrated grass and legume SWIFTSYND site soil water (observed red circles and predicted blue line) for a) L1 (0-10 cm), b) L2 (10-50 cm), c) L3 (50-100 cm). X axis December 2010 to July 2014. Y axis soil water mm. Linear regression statistics (R-squared, root mean square error (RSME) and ∑ (x-y)) are provided.

- Predicted soil water for L3 (50-100 cm) did not reach the minimum 107 mm on 19/2/13
- Predicted soil water for L3 (50-100 cm) was drier than the measured 110 mm on **18/9/13**

Possible explanations for these discrepancies between observed and predicted values at the grass only site include:

- Errors in measured data (e.g. 11/12/12, 18/9/2013, 22/5/12)
- Estimated rainfall distribution didn't capture the occurrence of rainfall at the site (e.g. 18/9/13)
- General inconsistencies in measured data
    - dry at depth despite being wet in L1 & L2 (19/2/13) possibly an impedance to drainage
    - wet at depth despite being dry in top 10 cm possibly due to pasture plants removing water from the upper layers or lateral drainage (11/12/12)

Running the calibrated grass only model with SILO climate file only (no site rainfall) produced a slight improvement in L1 (RMSE 2.72, R^2 0.85), but worse for L2 (RMSE 12.29, R^2 0.51) and L3 (RMSE 11.18, R^2 0.00). The calibrated model was also run with various amounts of rainfall (5-40 mm) added at 15/9/13. The addition of rainfall ensured the model reached L1 observed value for this period but not for the other soil layers and the calibrated relationships were all worse.

Calibrating the grass and legume model to measured soil waters was initially based on the grass only site. The relationships between observed and predicted were excellent at this site for top (L1) and bottom (L3) soil layers (R^2 0.98, 0.99 respectively), with the worst relationship (R^2 0.48) occurring at L2 (Fig. 2).

10.6.2 Pasture production

Pasture structure, soil fertility and pasture nitrogen levels were calibrated using site measurements of plant height, and green cover to obtain green yield, and simulated N Yield TSDM and % N Yield TSDM relationships.

A similar height yield relationship was measured at both SWIFTSYND sites with plant height for 1000 kg/ha estimated as 10.3 (Fig. 3). The height yield relationship is a measurement of the plant structure. This aspect of plant structure influences growth through the impact of vapour pressure deficit. The higher the vapour pressure deficit (highest at the soil surface and decreases with height) the lower the amount of growth produced per unit of transpiration.

GRASP uses two ways to estimate pasture growth: one method is based on grass basal area (GBA) and growth per unit basal area; and the other is transpiration by transpiration use efficiency. GRASP selects the maximum of the two estimates.

The first approach is often used at the start of the growing season when green cover is low and hence transpiration driven growth is also low. Perennial grass basal area was estimated from measurements obtained in July 2014 and the average grass basal area and water use efficiency for basal area change. Grass basal area for grass only (4.7%) and the grass and legume (4%) sites were within the range for perennial native pastures (3-6%). Potential regrowth rate kg/ha DM grown / day / unit basal area was estimated from days since start of the growing season. It was considered that the start of growing season occurred after 50 mm of rain fell over a two week period. Pasture growth based on grass basal area and growth per unit basal area (32-34 kg/ha/day) was as expected with buffel pastures higher than a healthy and productive native pasture (20 kg/ha/day).

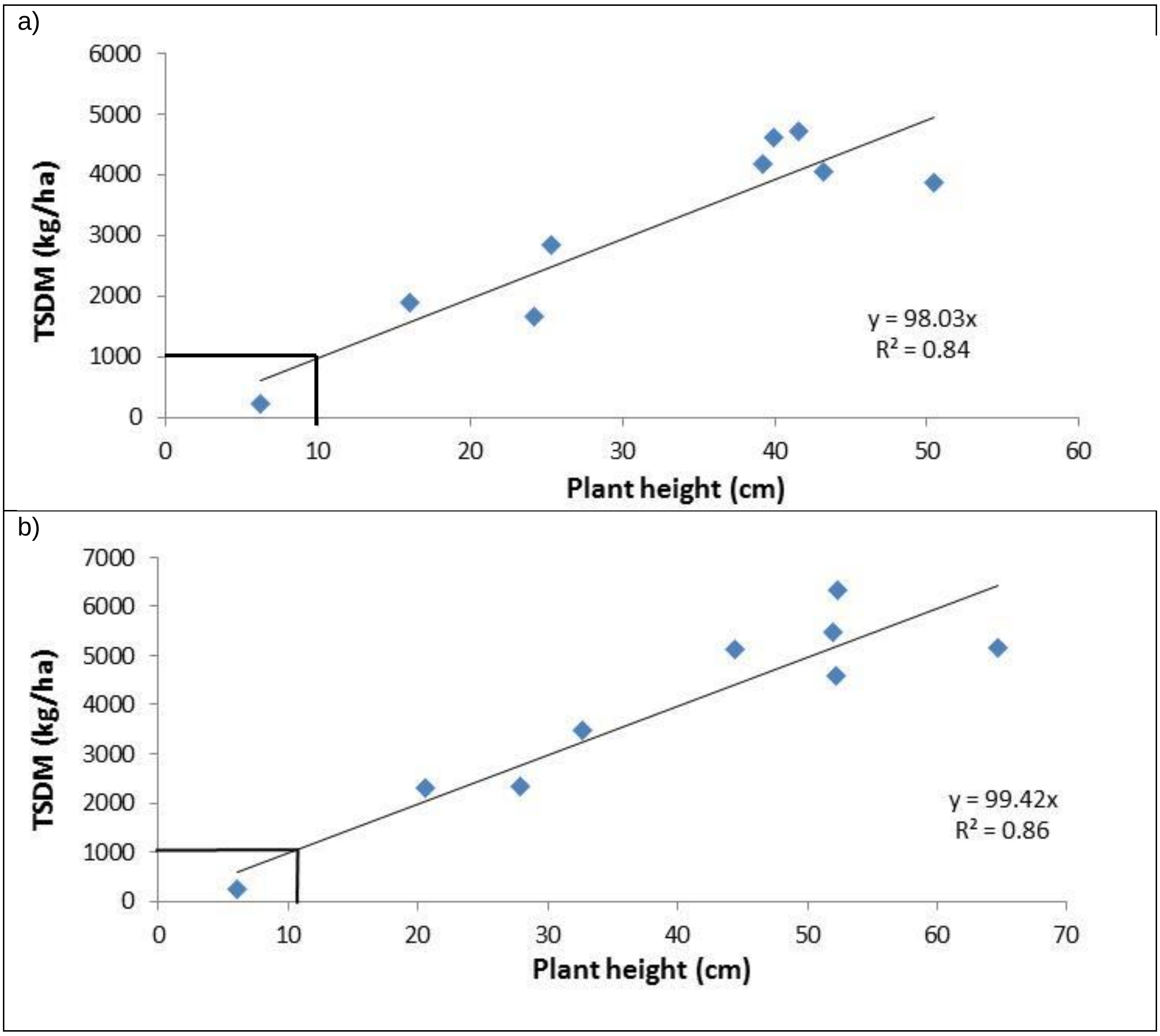


Figure 3 – Height yield relationship at Thisit a) grass only pasture and b) grass and legume pasture on cracking brigalow clay soil.

The green yield to green cover relationship allows determination of green yield at which both transpiration and radiation interception is 50%. Green cover (green biomass proportion of TSDM) was calculated from stem and leaf separated data collected in the second and third harvests each year. For the other four harvests, where there was no separation data, green yield was estimated as the proportion (from species composition observations) of total yield (Fig.4).

These relationships drive transpiration and radiation interception. Pasture growth is calculated under both transpiration limiting (low soil water) and radiation limiting conditions for each day, with the most limiting factor estimating growth. Under water limited conditions, pasture growth is determined from the product of transpiration and transpiration efficiency. Pasture growth under radiation limited conditions is determined from intercepted solar radiation and radiation use. The estimated value of 1663 kg/ha for green yield at 50% green cover was used for grass only site (R^2 0.62) and grass and legume site (R^2 0.79) (Fig. 4).

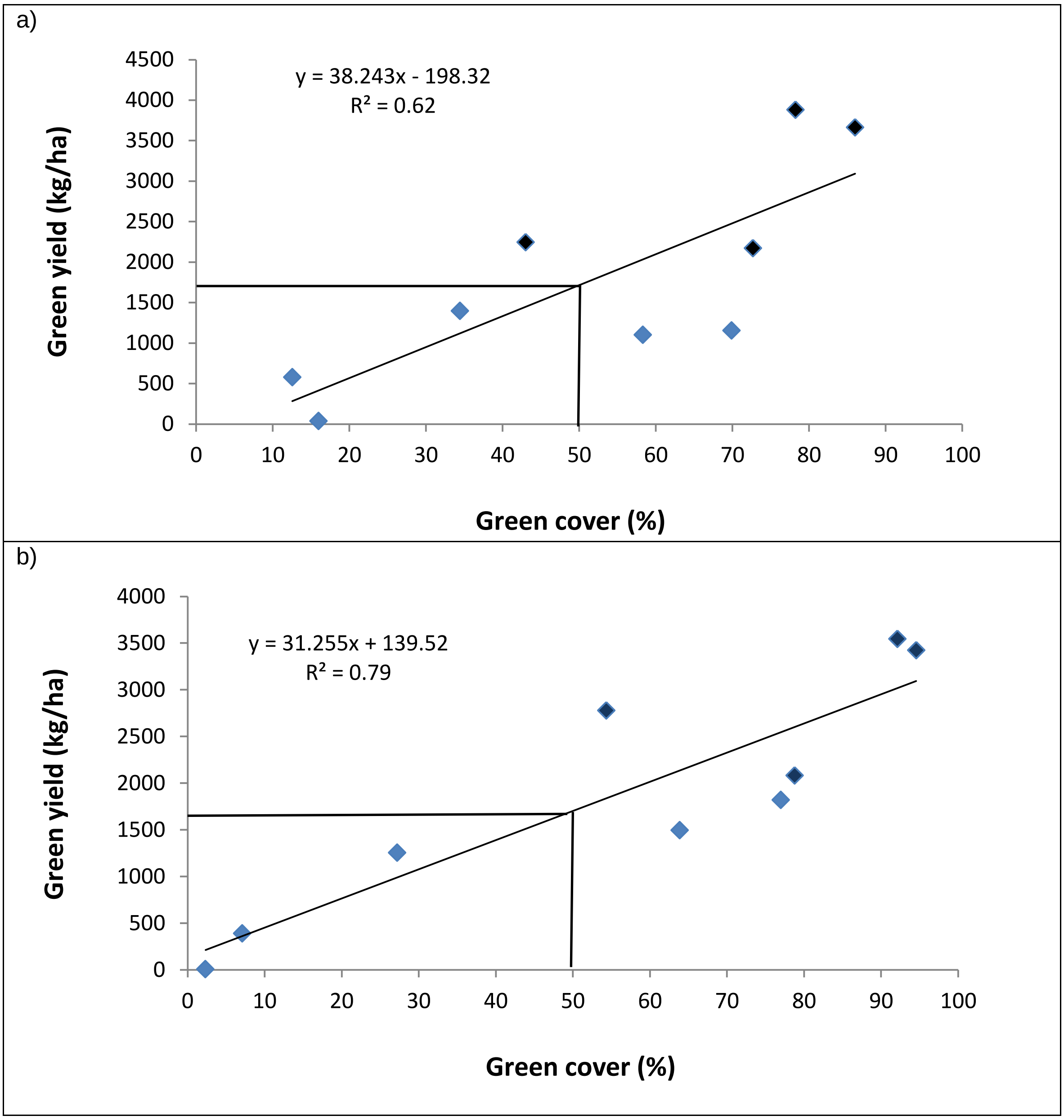


Figure 4 – Green yield and cover relationship at Thisit a) grass only pasture and b) grass and legume pasture on cracking brigalow clay soil. Green yield was calculated from stem and leaf separated data (black diamond) and estimated from total standing dry matter using observed green cover.

10.6.3 Soil fertility and pasture nitrogen levels

Nitrogen is a key determinant of growth in many native pastures in northern Australia, particularly in areas above about 650mm rainfall. GRASP has a simple calculation of nitrogen limitation so both limitations of climate and soil fertility can be represented in simulations of pasture growth. The simple nitrogen-limitation sub-model is based on a constant potential N uptake and minimum nitrogen concentration being determined for each site. Hence, potential annual growth is a constant.

