# Increasing Soil Carbon in Degraded Cropping and Grazing Land

AOTG Project Ref No: **AOTGR1-137**

## Final Report:

**Pasture measurements and bio-economic analyses to assess effects of climate, grazing pressure and pasture rundown on soil carbon and returns from legume-based sown pastures in the Condamine region of Southern Queensland.**

*By JF Clewett, Director and Principal Scientist, Agroclim Australia, April 2015*

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## Executive Summary: Key Findings and Their Significance

The Condamine catchment has been identified as a key area in Australia where there is potential to build soil carbon. There are approximately 1 million hectares of degraded crop and grazing lands in the region that could be potentially improved through establishment of sown pastures, particularly legume-based pastures that have capacity to add nitrogen, lift productivity and build soil carbon.

This document provides a final report on several sub-components for the Condamine Alliance project "*Increasing soil carbon in degraded cropping and grazing Land (AOTGR1-137)".* The overall objectives of this project were to measure, assess and communicate the impact and feasibility of practices for increasing soil carbon sequestration in cropping and grazing land in the Condamine catchment. Field studies from July 2012 to March 2015 at nine trial sites tested the value of returning crop land to pasture, renovation of pastures and the use of manure and inorganic fertilizer.

As part of the overall project, the objectives addressed in this report focus on bio-economic analyses to assess the value of sown pastures in the Condamine region in terms of their capacity to build soil carbon and provide significant economic benefits to industry. The influence of seasonal conditions, land type and management were considered. This included the effects of grazing pressure, manure, fertilizer and importantly the use of legumes. A sown pastures version of the GRASP grazing systems model was used to estimate the effects of season and management on pasture growth and condition, beef production, economic returns, soil carbon sequestration and green-house gas emissions. Nitrogen available for pasture growth was a key component of the model concerning effects of pasture rundown and the influence of legumes. Potential effects of other nutrient limitations particularly phosphorous were recognised but not included in simulation analyses. Soil tests and pasture measurements of net primary production from exclosures and pasture yield/composition from grazed paddocks at the trial sites were used to calibrate and test the modelling process.

The sub-tropical sub-humid inland climate of the Condamine region is favourable for growing sub-tropical grass-legume sown pastures in most years. The long-term average rainfall for the region is 672 mm. Weather conditions during the trial period were variable with several extended periods of hot and dry drought conditions; particularly in 2013 and 2014. The modelling and simulation studies were an important tool for overcoming the influences of climate variability on results, as well as reasonable inferences due to the short term duration of the project.

The mean observed value of soil carbon (0-30 cm) across all trial sites was 1.13%. Values ranged from 0.63 to 0.88 % carbon (31 to 35 t/ha) on light sandy soils of the Brigalow and Alluvial plains to an average of 1.68 % carbon (52 t/ha) for the black cracking clays of the Basalt uplands with some values up to 2.16%.

The mean annual growth of pastures across all sites, pastures, grazing pressures and climatic conditions was estimated to be 3076 kg/ha. This mean was substantially higher on the more fertile clay soils of the region's Basalt Uplands (3898 kg/ha) but lower on less fertile loam soils of Alluvial Plains (2648 kg/ha) and the sandstone derived soils of the Brigalow Uplands (2708 kg/ha).

The optimum commercial grazing pressure in terms of maximum economic return per hectare was estimated to be 25 to 30% utilisation of pasture growth and this was consistent across all trial sites and land types. Lower utilisation levels were estimated to increase live weight gains per head but this reduced overall economic returns. Higher utilisation levels increased short-term economic gain but were likely to cause detrimental effects on pasture condition if persistently used, and also reduce live weight gains per head. This led to lower gross margins and would ultimately lead to reduced soil carbon.

Use of legume-based sown pastures in the GRASP simulation experiments was estimated to maximise economic returns at all sites. At the optimum grazing pressure the mean gross margin across all sites of legume-based sown pasture was $78.60/ha compared to $44.50/ha and $40.50/ha respectively for sown grass pastures and native pasture.

Soil carbon sequestration rates were estimated from simulation modelling to be much higher in the first decade after planting a sown pasture than in later decades. This reflected changes in pasture productivity associated with pasture rundown and the progress of soil carbon levels towards new equilibrium conditions. In 50 year simulations (repeated for four different time periods at each site), the mean carbon sequestration of sown grass pastures for the first decade was 459 kg/ha/year compared with 10, 15 and -36 kg/ha/year over the last three decades. Grass-legume pastures had the highest carbon sequestration rates. They were estimated to sequester an average of 595 kg/ha/year for the first decade after sowing and 113 for the second decade. This was followed by an average of 32 kg/ha/year over the last three decades.

Cattle methane emissions were calculated on the basis of dry matter intake. Estimates from GRASP simulations showed that sown pastures should help to reduce green-house gas emissions because:

- the additional mean annual soil carbon sequestered by sown grass pastures (relative to native pasture) was 412 kg CO2e /ha and this was substantially more than the corresponding increase in methane emissions (58 kg CO2e/ha) due to higher stocking rates
- the difference was greater for sown grass-legume pastures. Legume-based sown pastures increased carbon sequestration relative to native pasture by 1411 kg CO2e /ha compared with the much lower increase in methane emissions of 127 kg CO2e /ha.

Nitrous oxide emissions as CO2e were estimated from legumes (due to nitrogen fixation) and from livestock urine and faeces due to increased stocking rate on sown pastures. These estimates were low in comparison to carbon sequestration and were lower than methane emissions.

Key messages communicated to producers at a series of field days in March 2015 were:

- Degraded crop and grazing lands are improved through establishment of legume-based pastures with bonus payoffs in production, carrying capacity, economic returns, and GHG emissions and sequestration rates.
- Sown pastures are usually most productive in the first few years after planting and then gradually decline in productivity (known as “pasture rundown” ) in the following years because of nutrient limitations mainly nitrogen
- Maintaining legumes in pastures increases soil nitrogen, pasture growth and cattle production.
- Legumes can help to offset pasture rundown.
- While droughts cause significant losses in some years, nitrogen is limiting in most years.
- Stocking rates should aim to utilise 25 to 30 % of pasture growth.
- Increased pasture production builds soil carbon which improves soil health.

The study has highlighted several concepts that include the following.

- Pasture rundown is a consistent feature of sown pastures in grazing systems and therefore needs to be taken into account in farm management planning processes and carbon sequestration rate calculations
- Legume contributions of nitrogen to foster additional grass growth were important at all sites to either offset or overcome the effects of pasture rundown. They enable production to plateau at a higher level than grass only pastures, which emphasises the importance of legumes in sown pastures.
- Legumes are a relatively minor cost when establishing a sown pasture but they contribute greatly to the profitability of sown pastures. This highlights the value of developing technologies to improve the reliability and resilience of agricultural practices to successfully establish and maintain palatable legume-based sown pastures.

Lucerne was demonstrated to be a highly successful legume for pastures on the heavier clay soils of the Condamine region, however, more summer active legumes might give additional benefits in the regions summer dominant rainfall climate. The summer growing legumes, shrubby stylos, particularly Caatinga stylo, desmanthus, Wynn cassia, fine-stem stylo and leucaena are options that should be considered.

The sown pastures version of the GRASP model has proved to be a useful tool in several ways. Firstly, it provided a mechanism to integrate information from the trial sites and elsewhere which was then used to interpolate and extrapolate data across sites, time periods and levels of output relevant to industry. Secondly, the simulation results are providing industry with information for discussion that would be otherwise not available, and thirdly GRASP and the sown pastures version of GRASP are providing a platform that may well be useful to other projects.

The Condamine Catchment is a highly productive agricultural region and this study has shown that it has the potential to significantly increase soil carbon over a large area with legume-based pastures. The region stands out as an area in Australia to continue work to demonstrate, test the value and seek adoption of sown pastures. Therefore it is recommended that further work be conducted in this field to work with the farming community in planned extension programs to demonstrate the advantages of legume-based pastures for increasing productivity, building soil carbon and improving economic returns. This work should integrate field studies, analyses and communications that emphasise farming practices that help to overcome risks including the risks that are linked with agronomy, grazing management, financial issues and climate variability.

The need for this work to continue is accentuated by the continuing rise of carbon dioxide levels in the atmosphere and resulting effects on rising global temperatures and increased climate variability, and also to clarify issues concerning the storage of carbon in soils as a greenhouse gas abatement strategy.

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# 1. Introduction

This document provides a final report on several components for the Condamine Alliance project *"Increasing soil carbon in degraded cropping and grazing land* (AOTGR1-137)".

Livestock grazing systems from sown pastures are integral to agriculture in the Condamine Catchment. The catchment has some 1.1 million ha of native and sown pastures and a further 0.9 million ha of cultivation (Richardson, 2014). Grain, cotton and beef are the region's main economic drivers. There are large areas of the catchment that were formerly used for dairy where use of supplements and high grazing pressures enabled high levels of milk production from pastures and forage crops. Consequently these lands are often in poor condition, low yielding and have depleted soil carbon reserves. Pasture rundown (Myers and Robbins 1991, Peck et al. 2011) is often linked with depletion of soil carbon. Tothill and Gillies (1992) in assessing the condition of pastures throughout northern Australia found that 50% of the Southern Queensland bluegrass and Brigalow pastures that dominate the Condamine catchment (Weston et al. 1981) were degraded through overgrazing and showing fertility decline. Walker and Weston (1990) estimated that 75 % of the Southern Brigalow and Queensland blue grass pastures were suitable for sown pasture development particularly with legumes. Although further research is needed, the technology for pasture improvement in the region is reasonably well known (Lloyd 2007, Lloyd et al. 2012, Peck et al. 2011) and thus a high proportion of the 1.2 million ha of pasture in the Condamine catchment could be potentially suitable for renovation to increase productivity.