During the first growth period of the growing season (while accumulated transpiration is very low), an initial pulse of nitrogen is present in the dry matter. This initial pulse normally is ~2 to 5 kg N/ha and does not exceed 10 kg N/ha for tropical native pastures. Pastures which store nitrogen in the roots and crowns, and in soils where release of nitrogen occurs quickly in the growing season, may have higher values. The initial nitrogen was estimated from % N and N yields (% N x standing dry matter) from 1st harvests for each year of sampling. This value was estimated to be 7 kg N/ha for the grass only site, and 5 kg N/ha for the grass and legume site.

The more rapidly that nitrogen is mineralised the higher the value of N uptake per 100 mm transpiration. These values can be estimated from the second harvest field data (total kg N/ha) and transpiration of pastures and trees outputs from GRASP. Common values are ~10 kg N/100mm in northern dry monsoon climates and 5-6 kg N/100mm in southern Queensland. Higher values were often found in central Australia 13-15kg N/100mm. Values of 15 kg N/100 mm and 27 kg N/100mm were estimated for the grass only and grass and legume sites respectively.

Maximum N Uptake is an indication of the fertility of a site and can be estimated from harvest data that aligns with peak standing crop. Values of between 10-25 kg N/ha are common, with very fertile soils reaching up to 40 kg N/ha. To ensure simulated N uptake reached measured N uptake of peak yield, max N Uptake of 43 kg N/ha and 68 kg N/ha were estimated for the grass only and grass and legume sites respectively.

The % N at zero growth was estimated from % N present at the end of a good/extended growing season when some green material is still present (harvest 3). Typical values for average native pastures (C4 grasses) are between 0.45 and 0.68, whilst forbs and C3 plants often have higher values than C4 plants. Grass only site values of 0.78 was used, whilst 1.15 was used for grass and legume site. In the NT, with decreasing latitude from tropical savannas, the average value of % N at zero growth increased with higher contribution of forbs and C3 grasses to total pasture.

A default value of 2.5% is used for the maximum N% in pasture. Higher values have been measured in fertilised sown pastures, but the application of GRASP in these cases has not been tested. 2.5% N is a common value observed at the start of the season in native grass dominated pastures. At and below this value, nitrogen is present in protein (rubisco) that initially fixes CO_2 in the leaf contributing to higher growth rates in younger, greener leaf than leaf with lower nitrogen content. C3 plants usually have higher values than C4 plants, and forbs can have higher values than grasses. This can be estimated from %N in early growth. The default value of 2.5% was used for grass only site and 3.0% for the grass and legume site.

10.6.4 Best fit

Several key parameters that cannot be derived by direct calculation from SWIFTSYND data were estimated using best fit simulation approach. Transpiration efficiency (TUE), or the amount of dry matter produced per mm of water transpired, is a key parameter that drives pasture growth in GRASP and is related to general site fertility, the higher the value the more productive the site. For perennial pastures general TUE values are between 7-20 kg/ha/mm of water transpired, For the grass only and grass and legume sites the estimated value for TUE was 17.2 kg/ha/mm and 19.5 kg/ha/mm respectively.

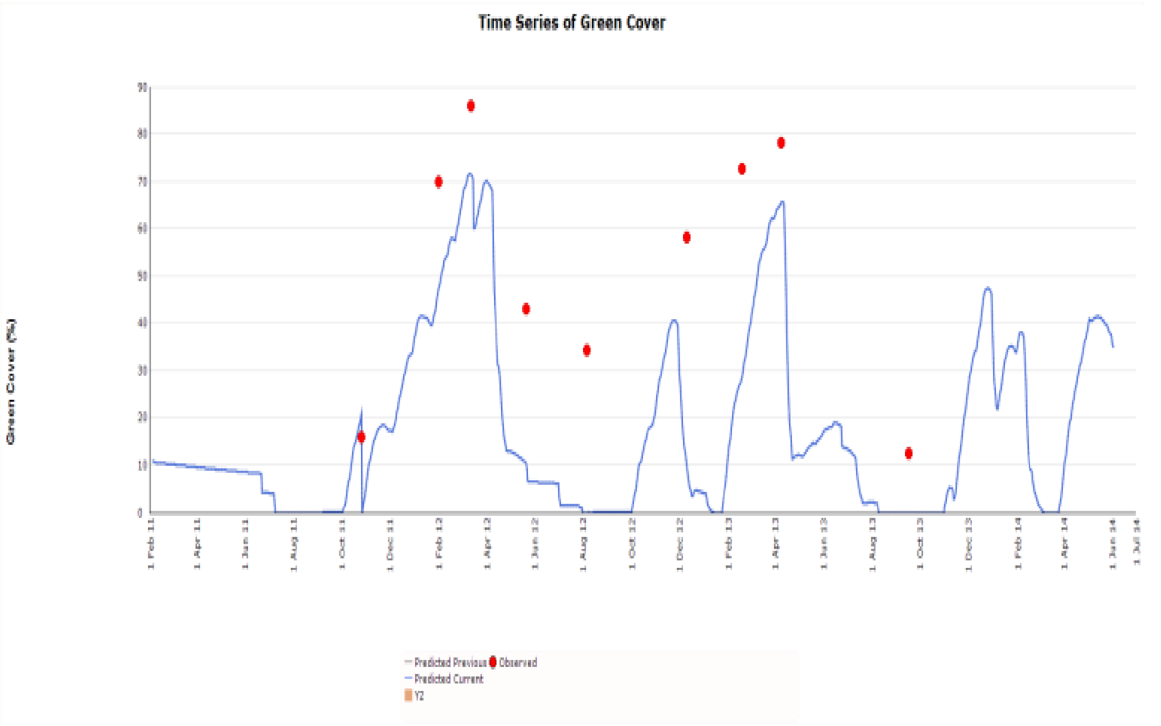
Observed pasture yield is the net result of growth and detachment. In general, detachment is greater when material is dry/dead. Detachment for forbs and annual grasses will generally be higher than perennial grasses. Detachment rates in SWIFTSYND sites tend to be very low because resets remove old plant material and there is little disturbance of plants from animals. Detachment rates in SWIFTSYND sites across the NT were highest in the arid zone where forbs and annuals dominate and lowest in Sturt Plateau where swards were perennial grass dominated. Daily detachment rates for dry and wet seasons were 0.0001 & 0.0008 respectively for both pastures.

A soil water index at which above ground growth ceases is used to represents when plants (that are still green but have switched to root growth or maintenance mode) continue to use water although there is no net above ground assimilation. Values of 0.3-0.4 are commonly used for this soil water index. This parameter can be confusing as it represents a number of different processes such as drought, the impact of heavy grazing, root shoot partitioning, the thresholds of surface soil-water required for germination and seedling establishment.

GRASP assumes that green canopy cover will be in equilibrium with available soil-water. The soil-water index at which green cover is at its maximum should always be larger but similar to that soil-water index where plants are showing first signs of stress. Although buffel tends to lose green cover at relatively high soil-water thresholds, the soil water index for maximum cover and cessation of above-ground were estimated as 0.3 & 0.2 for both sites.

In calibrating the models precedence was given to achieving the best possible relationships between predicted and measured data for N Yield TSDM and Standing Dry Matter (SDM). The calibrated grass only and grass and legume models only produced reasonable agreement between the predicted data and observed values of green cover (Fig. 5, R^2 0.63, R^2 0.64 respectively), N yield of total standing dry matter (Fig. 6, R^2 0.60, R^2 0.66 respectively) and %N yield of total standing dry matter (Fig. 7, R^2 0.57, R^2 0.54 respectively). There was a very good relationship between predicted data and observed values of standing dry matter for the calibrated grass only and grass and legume models (Fig. 8, R^2 0.92, R^2 0.98 respectively).

a) RSME = 29.1, ∑(x-y) = 217, R-squared = 0.64



b) RSME = 31.5, ∑(x-y) = 217, R-squared = 0.63

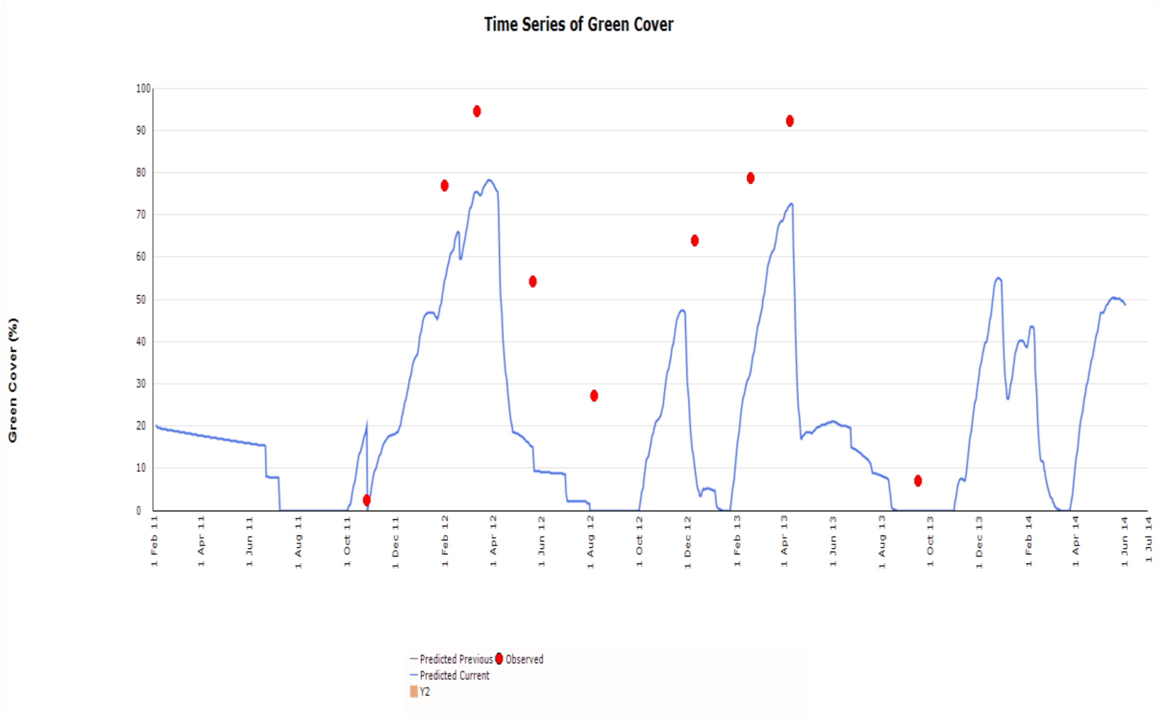
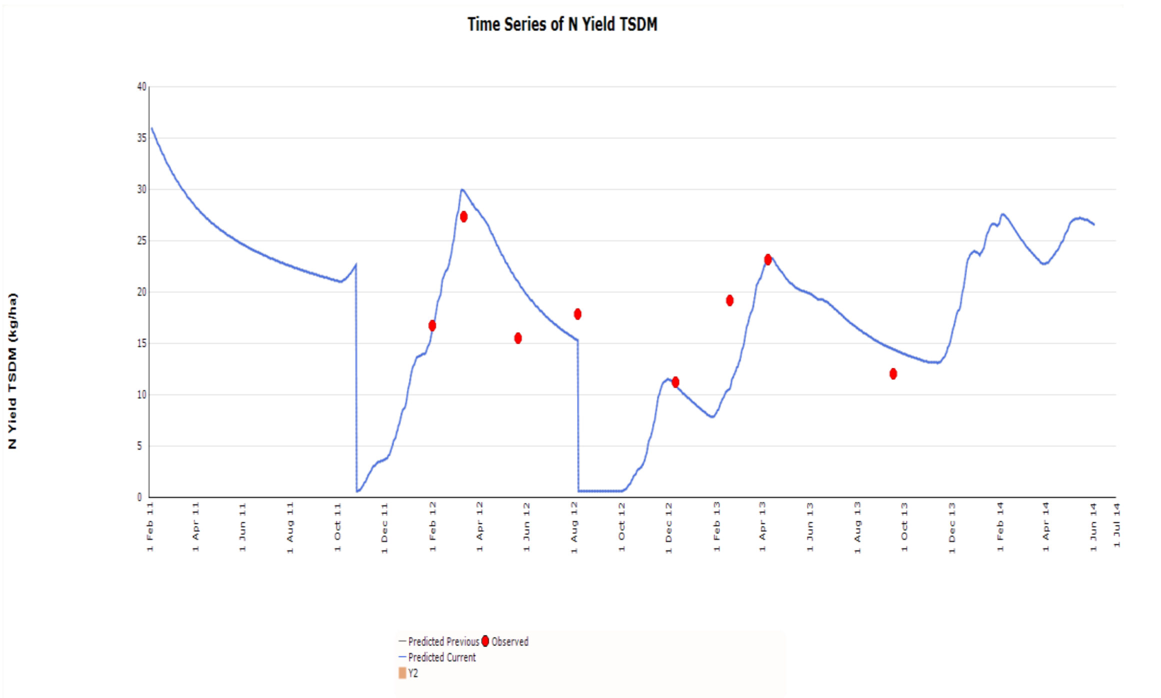


Figure 5 – Time series for calibrated a) grass and b) grass and legume SWIFTSYND site green cover (observed red circles and predicted blue line). X axis December 2010 to July 2014. Y axis green cover %. Linear regression statistics (R-squared, root mean square error (RSME) and ∑ (x-y)) are provided.

a)RSME = 3.91, ∑(x-y) = 1.13, R-squared = 0.60



b)RSME = 7.29, ∑(x-y) = -19.7, R-squared = 0.66

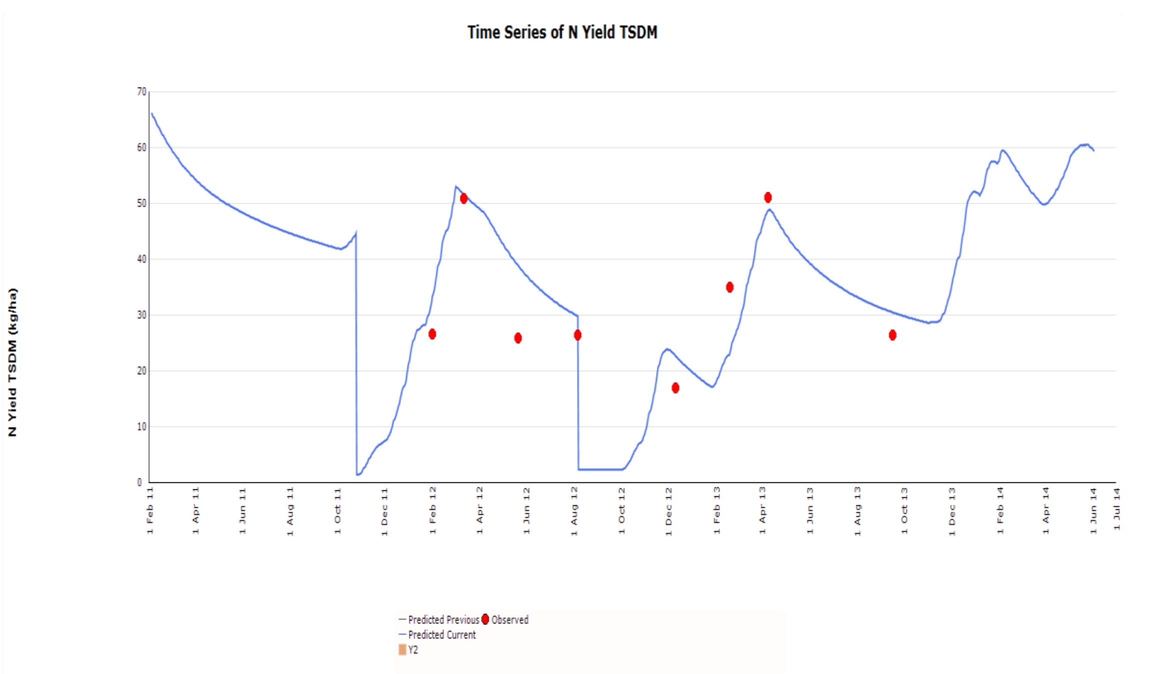
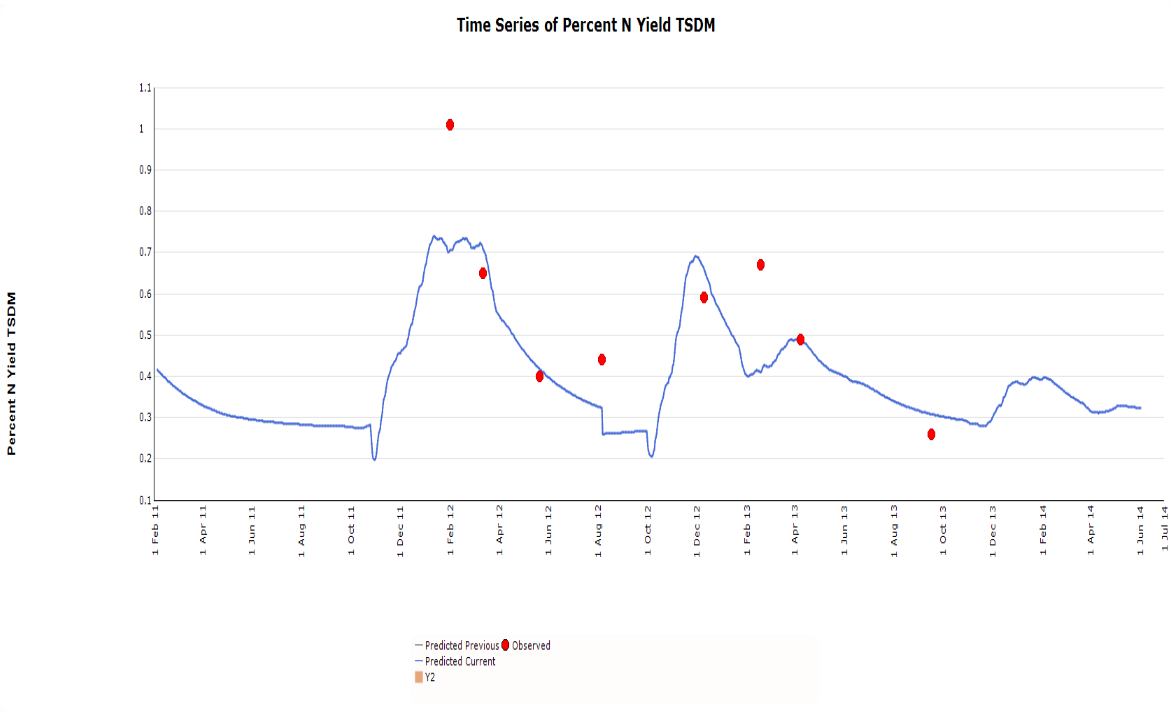


Figure 6 – Time series for calibrated a) grass and b) grass and legume SWIFTSYND site N Yield of TSDM (observed red circles and predicted blue line). X axis December 2010 to July 2014. Y axis N Yield TSDM kg/ha. Linear regression statistics (R-squared, root mean square error (RSME) and ∑ (x-y)) are provided.

a) RSME = 0.15, ∑(x-y) = 0.49, R-squared = 0.57



b) RSME = 0.17, ∑(x-y) = -0.40, R-squared = 0.54

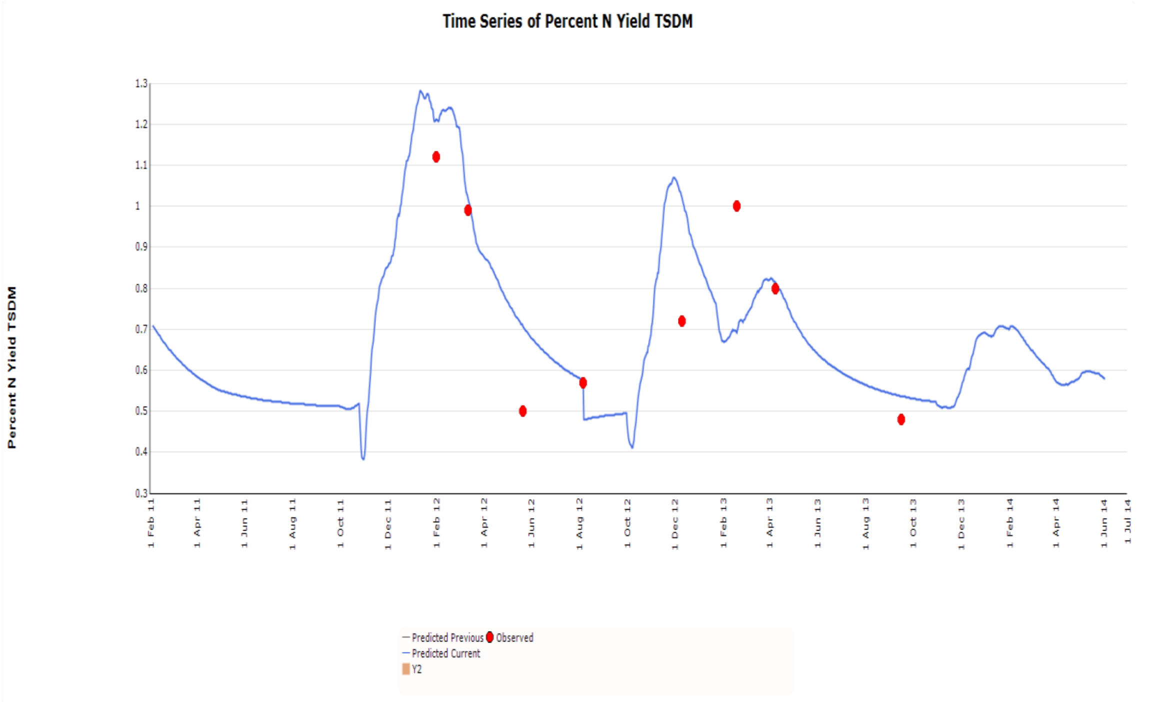
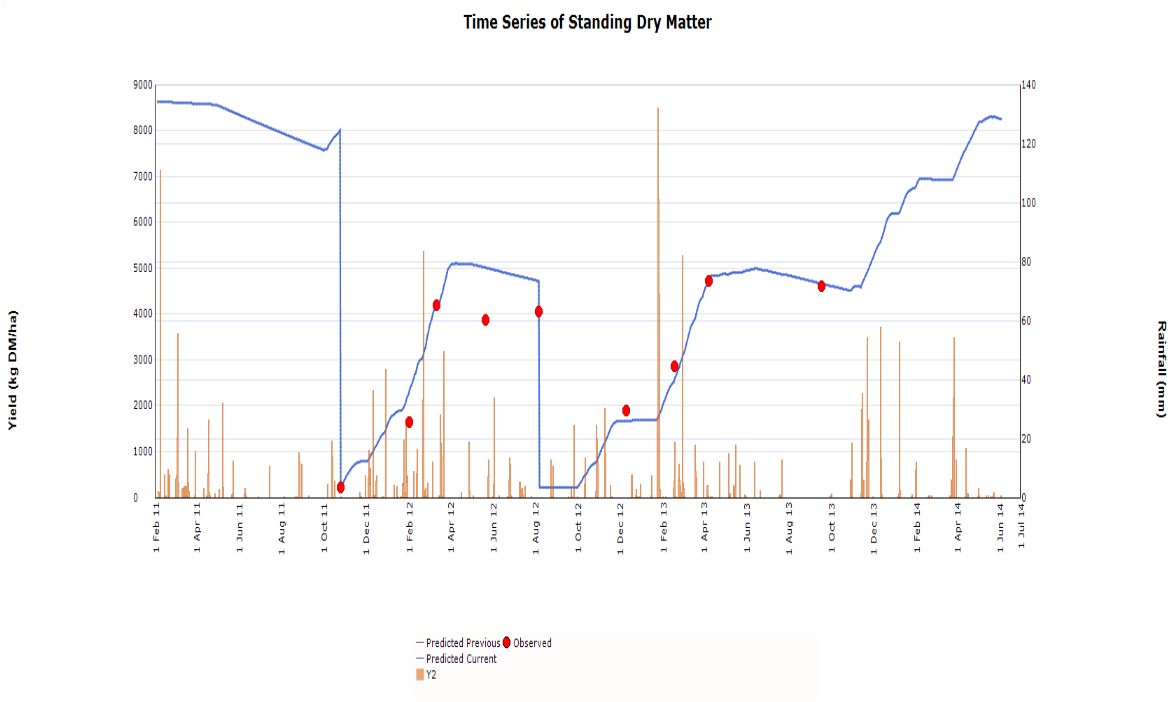


Figure 7 – Time series for calibrated a) grass and b) grass and legume SWIFTSYND site N% of TSDM (observed red circles and predicted blue line). X axis December 2010 to July 2014. Y axis N% TSDM kg/ha. Linear regression statistics (R-squared, root mean square error (RSME) and ∑ (x-y)) are provided.