The Condamine region was identified by Baldock et al. (2009) as being one of the areas in Australia with the highest potential capability for enhancing soil carbon content and had the most potential of all areas in Queensland (Figure 1.1a). In particular, they identified the catchment as having high levels of soil carbon depletion and importantly a high gains index so that changes in agricultural management practices could help to rebuild soil carbon levels. Significant areas of cultivated land of the region are described by farmers as being *"rundown"* or *"tired"* from declines in productivity due to erosion, nutrient losses and loss of soil organic matter. Using satellite imagery, cropping history and selecting for high clay content soils Richardson (2014) identified some 30 % (0.3 million ha) of cultivated land in the Condamine catchment as now marginal for cropping (Figure 1.1b). These lands could potentially be improved by establishing sown pastures, particularly legume-based pastures with capacity to add nitrogen and therefore lift productivity. When suitable pasture lands and those needing renovation are also included then the total catchment area suited to legume-based pastures approaches 1 million ha.

Rates of carbon sequestration are driven by several factors in grazing systems. The most important of these is pasture productivity as the primary input of carbon to the soil but also includes soil temperature, moisture, texture and cover as factors governing the soil carbon balance (Jenkinsen et al. 1990, Bell and Lawrence 2009, Eady et al. 2009, Sanderman et al. 2010). In broad terms, it is the effects of climate and agricultural practice (e.g. grazing pressure, land use change or choice of species) causing change in pasture productivity that is the main driver causing change in depletion or sequestration rates of soil carbon (Grace et al. 1998, Hill 2006, Eady et al. 2009). Most plant carbon entering the soil is rapidly lost again by decay processes as carbon dioxide with only a fraction remaining long-term.

Several challenges exist to farmers changing their agricultural practice to build soil carbon by renovating existing pastures or converting cultivated land to permanent pasture. This includes financial and social pressures, climatic risk and a lack of understanding of expected costs and returns.