a) RSME = 508, ∑(x-y) = -2077, R-squared = 0.92



b) RSME = 296, ∑(x-y) = -672, R-squared = 0.98

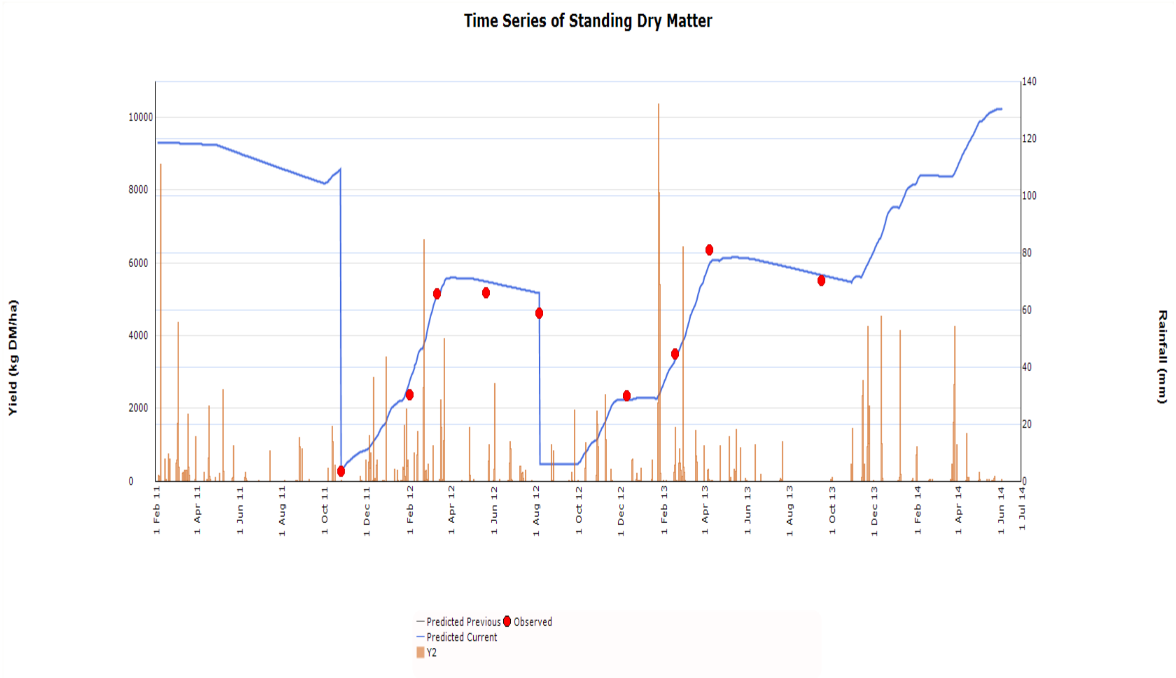


Figure 8 – Time series for calibrated a) grass and b) grass and legume SWIFTSYND site total standing dry matter (observed red circles and predicted blue line). X axis December 2010 to July 2014. Y axis total standing dry matter (TSDM) kg/ha. Rainfall (mm) also shown (orange bars). Linear regression statistics (R-squared, root mean square error (RSME) and ∑ (x-y)) are provided.

10.7 Appendix B: Calibration of SWIFTSYND sites at Kookaburra property

A systematic approach for model calibration was undertaken to ensure key biological and physical pasture processes were well represented in the GRASP model. Calibration of SWIFTSYND model was undertaken using CEDAR GRASP (version 1.1.45 2011) and GRASP Calibrator (version 1.31 Build 4328) software.

The systematic approach used to calibrate GRASP involved the following five steps:

11. Set parameter values based on literature, location and site data
12. Use field observations to calculate and set soil water parameters
13. Use field observations to calculate and set pasture production parameters
14. Adjust soil and plant parameters using visual ‘best fit’ and statistics
15. Review calibration results in relation to other sites and findings

This calibration procedure was undertaken using data collected from the grass only and grass and legume SWIFTSYND sites located at Kookaburra property. Once calibrated, the models can be extended over time since pasture establsihment and across similar soil types and pastures in central Queensland.

Calibration commenced using the parameters for average native pastures, location and the supplemented historical climate data.

10.7.1 Soil water

Volumetric soil water was calculated for the SWIFTSYND sites for seven of the eight harvest periods for which the data was available. Soil water measurements for the grass only site and grass and legume site (Table 1) were used to calibrate air dry, wilting point, and field capacity to estimate available water range of the three soil water layers available for pastures. As it is often difficult to access sites when they are wet and to obtain measurements at depth in very dry soils, the minimum and maximum field measurements may underestimate field capacity and wilting point.

Table 1 – Minimum and maximum soil water (mm) for L1 (0-10 cm), L2 (10-50 cm) and from L3 (50-100cm) collected from grass only and grass and legume SWIFTSYND sites over 2 years from November 2011-September 2013.

	Grass only site		Grass and legume site	
Soil water layer	Minimum (mm)	Maximum (mm)	Minimum (mm)	Maximum (mm)
L1 (0-10 cm)	8.9	23.6	11.2	29.7
L2 (10-50 cm)	71.4	**86.5**	87.9	133.6
L3 (50-100 cm)	107.2	134.4	129.1	139.2

It was assumed that there was deep soil evaporation from the cracking clay soils, and, as such, the minimum soil moisture measured at the site provided estimates of air dry soil moisture for the three soil layers. Air dry is the minimum possible soil water due to the removal of water by plants and evaporation. Wilting point was estimated to be a few mm greater than air dry. Field capacity was estimated from the maximum soil moistures measured at the site (often an under-estimate) and the relationship between field capacity and wilting point derived from calibration of sites in Queensland for all soil types.

The maximum measured soil waters from the grass only site differed from the estimated field capacity, and particularly for L2 & L3. The maximum measured soil water from L2 (86.5 mm) for grass only site was only 15 mm higher than the measured minimum (Table 1). For a loam or clay textured soil, it is expected that between 60-80 mm would be available for plants between 10-50cm (L2). Similarly for L3 at the grass only site, for a typical loam or clay textured soil L3 the expected plant available water (between 50-75 mm) was double that of the measured 27 mm. Plant available water for the grass and legume site was also less than expected for L2 (46 mm) and L3 (10 mm).

Despite the two SWIFTSYND sites being located next to each other there were large differences in measured soil water from the two sites over the two years samples were collected (Table 2). The total soil water (0 -100 cm) measured from the grass and legume site was between 24 and 80 mm more than the grass only site over the two years, with the largest differences occurring in the first year of sampling (Table 2). The greatest differences (between 16 and 51 mm) in soil water between the sites occurred at L2 10-50cm, although measured soil water at 50 -100 cm depth (L3) at the grass and legume site was also greater (4-24 mm) than measurements for same depth at the grass only site (Table 2).

Table 2 – Difference between measured soil water from grass and legume SWIFTSYND site and grass only SWIFTSYND site over the two years (March 2012 – September 2013) samples were collected.

	Year 1 sampling			Year 2 sampling			
Soil water layer	Mar 2012	May 2012	Aug 2012	Dec 2012	Feb 2013	April 2013	Sep 2013
L1 (0-10 cm)	7	4	7	2	6	3	4
L2 (10-50 cm)	27	19	51	16	30	17	17
L3 (50-100 cm)	24	24	22	10	12	4	15
Total (0-100 cm)	54	47	80	29	48	24	36

It is difficult to assess whether the unexpected measured soil waters (both minimum and maximums) reflect sampling difficulties (particularly grass only L2 maximum) or reflect specific site characteristics. The sites are located on sloping and undulating brigalow clay soils. Following analysis of soil chemical tests, it was considered likely that the presence of chloride, sodium and other salts in the soils were causing some soil structure issues and root penetration difficulties. It was estimated effective root depth was 90cm at grass only site and 60-90 cm at the grass and legume site. The greater amount of measured soil water at the grass and legume site compared with the grass only site is, in addition to any influence of soil structural issues in L3 at grass and legume site, is most likely due to higher ground cover (average over two years 76% compared with 58% respectively) resulting in better infiltration and less runoff. These site specific soil characteristics need to be taken into consideration when determining whether the sites are representative of the spatial heterogeneity of the grey clay brigalow soils.

Calibrating soil water for these sites took into consideration the following assumptions:

- there was some loss of soil water from the grey cracking clays, with a value of 0.7 mm/day soil water lost in the calibrated model
- the measurements sampled from both sites at the same time were evaluated to help determine minimum and maximum values
- measurements or "new" measurements were used to estimate wilting points and field capacity using the relationship from calibrated Queensland soils
- 'best fit' simulation methods in comparing field data and simulated data for all soil water layers were used to adjust soil water parameters

The calibrated relationships between observed (measured soil water) and GRASP predicted soil water were best at the grass and legume site (Fig. 1 & 2). However, at this site, despite a reasonable R^2 0.46, the relationship between predicted and measured soil water for L3 (50 -100 cm) was poor in the first year and only fair in the second year (Fig.2). At the grass only site, the calibrated relationships between observed and predicted soil water were poorer with increasing soil depth, with no relationship between predicted and measured for L2 (Fig. 1).

Calibrating the grass only model to measured soil waters was difficult, with the greatest differences between measured and predicted values for the three soil layers (Fig. 1) as follows:

- Predicted soil water for the top 10cm (L1) was lower than the observed 21 mm (predicted 15.4 mm) on **15/5/12** and 24 (predicted 17.5 mm) on 22/2/13.
- Predicted soil water for L2 (10-50cm) was much lower than the observed on **15/5/12** (77 cf. 82 mm), 11/4/13 (72 cf. 86 mm) and 19/9/13 (58 cf. 81 mm).
- Predicted soil water for L2 (10-50cm) was higher (110 mm) than the observed soil water (82 mm) on **8/8/13**.
- Predicted soil water for L3 (50-100 cm) was much lower than the observed on 11/4/13 (123 cf. 134 mm) and 19/9/13 (105 cf. 125 mm).
- Predicted soil water for L3 (50-100 cm) was higher (137 mm) than the observed soil water (107 mm) on **8/8/13**.

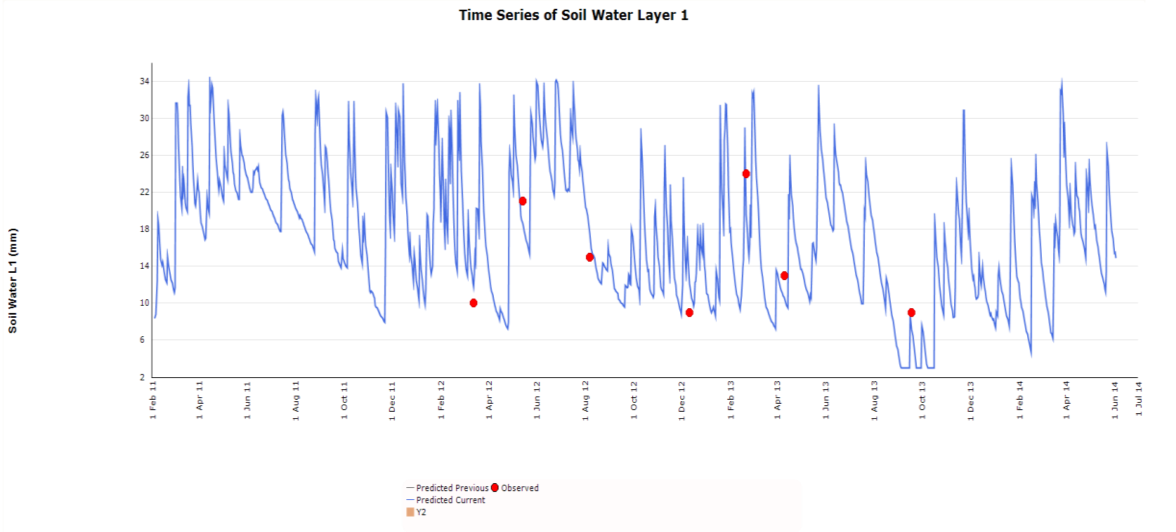
Possible explanations for these discrepancies between observed and predicted values at the grass only site include:

- Site specific impedance in L2, with little correlation to measured soil water and rainfall, also impacting soil water in L3
- Estimated rainfall distribution didn't capture the occurrence of rainfall at the site, underestimating rainfall (e.g. 15/5/12, 11/4/13, 19/9/13) or overestimating rainfall (8/8/13).

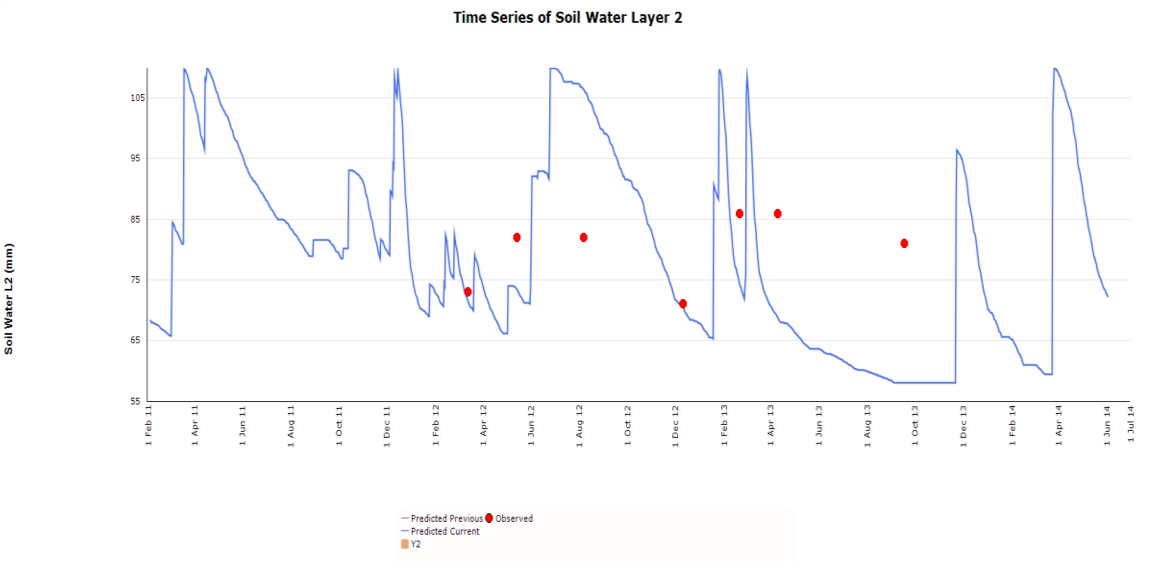
Calibrating the grass and legume model to measured soil waters was initially based on the grass only site. The relationships between observed and predicted were good at this site for top (L1) and middle (L2) soil layers (R^2 0.82, 0.87 respectively), with the worst relationship (R^2 0.46) occurring at L3 (Fig. 2).

Measured soil water for L3 only varied between 132 and 139 mm over the two years of sampling. The greatest differences between measured and predicted values for the three soil layers for the grass and legume site (Fig. 2) are as follows:

a) RSME = 2.79, ∑(x-y) = 3.25, R-squared = 0.76



b) RSME = 15.3, ∑(x-y) = 37.7, R-squared = 0.01



c) RSME = 14.8, ∑(x-y) = -11.1, R-squared = 0.11

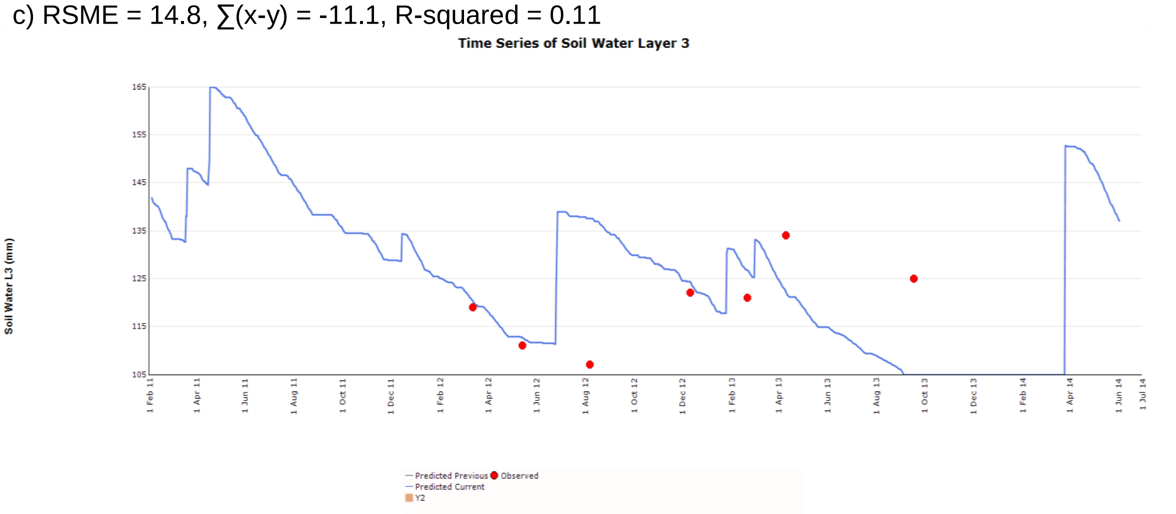
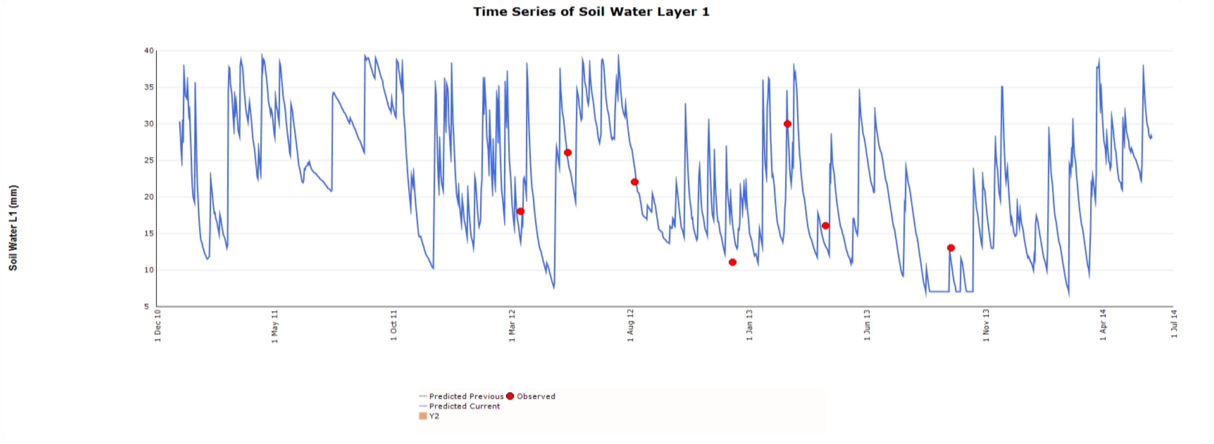


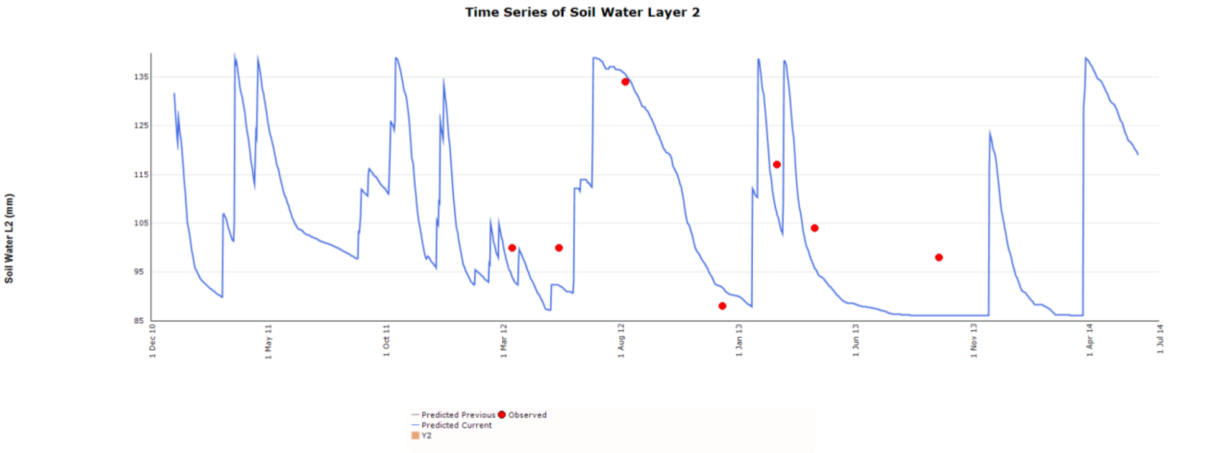
Figure 1 – Time series for calibrated grass only SWIFTSYND site soil water (observed red circles and predicted blue line) for a) L1 (0-10 cm), b) L2 (10-50 cm), c) L3 (50-100 cm). X axis December 2010 to July 2014. Y axis soil water mm. Linear regression statistics (R-squared,

root mean square error (RSME) and ∑ (x-y)) are provided.

a) RSME = 2.88, ∑(x-y) = 3.02, R-squared = 0.82



b) RSME = 7.82, ∑(x-y) = 38.6, R-squared = 0.87



c) RSME = 9.85, ∑(x-y) = 22.6, R-squared = 0.46

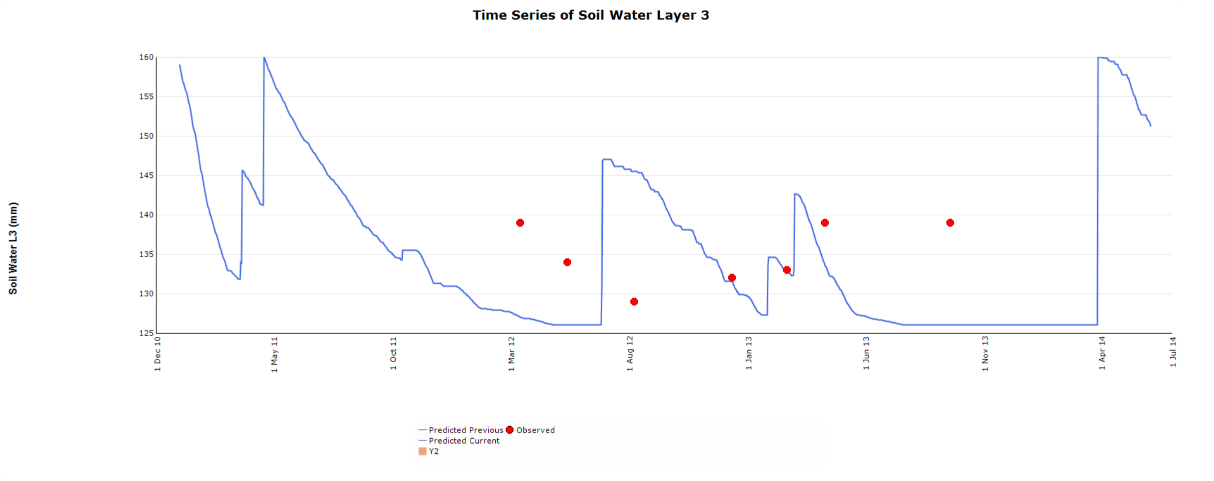


Figure 2 – Time series for calibrated grass and legume SWIFTSYND site soil water (observed red circles and predicted blue line) for a) L1 (0-10 cm), b) L2 (10-50 cm), c) L3 (50-100 cm). X axis December 2010 to July 2014. Y axis soil water mm. Linear regression statistics (R-squared, root mean square error (RSME) and ∑ (x-y)) are provided.

- Predicted soil water for the top 10cm (L1) was ~ 20% lower than the observed 18 mm (predicted 14 mm) on 14/3/12, 13 mm (predicted 11 mm) on 19/9/13 and 16 mm (predicted 13 mm) on 11/4/13.
- Predicted soil water for the top 10cm (L1) was ~30% higher than the observed 11 mm (predicted 16 mm) on 12/12/12 and only slightly higher than 22 mm (predicted 24 mm) on 8/8/12.
- Predicted soil water for L2 (10-50cm) was ~10% slightly lower than the observed on 14/3/12 (94 cf. 100 mm),14/5/12 (92 cf. 100 mm), 21/2/13 (105 cf. 117 mm), 11/4/13 (94 cf. 104 mm) and 19/9/13 (86 cf. 98 mm).
- Predicted soil water for L3 (50-100 cm) was ~5% lower than the observed on 14/3/12 (127 cf. 139 mm), 14/5/12 (126 cf. 134 mm), 11/4/13 (134 cf. 139 mm) and 19/9/13 (126 cf. 139 mm).
- Predicted soil water for L3 (50-100 cm) was ~13% higher (146 mm) than the observed soil water (129 mm) on **8/8/13**.

Possible explanations for these discrepancies between observed and predicted values at the grass only site include:

- Site specific potential root penetration problems resulting in unused soil water in L3
- Estimated rainfall distribution didn't capture the occurrence of rainfall at the site, underestimating rainfall (e.g. 14/3/12, 11/4/13,19/9/13) or overestimating rainfall (8/8/13).

10.7.2 Pasture production

Pasture structure, soil fertility and pasture nitrogen levels were calibrated using site measurements of plant height, and green cover to obtain green yield, and simulated N Yield TSDM and % N Yield TSDM relationships.