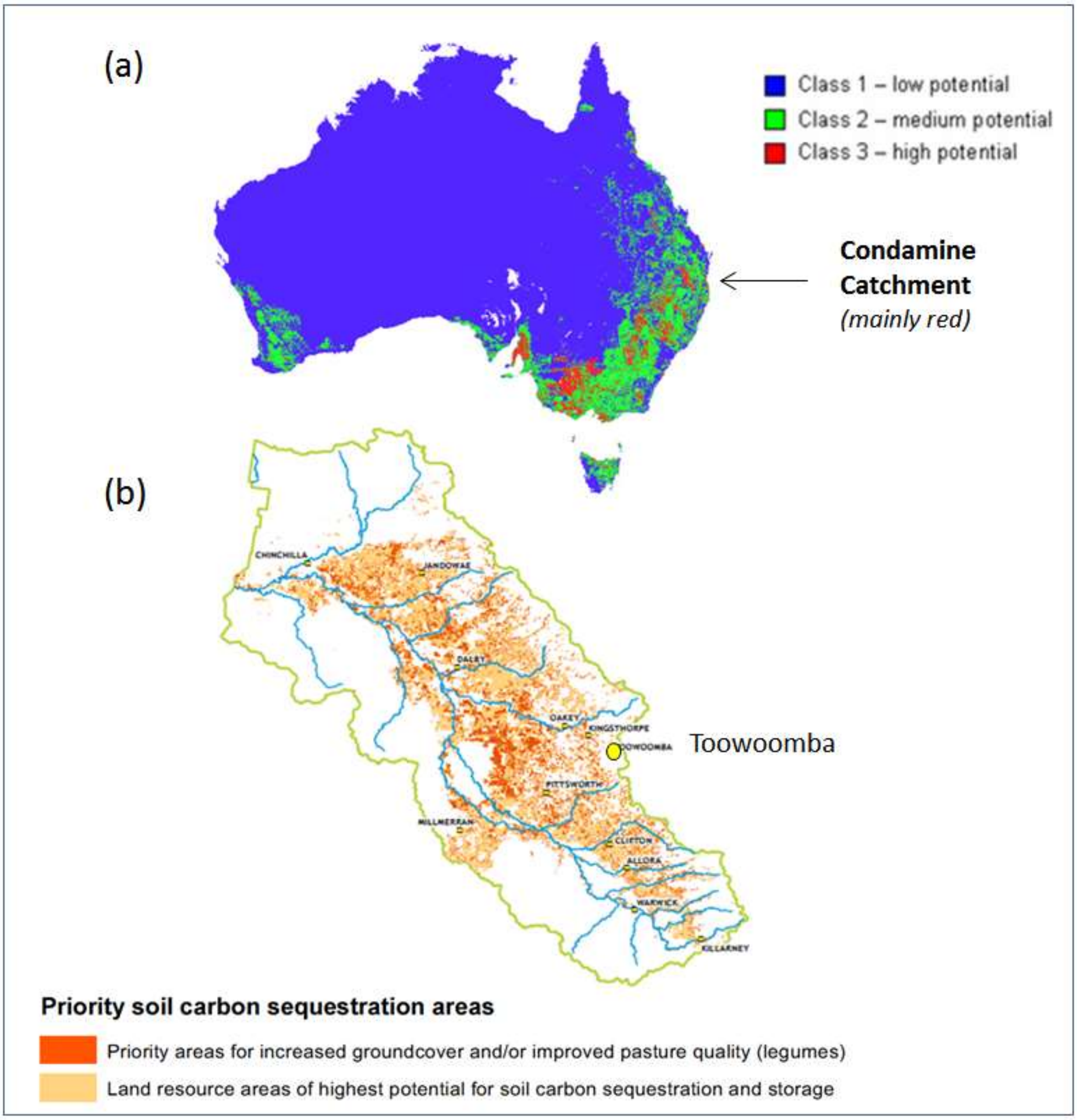


Figure 1.1 (a) Potential capability index for increasing soil carbon (source: Baldock et al. 2009) (b) Priority soil carbon sequestration areas in the Condamine Catchment for crops and leguminous based pastures based on satellite ground cover images (analysis restricted to high clay content soils, pasture condition not assessed) (source: Richardson 2014).

## 1.1. Objectives

The project's overall objective was to measure, assess and communicate the impact and feasibility of practices for increasing soil carbon sequestration in cropping and grazing land in the Condamine catchment. Field studies at nine trial sites tested the following management regimes from July 2012 to March 2015:

- returning marginal cropping land to pastures;
- grazing & pasture management; and,
- improving soil nutrition with manures and/or inorganic fertiliser.

As part of the overall project, the objectives addressed in this report are confined to and focus on:

1. the value of sown grass and grass-legume pastures in the Condamine region in terms of their capacity to build soil carbon and provide significant benefits to agricultural industry
2. the influence of seasonal conditions, land type and management (grazing pressure and use fertilizer and/or manure) on returns from sown grass and grass-legume pastures on: (a) pasture productivity and condition, (b) soil carbon sequestration rates, (c) cattle live weight gains, (d) economic returns, and (e) green-house gas emissions from fertilisers and livestock
3. Analysis of climatic conditions required to inform the above analyses
4. Pasture observations and soils data needed to support the analyses
5. Communication of results via field days, factsheets, conference proceedings and publications.

A series of 10 activities and 12 outputs were proposed in the project's operational plan. Several of these activities and outputs are within the scope of this report and are addressed in several sections as shown in Tables 1.1 and 1.2.

Table 1.1 Proposed activities for the overall project and those that are covered by this report

| Proposed Activity for Overall Project | Part of this report |
|---|---|
| 1. Development and submission of a project plan | No |
| 2. Identification and establishment of nine trial sites | No |
| 3. Undertake benchmarking activities at trial sites including identifying land use histories, mapping soil types and measuring soil carbon | No |
| 4. Ongoing monitoring, evaluation and reporting for trial sites including: measuring pastures for cover, pasture growth and biomass; measuring organic soil carbon levels; measuring and monitoring seasonal conditions; and pasture modelling and simulation | Yes (section 3) |
| 5. Evaluation of project data and reporting in terms of increased stored soil carbon for the practices trialled | Yes (section 4) |
| 6. Commencement and management of trials | No |
| 7. Ongoing monitoring, evaluation and reporting for trial sites re collection of data on yield, growth, fertiliser inputs, soil carbon and economic data associated with pasture management and climatic conditions, including data required for the GRASP pasture model | Yes (section 3) |
| 8. Ongoing monitoring, evaluation and reporting for trial sites re Collection and analysis of soil samples for soil carbon using procedures consistent with the Soil Carbon Research Program (SCaRP) | No |
| 9. Evaluation of project data and reporting of outcomes in terms increased carbon stored in soil, crop productivity and production costs for crop rotations trialled and | Yes (section 4) |
| 10. Raise the awareness of stakeholders and demonstrate the outcomes of the project through: (a) field days, workshops and farmer information sessions, (b) preparation and dissemination of media release and fact sheets, (c) dissemination and promotion via the Condamine Alliance website and industry newsletters and professional, peer-reviewed publications. | Partly (section 5) |

Table 1.2 Proposed outputs for the overall project and those that are covered by this report

| Proposed Project Output | Part of this report |
|---|---|
| 1. A peer reviewed final project report describing the on-farm practices trialled, the project methodology used, results and outcomes. | No |
| 2. Approved/agreed project plan to guide implementation (including monitoring, evaluation and communication components). | No |
| 3. Engaged networks of farmers in the targeted areas. | No |
| 4. Protocols for monitoring soils (including soil carbon); biomass (crops & pastures); weather (rainfall, temp, etc.); and management practices. | Partly (sections 2,3) |
| 5. 9 trial sites established and monitored to compare current and alternative management practices for impact on soil carbon. | No |
| 6. Records of the performance/impact of current and alternative management practices in relation to improving soil carbon. | No |
| 7. Records of relevant site data to inform analysis and modelling activities, including soil analysis results for sites over the life of the project. | Yes (section 3) |
| 8. Model and other analysis results to inform communication and reporting. | Yes (section 4) |
| 9. Records of project activities and landholder engagement, including targeted communication activities to support the achievement of project outcomes. | No |
| 10. Communication resources including: case studies, media releases, newsletter articles, information sheets, videos, photographs, etc. | Partly (section 5) |
| 11. Project evaluation data and information. | No |
| 12. Assessment of impact and feasibility of alternative practices for increasing soil carbon. | Yes (section 4) |