The height yield relationship is a measurement of the plant structure. This aspect of plant structure influences growth through the impact of vapour pressure deficit. The higher the vapour pressure deficit (highest at the soil surface and decreases with height) the lower the amount of growth produced per unit of transpiration. Estimated pasture height at 1000 kg/ha yield was 16.7 cm for the grass only site and 11.8 cm for the grass and legume pasture (Fig. 3). These pasture height yield relationships are within range of common values (10-20 cm) and indicate the contribution (~20% of total yield) of the taller *Bothriochloa bladhii* pasture (120cm) at the grass only site compared with the *Dichanthium sericeum* (70cm) dominated pasture at the grass and legume site.

GRASP uses two ways to estimate pasture growth: one method is based on grass basal area (GBA) and growth per unit basal area; and the other is transpiration by transpiration use efficiency. GRASP selects the maximum of the two estimates.

The first approach is often used at the start of the growing season when green cover is low and hence transpiration driven growth is also low. Perennial grass basal area was initially estimated from measurements obtained in July 2014 (3.7% grass only, 6.7% grass and legume). Potential regrowth rate kg/ha DM grown / unit basal area / days since start of the growing season (50 mm of rain over a two week period) was estimated from early growth measurements. The potential regrowth rate of the grass only site as estimated from site measurements was 12.95 kg/ha/day, a value commonly used for poor pastures. However, further calibration to “unusual” soil and pasture measurements resulted in very low, constrained pasture growth rate of 2.99 kg/ha/day. Conversely, the potential regrowth rate of the grass and legume site (22.5 kg/ha/day) was a similar value to that commonly used for a healthy and productive native pasture (20 kg/ha/day).

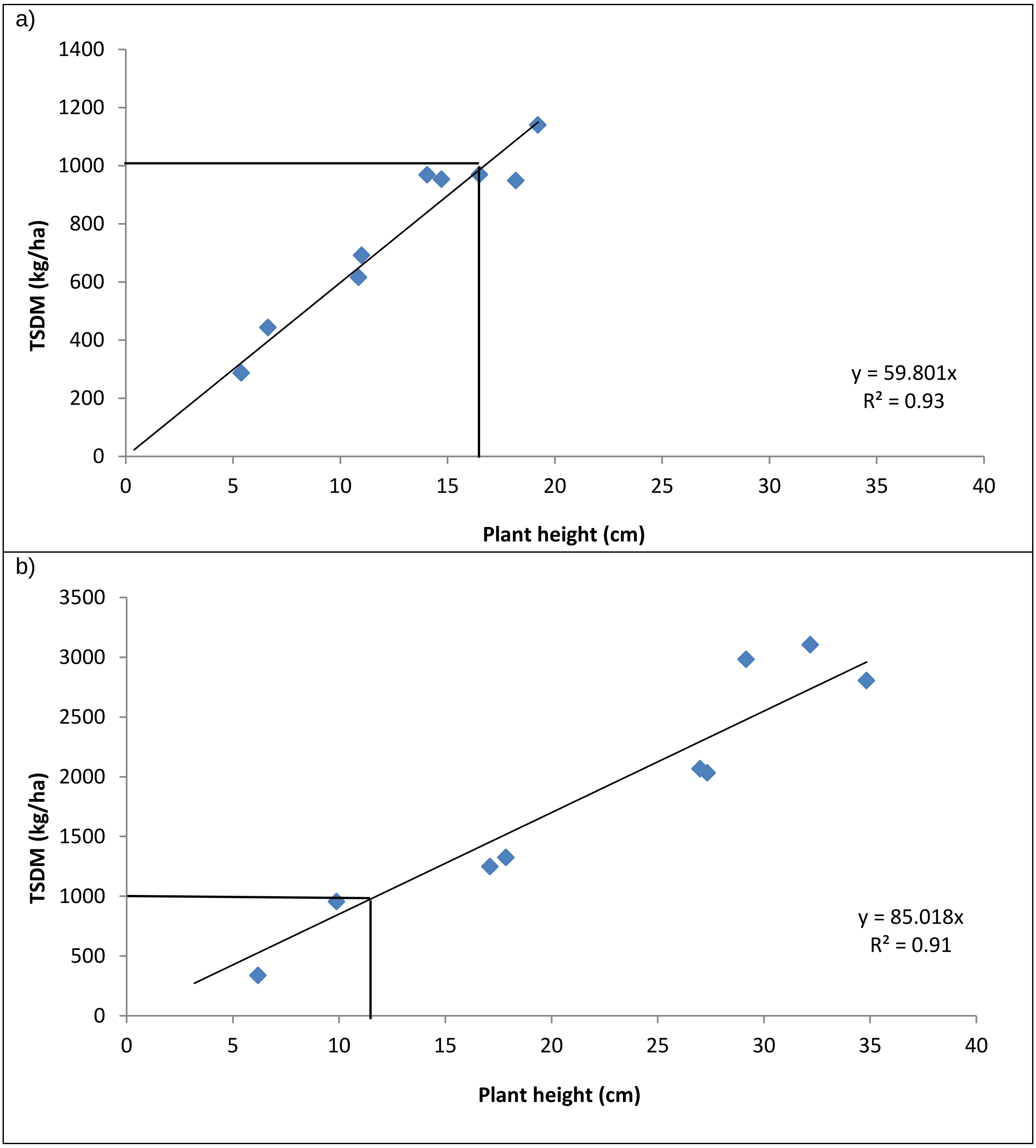


Figure 3 – Height yield relationship at Kookaburra a) grass only pasture and b) grass and legume pasture on cracking brigalow clay soil.

The green yield to green cover relationship allows determination of green yield at which both transpiration and radiation interception is 50%. Green cover (green biomass proportion of TSDM) was calculated from stem and leaf separated data collected in the second and third harvests each year. For the other four harvests, where there was no separation data, green yield was estimated as the proportion (from species composition observations) of total yield (Fig.4).

These relationships drive transpiration and radiation interception. The green yield to green cover relationship for both sites was only fair (R^2 0.38 grass only, R^2 0.48 grass and legume). Over the two years of sampling at the grass only site, green cover was not estimated to be more than 50%, and hence, it was necessary to extrapolate from the observed relationship to estimate the green yield parameter value. The estimated value for green yield at 50% green cover for grass only site was 575 kg/ha (R^2 0.38) and 1183 kg/ha for grass and legume site (R^2 0.48) (Fig. 4).

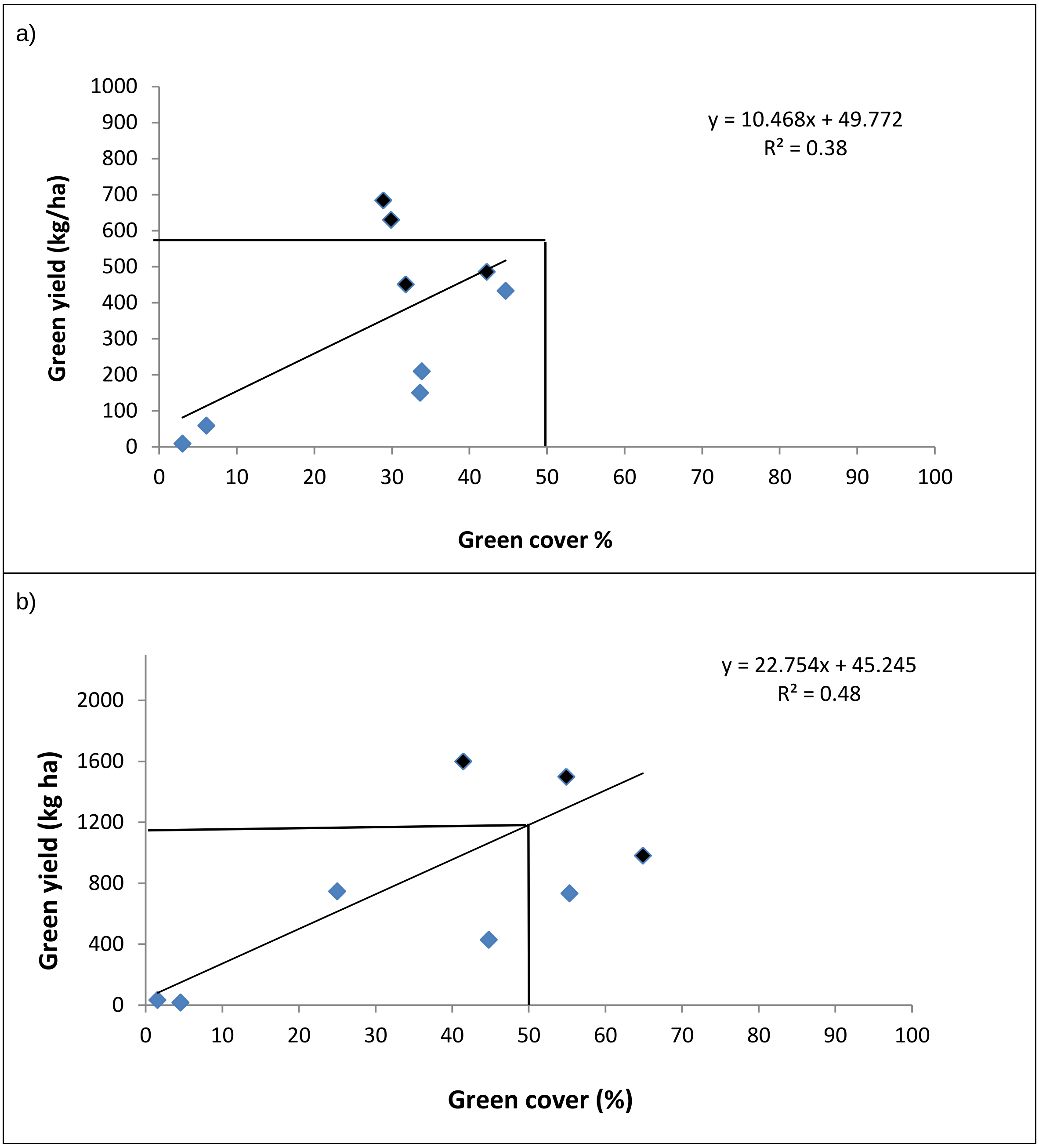


Figure 4 – Green yield and cover relationship at Kookaburra a) grass only pasture and b) grass and legume pasture on cracking brigalow clay soil. Green yield was calculated from stem and leaf separated data (black diamond) and estimated from total standing dry matter using observed green cover.

10.7.3 Soil fertility and pasture nitrogen levels

During the first growth period of the growing season (while accumulated transpiration is very low), an initial pulse of nitrogen is present in the dry matter. The initial nitrogen was estimated from % N and N yields (% N x standing dry matter) from 1st harvests for each year of sampling. This value was calibrated as 4.5 kg N/ha for the grass only site, and 3.7 kg N/ha for the grass and legume site. This initial pulse normally is ~2 to 5 kg N/ha and does not exceed 10 kg N/ha for tropical native pastures.

The more rapidly that nitrogen is mineralised the higher the value of N uptake per 100 mm transpiration. Values of 5 kg N/100 mm and 5.7 kg N/100mm were estimated for the grass only and grass and legume sites respectively. Common values are 5-6 kg N/100mm in southern Queensland.

Maximum N Uptake is an indication of the fertility of a site and can be estimated from harvest data that aligns with peak standing crop. Values of between 10-25 kg N/ha are common, with very fertile soils reaching up to 40 kg N/ha. A low value of 10 kg N/ha was calibrated for the grass only site, whilst 25 kg/ha was calibrated value for the grass and legume site.

The % N at zero growth was estimated from % N present at the end of a good/extended growing season when some green material is still present (Harvest 3). Typical values for average native pastures (C4 grasses) are between 0.45 and 0.68, whilst forbs and C3 plants often have higher values than C4 plants. Calibrated values of 0.65 was used both grass only and grass and legume sites.

A default value of 2.5% is used for the maximum N% in pasture. Higher values have been measured in fertilised sown pastures, but the application of GRASP in these cases has not been tested. 2.5%N is a common value observed at the start of the season in native grass dominated pastures. At and below this value, nitrogen is present in protein (rubisco) that initially fixes CO_2 in the leaf contributing to higher growth rates in younger, greener leaf than leaf with lower nitrogen content. The default value of 2.5% was used for both sites.

10.7.4 Best fit

Several key parameters that cannot be derived by direct calculation from SWIFTSYND data were estimated using best fit simulation approach. Transpiration efficiency (TUE), or the amount of dry matter produced per mm of water transpired, is a key parameter that drives pasture growth in GRASP and is related to general site fertility, the higher the value the more productive the site. For perennial pastures general TUE values are between 7-20 kg/ha/mm of water transpired. For the grass only and grass and legume sites the estimated value for TUE was 13.5 kg/ha/mm.