## 1.2. Description of Trial Sites and Management Regimes

The project's 9 trial sites were spread across the Condamine region with 3 sites in the eastern part of the catchment in the Clifton area, 3 central sites in the Bell/Jandowae area and 3 sites in the western part of the catchment in the Chinchilla area (see Figure 1.1). They covered a range of land types and soils with:

- Four sites on cracking clay soils of the Basalt Uplands with 3 sites in the Clifton district (*Colliery Park, Mirrabooka, and Parklyon) and* one pasture site in the Bell district at *Cattle Camp*
- One site on Brigalow plains clay soils in the Chinchilla district at *Oakleigh*
- Four sites on lighter soils with two of these sites on sandy loams of the Brigalow Uplands in the Bell/Jandowae district (*Oaklands and Roundview*), and two in the Chinchilla district with a pasture site on a hard setting clay loam alluvium (*Canimbla*), and one forage crop site on alluvium (*Leichardt Crossing*).

Soil tests for all trial sites (from David Hall, pers. comm.) are shown in Table 1.3

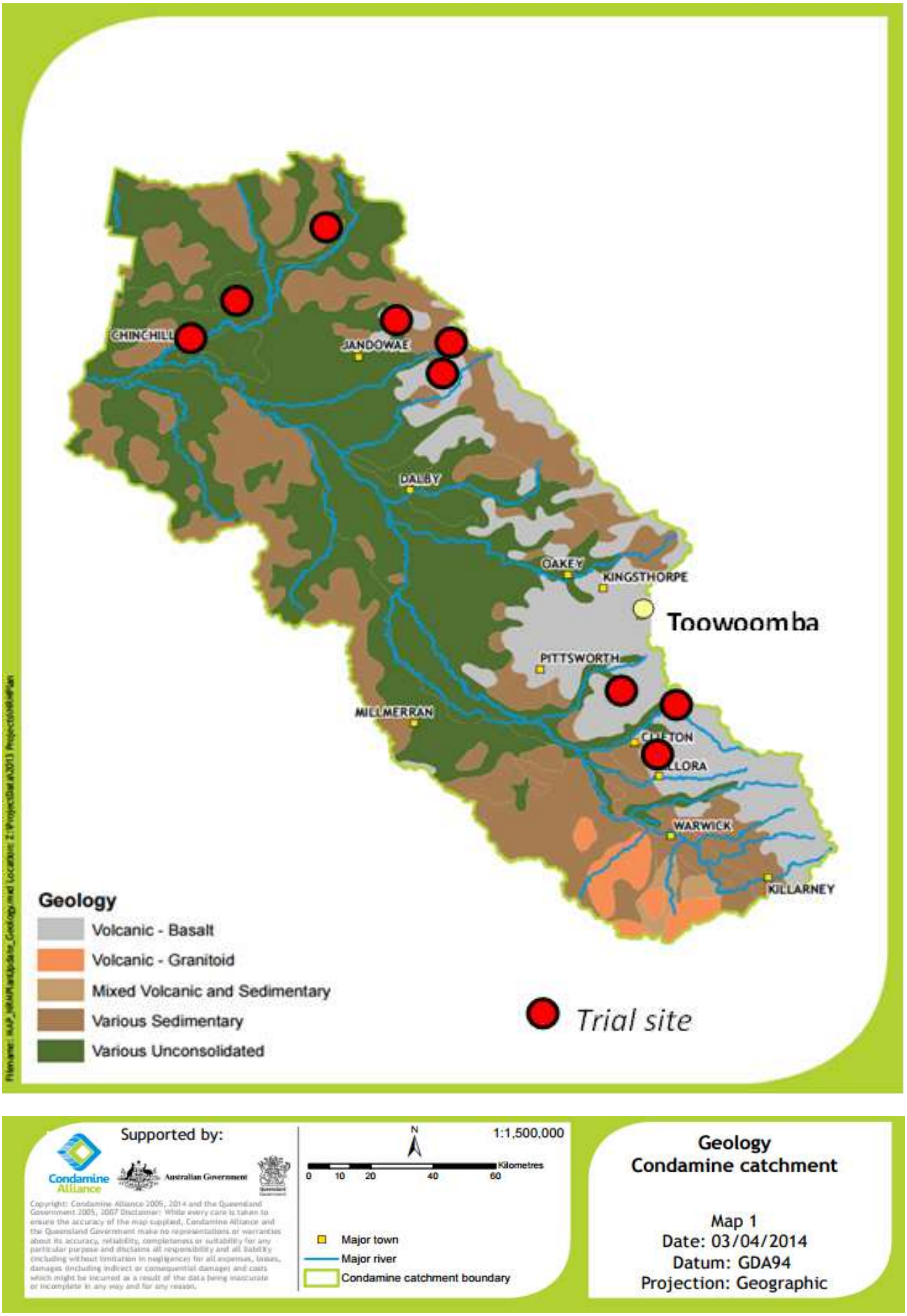


Figure 1.2 Trial site locations overlaid on geology map of Condamine Catchment. Condamine Alliance (2014)

While the following provides a brief description of the nine trial sites a more detailed description of soil types and their characteristics in the region can be obtained from land survey and field manuals for the region (Marshall (1988), Maher (1996), Harris et al. (1999) and Biggs (2001). Two sites were on land being converted from cultivation to legume-based permanent pastures. These were at:

- ***Colliery Park** (site 3)*-- Layton Free's beef and grain property at Clifton. This gently sloping 52 ha site with its coarse black cracking clay soils on the Basalt Uplands (*Charlton* soil type) had a long history of cultivation but limited soil depth and soil erosion restrict cropping. This site had two sown grass / legume pasture paddocks (one sown in 2007 and the other in 2012) that enabled useful comparisons, particularly in regards to pasture rundown. Both paddocks were successfully under-sown to oats using coated seed with several grasses at 10 kg/ha of coated seed (Rhodes, Gatton panic, Bissett creeping blue grass, Premier digit grass and bambatsi) and 1 kg/ha of Flaredale lucerne. Both pastures grew well and were rotationally grazed at high rates for short periods.
- **Oakland** (site 7) -- Sam and Kate Haig's beef and grain property at Jandowae. This 41 ha trial site on the Brigalow Uplands has lighter sandy loam and clay loam surface soils (Diamondy soil type) derived from sandstone and has been cropped consistently over the last decade for fodder, pulse and millet. This site trialled green manure crops to improve soil nitrogen and organic carbon prior to planting pasture. The green manure crops were incorporated back into the soil while green, not only as a source of nitrogen, but also organic matter for soil microbial organisms. Wooly pod vetches were sown with oats in June 2013. The original plan was to establish a permanent grass-legume pasture in January 2014, however, low rainfall prevented sowing and thus another forage crop (barley) was planted in the winter of 2014. The permanent pasture (Katambora Rhodes and Bissett creeping blue grass) was sown on 25 Feb 2015 as coated seed at 5.5 kg/ha and fertilized with Starter Z (an N,P,K, Zn mix) at 20 kg/ha (2.2 kg N/ha). The winter active woolly pod vetches had previously set a good crop of seed and are expected to persist in the sown pasture.

Five sites were established on sown and native pastures needing renovation. These were at:

- **Roundview** (site 9) -- John Walker's beef and grain property at Bell. This 32 ha site of undulating scrub soils (3-7% slope, brown sandy loam surface over sandy clay subsoil) on Brigalow Uplands derived Jurassic shales and sandstones was cultivated for wheat in the 1960's and 70's and then sown to pasture for dairy. The site was in C condition with green couch grass pasture with cotton bush, African boxthorn and a range of broadleaf weeds. The trial site had two paddocks; control and treated. The grazing management in use before the trial was continued on the control paddock of 22 ha. The treated paddock of 10 ha was chisel ploughed in Jan 2013 and subsequently sown to a short–term leguminous cover crop of Dolichos lab lab. The plan was to sow a permanent pasture in Jan 2014 but because of dry weather it was not sown till Dec 2014 when leucaena was established. It was performing well in March 2015 and the intention was to establish sown grasses with the leucaena in Jan 2016.
- ***Cattle Camp*** (site 8) -- Harry and Judy Pickering's beef property at Bell. This 20 ha site with coarse black cracking clay soils on the Basalt Uplands (*Charlton* soil type) was cleared in the 1950's and cultivated until 2007 when permanent grass pastures were successfully established. This trial is on sloping land (7%), is fenced into six contour bays and is rotationally grazed with some 30 other paddocks in the grazing system. This site had 2 reps of 3 treatments. There were two control bays of sown grass pasture (Rhodes, bambatsi, Premier digit, Bissett creeping

blue, Floren creeping blue and purple pigeon) established in 2007. The treatments were: (a) sod-seeded lucerne in two bays in January 2013 at 3 kg/ha, and (b) poultry manure applied at 6 t/ha (3.5% N) in December 2012 in the other two bays. The Lucerne was successfully established and maintained in the pasture but the manure seemed to have little effect. Grazing pressure on each bay was recorded. Live weight gains of cattle were recorded in 2013 and 2014.