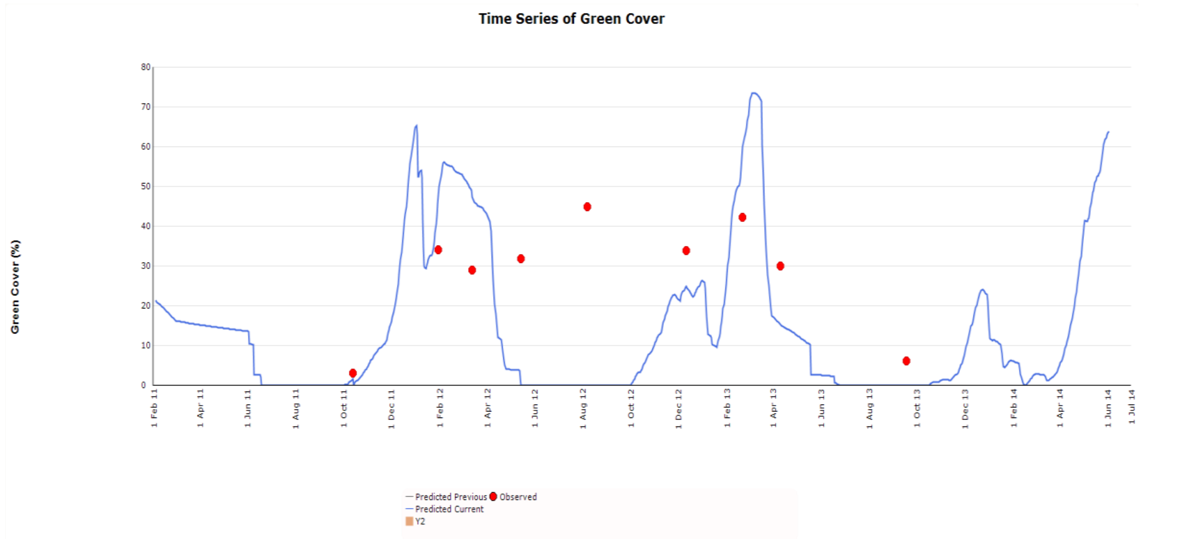
Observed pasture yield is the net result of growth and detachment. In general, detachment is greater when material is dry/dead. Detachment for forbs and annual grasses will generally be higher than perennial grasses. Detachment rates in SWIFTSYND sites tend to be very low because resets remove old plant material and there is little disturbance of plants from animals. Calibrated daily detachment rates for dry and wet seasons of 0.0001 & 0.0008 and 0.0001 & 0.0005 respectively were used for grass only and grass and legume pastures.

A soil water index at which above ground growth ceases is used to represent when plants (that are still green but have switched to root growth or maintenance mode) continue to use water although there is no net above ground assimilation. Values of 0.3-0.4 are commonly used for this soil water index. GRASP assumes that green canopy cover will be in equilibrium with available soil-water. The calibrated soil water index for maximum cover and cessation of above-ground were 0.4 & 0.2 respectively for grass only site, and 0.3 & 0.2 respectively for the grass and legume site.

At the grass only site, the highest level of green cover (45%) was measured during winter (8/8/12) of the first year where there had been a couple of rain events (20-30 mm) during June/July. The relationship between the predicted data and observed values of green cover was only poor (R^2 0.20) for grass only site only (Fig. 5), but there was reasonable agreement (R^2 0.62) between the predicted data and observed values of green cover at the grass and legume site (Fig. 5).

Calibration of both sites was undertaken whilst taking into consideration the impact of reset on pasture growth, low cover and grass basal area of grass only site compared with grass and legume site, and constant and narrow range of soil water in L2 (grass only) and L3 (grass and legume). In calibrating the models precedence was given to achieving the best possible relationships between predicted and measured data for N Yield TSDM and Standing Dry Matter (SDM). The calibrated grass only and grass and legume models achieved the best possible fit for N yield of TSDM (Fig. 6, R^2 0.78, R^2 0.46 respectively) and SDM (Fig. 8, R^2 0.78, R^2 0.89 respectively) although at both sites the resulting % N TSDM relationships were poor (Fig. 7 R^2 0.30, R^2 0.14 respectively).

a) RSME = 21.6, ∑(x-y) = 57.7, R-squared = 0.20



b) RSME = 21.4, ∑(x-y) = 148, R-squared = 0.62

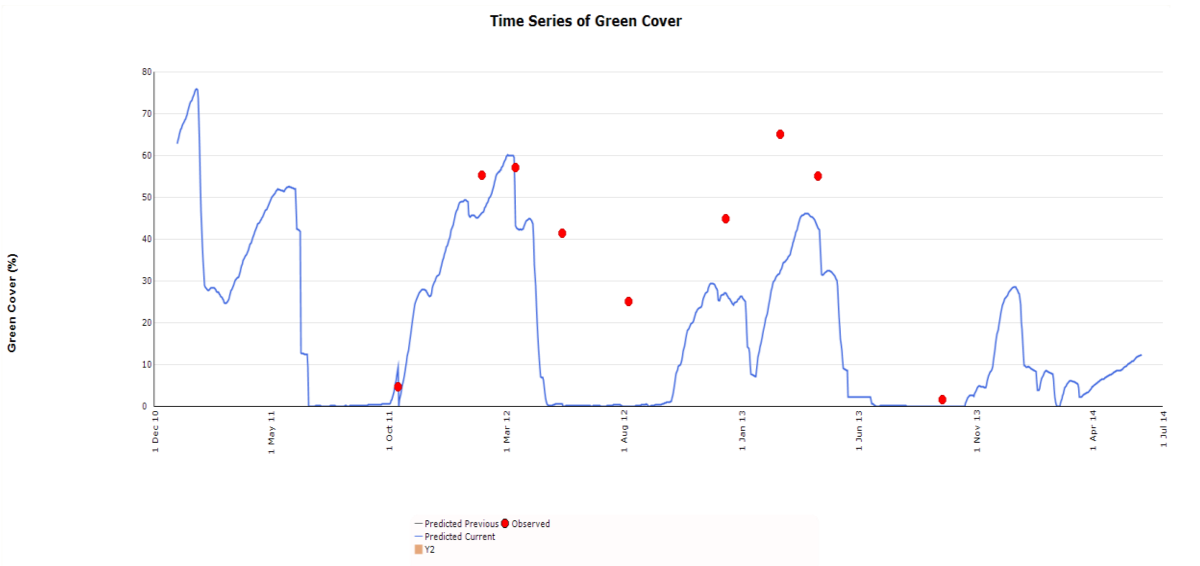
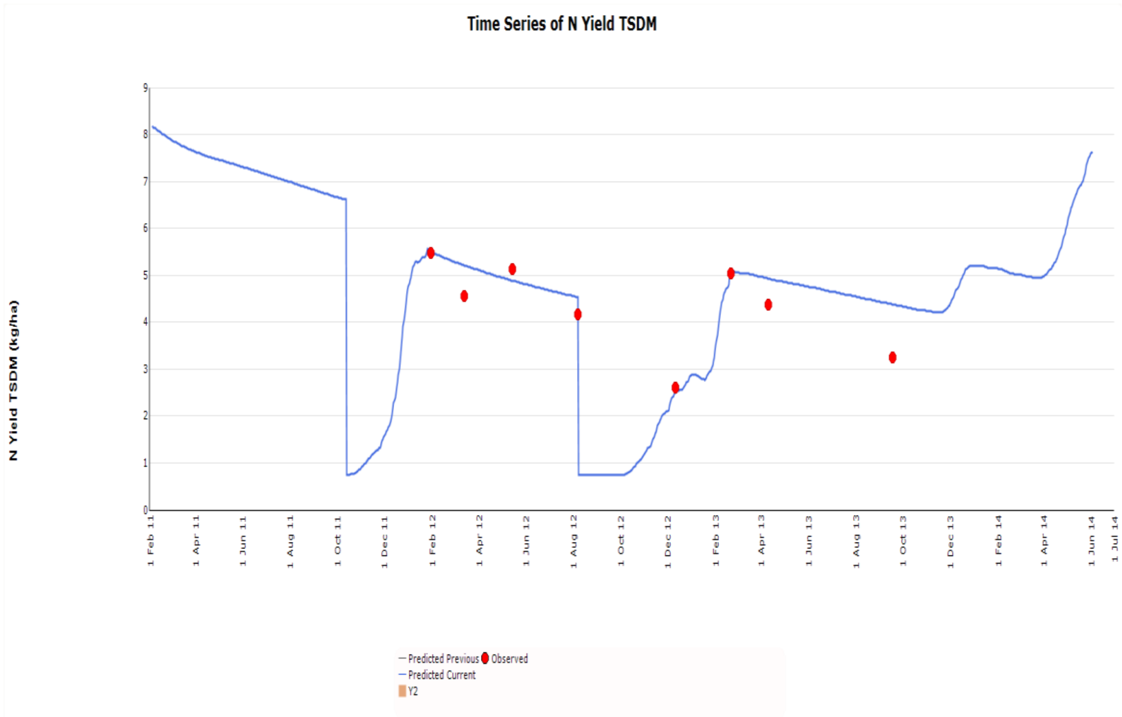


Figure 5 – Time series for calibrated a) grass and b) grass and legume SWIFTSYND site green cover (observed red circles and predicted blue line). X axis December 2010 to July 2014. Y axis green cover %. Linear regression statistics (R-squared, root mean square error (RSME) and ∑ (x-y)) are provided.

a) RSME = 0.53, ∑(x-y) = -2.47, R-squared = 0.78



b) RSME = 3.16, ∑(x-y) = 15.0, R-squared = 0.46

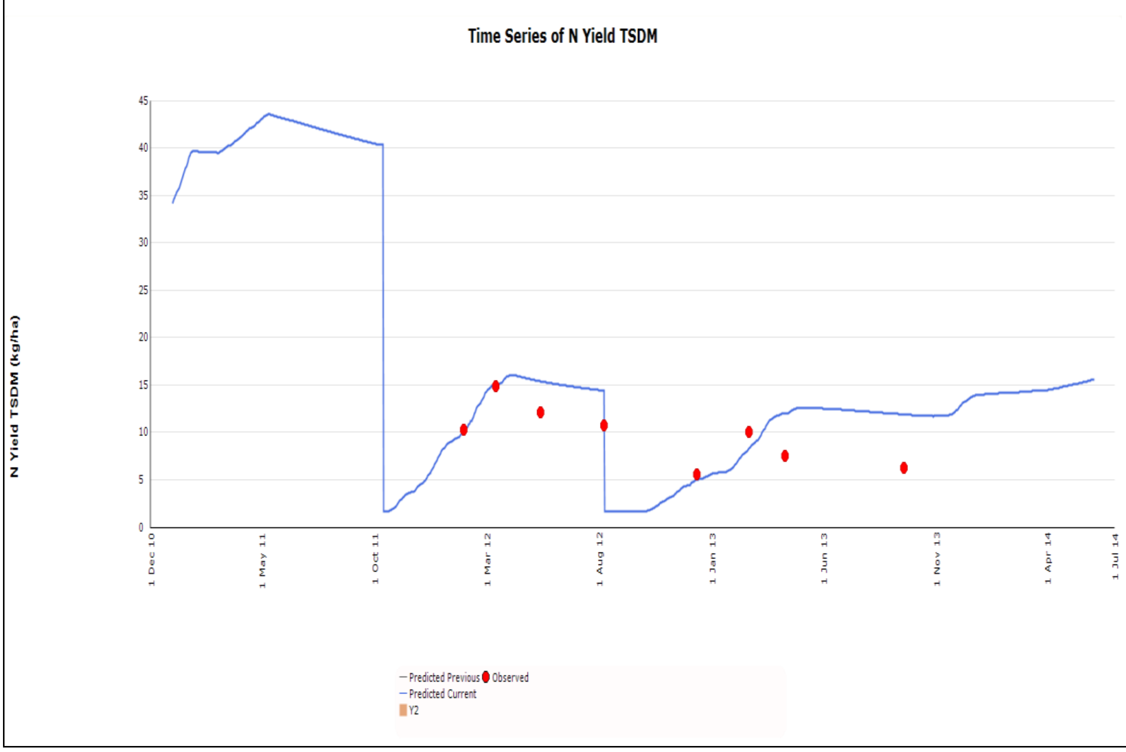
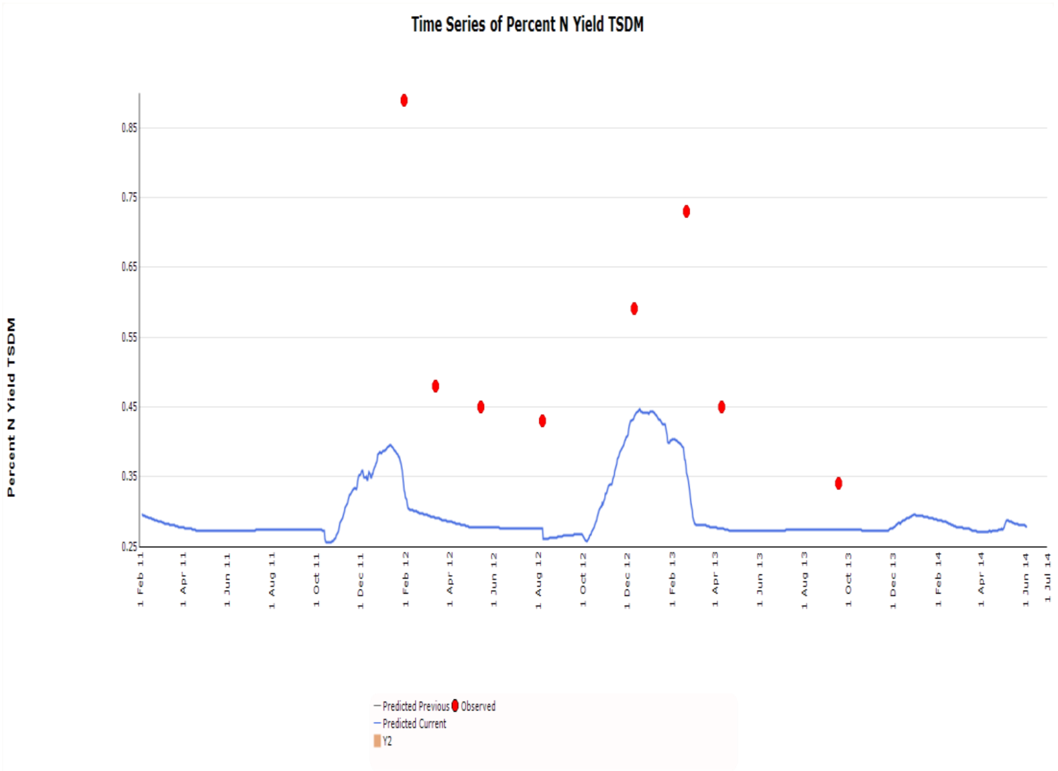