- ***Mirrabooka*** *(site 2)* -- Don Vernon's beef and grain property at Clifton. This steeply sloping black soil site of 40 ha on the Basalt Uplands on *Kenmuir* and *Charlton* soils (upper and lower slopes) is in C condition and is the only timbered native pasture paddock in the trial. The trees (mainly silver leafed ironbark) are mature, scattered and have an average basal area of 2 to 3 $m^2$/ha. Pasture species included Pitted bluegrass, windmill grass and Queensland bluegrass and the native legume Glycine. This site tested direct drilling of legumes into the native pasture on half the area using a broad range pasture mix that included clovers, medic, woolly pod vetch and Lucerne. Establishment of the legumes was very poor. Both halves of the trial site were grazed as one unit with high grazing pressures in the first two years of the trial but were destocked in mid-2014 until March 2015 to enable pasture recovery.
- ***Canimbla*** *(site 4)* -- Roger Boshammer's beef and grain property at Chinchilla. This 120 ha site on texture contrast hard-setting alluvial soils (*Nudley* soil type) of Charley's creek was cultivated for wheat until 2007 and then converted to pasture (buffel, Rhodes, sabi grass). This site tested the use of a band-seeder to: (a) spray narrow strips (0.5m wide) of the existing pasture with Glyphosate at 2L/ha, (b) apply fertilizer (4.5 and kg/ha of N and P), and (c) in the same operation direct-drill a grass legume pasture mix of Premier digit, Bissett creeping blue grasses and woolly pod vetch, Wynn cassia, Desmanthus and fine-stem stylo legumes. The band-seeding was not very successful on this occasion because of seasonal conditions and ineffective control of the existing pasture. Half the paddock was sown and the paddock was grazed as one unit.
- ***Oakleigh*** (site 6) -- Trevor Ford's beef property at Chinchilla. This 24 ha site of two paddocks on grey clay Brigalow plains (*Kapunn* soil type) was cultivated until 2003 and then converted to pasture. Several grasses were sown across the trial site including Rhodes, Digit, bambatsi, Bissett creeping blue. Management of one paddock was held constant (control paddock) while part of the other paddock was slashed and fertilised with 103 kg/ha of nitrogen and 16 kg/ha of phosphorus in December 2012. Rapid pasture growth resulted and it was then cut for hay in March 2013. Both paddocks were rotationally grazed.

Two further trial sites were based on grain and forage cropping enterprises at:

- ***Parklyon*** (grain crops) (site 1) -- Pat and Liam Lyons' dairy and grain property near Clifton. A 50 ha grain paddock under continuous zero till cultivation for 10 years was split with half continuing to grow grain (wheat/sorghum) and the other half testing use of legumes (mung beans) and applications of poultry manure in the crop rotation. The control and treated ends of this paddock are very different and produced large differences in crop yield.
- ***Leichhardt Crossing*** (forage crops) (site 5) -- David Fuller's beef property near Chinchilla. This 20 ha site on the flood plain of the Condamine River (deep sand, *Davy* soil type) tested benefits of applying inorganic fertiliser to forage crops for beef production. Forages included pearl millet / Caloona cow peas in summer and oats in winter.

Further details of the trial sites and treatments are given in the Project Plan (Condamine Alliance 2012).

Table 1.3 Soil test results for 0-30 cm layer for all trial sites in October 2012 and April 2014 (source: David Hall pers. comm.). Soil samples were taken from 0-10, 10-20 and 20-30 cm. Data shown are the means from these depths. Bulk density was calculated for each layer from 2014 soil texture data. Percent total N and percent total P are the means for 2012 and 2014.