Figure 6 – Time series for calibrated a) grass and b) grass and legume SWIFTSYND site N Yield of TSDM (observed red circles and predicted blue line). X axis December 2010 to July 2014. Y axis N Yield TSDM kg/ha. Linear regression statistics (R-squared, root mean square error (RSME) and ∑ (x-y)) are provided.

a) RSME = 0.27, ∑(x-y) = 1.85, R-squared = 0.30



b) RSME = 0.20, ∑(x-y) = 0.19, R-squared = 0.14

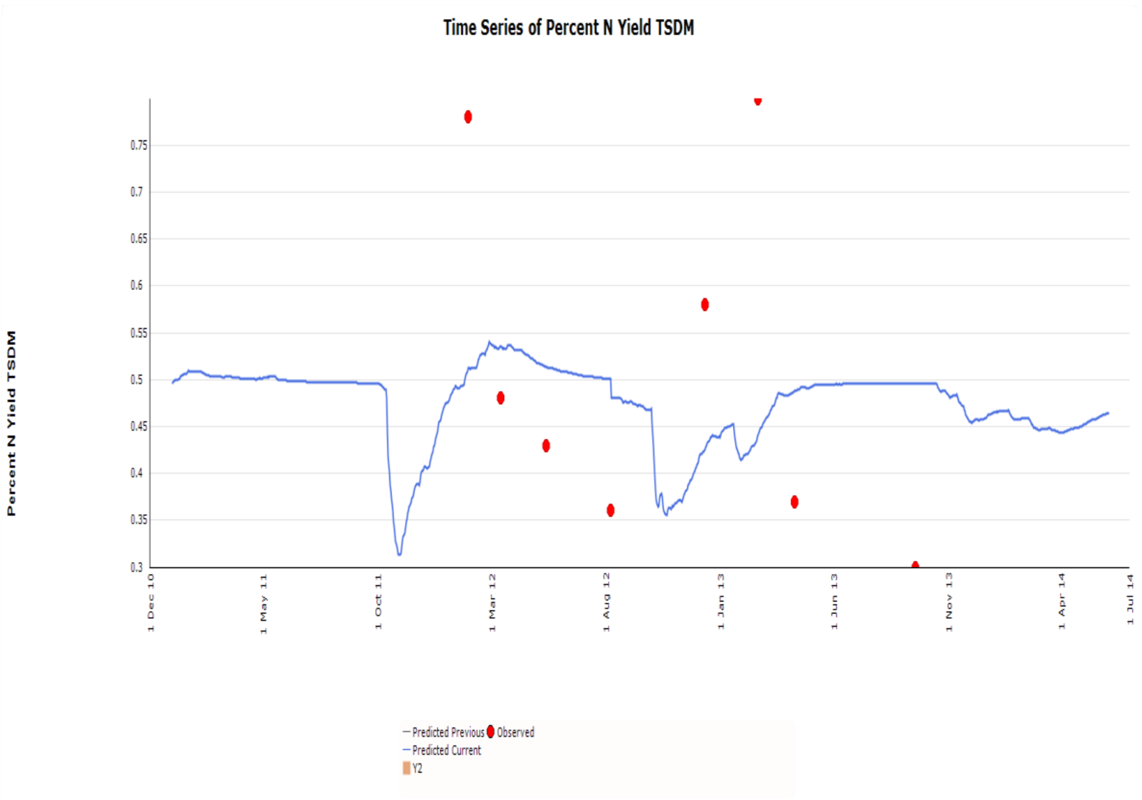
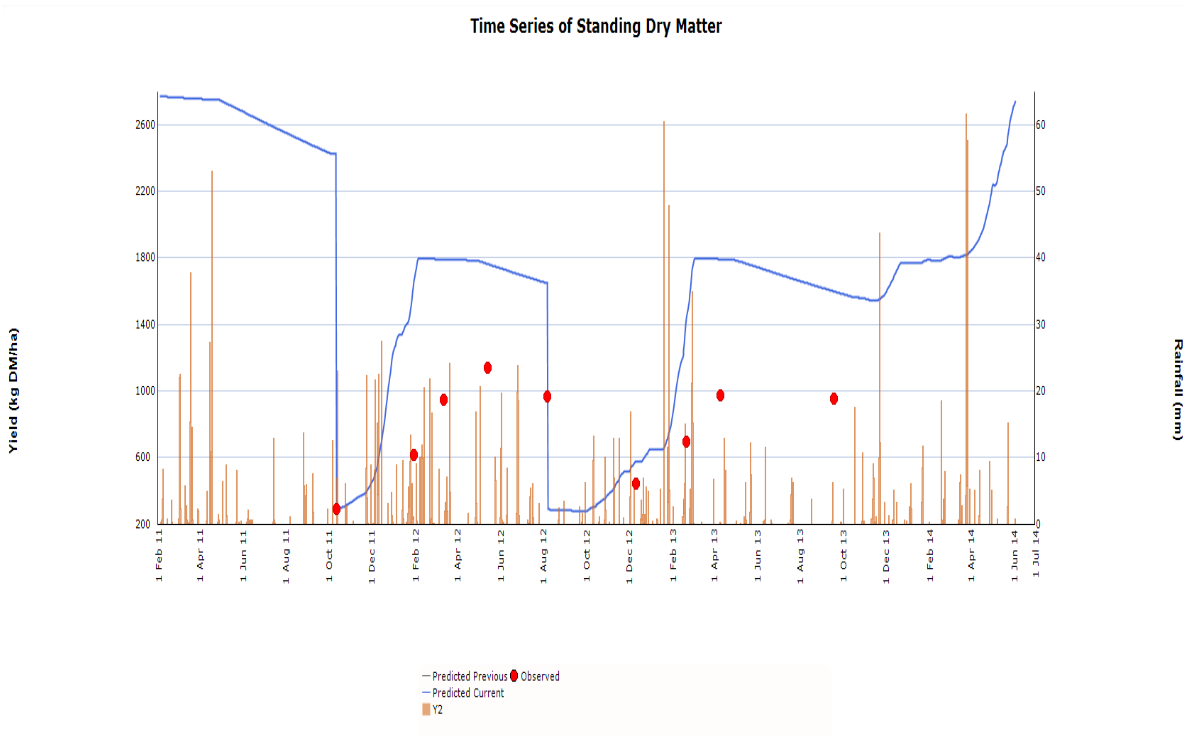


Figure 7 – Time series for calibrated a) grass and b) gras sand legume SWIFTSYND site N% of TSDM (observed red circles and predicted blue line). X axis December 2010 to July 2014. Y axis N% TSDM kg/ha. Linear regression statistics (R-squared, root mean square error (RSME) and ∑ (x-y)) are provided.

a) RSME = 692, ∑(x-y) = -5528, R-squared = 0.78



b) RSME = 384, ∑(x-y) = 2071, R-squared = 0.89

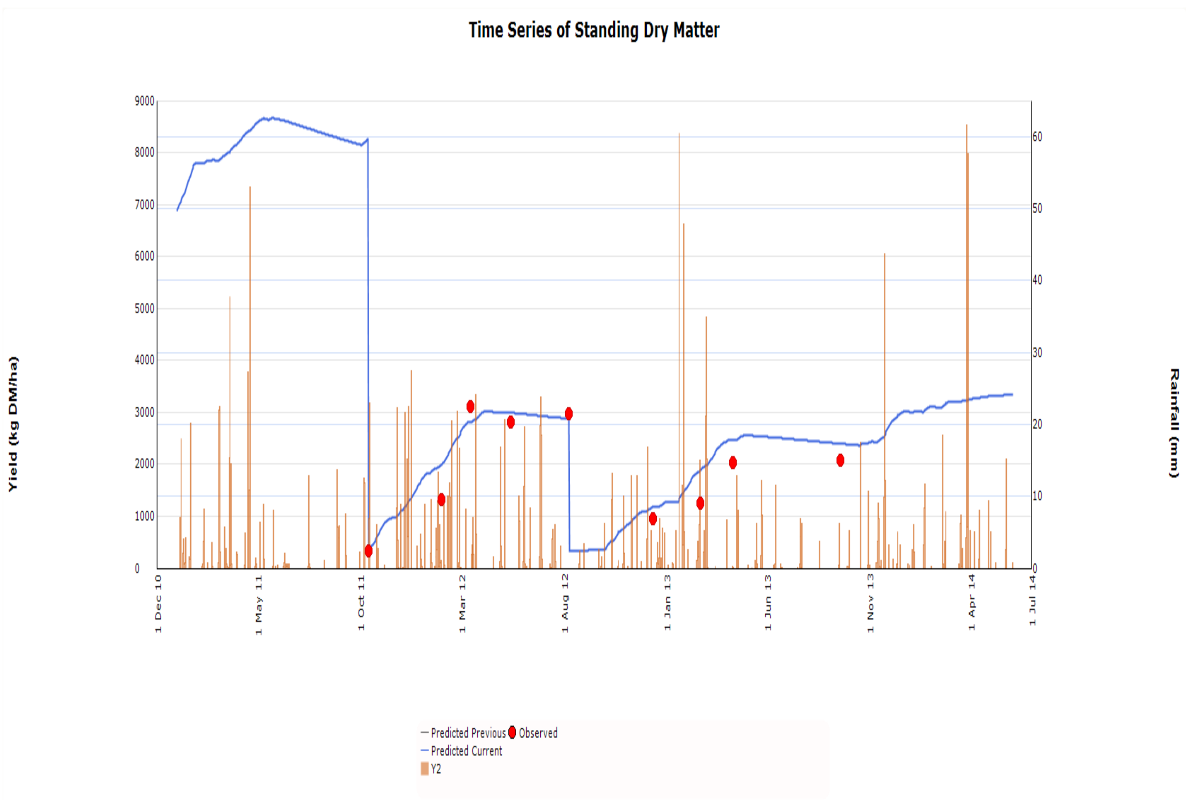


Figure 8 – Time series for calibrated a) grass and b) grass and legume SWIFTSYND site total standing dry matter (observed red circles and predicted blue line). X axis December 2010 to July 2014. Y axis total standing dry matter (TSDM) kg/ha. Rainfall (mm) also shown (orange bars). Linear regression statistics (R-squared, root mean square error (RSME) and ∑ (x-y)) are provided.