| **Site** | **Paddock** | **Soil Texture** | **Bulk Density** (g/cc) | **Mean Total** % N | **Mean Total** % P | **Soil Carbon** % C Oct 2012 | % C April 2014 | Mean % C | Total (t/ha) |
|---|---|---|---|---|---|---|---|---|---|
| **Colliery Park** | 2012 Plant | Silty clay | | 0.12 | 0.09 | 1.55 | 1.79 | 1.67 | 51.6 |
| | 2007 Plant | Silty clay | | 0.11 | 0.07 | 1.10 | 1.97 | 1.54 | 47.4 |
| | **Mean** | | **1.03** | **0.12** | **0.08** | **1.33** | **1.88** | **1.60** | **49.5** |
| **Mirrabooka** | Control | silty clay | | 0.11 | 0.10 | 1.45 | 1.58 | 1.51 | 47.6 |
| | +legumes | silty clay | | 0.12 | 0.13 | 1.73 | 0.99 | 1.36 | 42.4 |
| | **Mean** | | **1.04** | **0.11** | **0.11** | **1.59** | **1.28** | **1.44** | **44.8** |
| **Parklyon** | Manure | silty clay | | 0.14 | 0.05 | 2.17 | 2.41 | 2.29 | 71.3 |
| | Control | silty clay | | 0.13 | 0.05 | 1.70 | 0.94 | 1.32 | 41.2 |
| | **Mean** | | **1.04** | **0.14** | **0.05** | **1.93** | **1.67** | **1.80** | **56.3** |
| **Canimbla** | Control | Sandy clay loam | | 0.07 | 0.02 | 0.74 | 0.98 | 0.86 | 39.5 |
| | Band seeded | Sandy clay loam | | 0.07 | 0.01 | 0.67 | 0.92 | 0.80 | 36.5 |
| | **Mean** | | **1.53** | **0.07** | **0.01** | **0.71** | **0.95** | **0.83** | **38.0** |
| **Oakleigh** | Control | Sandy clay | | 0.05 | 0.01 | 0.61 | 0.80 | 0.71 | 33.0 |
| | +N Paddock | Sandy clay | | 0.06 | 0.01 | 0.62 | 0.97 | 0.79 | 37.1 |
| | **Mean** | | **1.56** | **0.06** | **0.01** | **0.62** | **0.88** | **0.75** | **35.1** |
| **Leichardt** | Field 1 | Fine Sandy Clay Loam | | 0.08 | 0.03 | 0.56 | 0.94 | 0.75 | 37.6 |
| **Crossing** | Field 2 | Fine Sandy Clay Loam | | 0.03 | 0.01 | 0.25 | 0.48 | 0.36 | 18.2 |
| | **Mean** | | **1.68** | **0.05** | **0.02** | **0.40** | **0.71** | **0.55** | **27.9** |
| **Cattle Camp** | Control | silty clay | | 0.16 | 0.14 | | 1.83 | 1.83 | 60.3 |
| | + Legume | silty clay | | 0.16 | 0.08 | 1.70 | 2.16 | 1.93 | 63.7 |
| | + Manure | silty clay | | 0.14 | 0.10 | 1.47 | 1.90 | 1.69 | 55.6 |
| | **Mean** | | **1.10** | **0.15** | **0.09** | **1.58** | **2.03** | **1.81** | **59.6** |
| **Roundview** | Control | sandy loam | | 0.08 | 0.05 | 0.67 | 0.73 | 0.70 | 33.0 |
| | +legume | sandy loam | | 0.07 | 0.04 | 0.60 | 0.74 | 0.67 | 33.0 |
| | **Mean** | | **1.61** | **0.08** | **0.04** | **0.64** | **0.73** | **0.69** | **33.0** |
| **Oakland** | East side | sandy clay loam | | 0.05 | 0.03 | 0.50 | 0.74 | 0.62 | 31.2 |
| | West side | sandy clay loam | | 0.05 | 0.03 | 0.71 | 0.51 | 0.61 | 30.7 |
| | **Mean** | | **1.68** | **0.05** | **0.03** | **0.60** | **0.63** | **0.61** | **31.0** |

# 2. Analyses of Climate data and Weather Observations

## 2.1. Introduction and Methods

Weather data at each trial site was required to assess environmental conditions during the trial period and to enable the trial results to be extrapolated to other seasons, locations and over longer periods of time using the GRASP model. Weather records were obtained from two main sources.

Firstly, long-term historical records for each site were obtained by downloading interpolated Bureau of Meteorology weather records from the SILO website (www.longpaddock.qld.gov.au/silo/)( Jeffries et al. 2001). The method provides gridded sets of interpolated weather data from the Bureau of Meteorology for a latitude and longitude of the user's choice. The grid size is 0.05 * 0.05 degrees and is updated daily. This enables access to estimates of daily weather data within 3 km of the trial paddocks and provides estimates of daily data over the past century for rainfall, temperature (max, min), vapour pressure (9am and 3pm), solar radiation and pan evaporation.

Secondly, weather data during the trial period was recorded at each site using automatic weather stations that measure rainfall, rainfall intensity and daily maximum, minimum and mean temperatures. Software was developed to check and join this data with the SILO data for input to the biophysical and economic analysis, however, for reasons described below this data was not used in analyses. Daily rainfall totals from nearby farm houses were used as a backup and for error checks on the automatic weather stations.

The Rainman StreamFlow package (Clewett *et al.* 2003) was used to assess characteristics of both the long-term historical weather data and weather conditions recorded during the trial period. This included analysis of daily, seasonal and annual data in relation to rainfall, temperatures (including frost) and estimates of evaporation. Comparisons between the 9 sites and additional stations (e.g. Chinchilla, Jandowae, Bell and Clifton) across the Condamine Catchment were made.

## 2.2. Long-term Climate

The Condamine Region has a sub-tropical sub-humid inland climate that is favourable for growing sub-tropical grass-legume sown pastures in most years. The long-term average rainfall for the region is 672 per annum and is summer dominant with 39% in summer months (December – February) and 18% in winter months (June-August). Mean minimum and maximum temperatures in summer are 17.3 and 30.3 deg C respectively, and in winter 4.4 and 18.8 deg C respectively.

Monthly and annual rainfall variability is high at all locations across the Condamine region as shown by the example in Figure 2.1 and this has significant influence on sown pastures particularly during the establishment phase. High variability of rainfall is due in part to the influence of ENSO (El Nino / Southern Oscillation) (Clewett and Clarkson 2007). For example, median rainfall of 672 mm for the region drops to 569 mm during El Nino years when the average SOI is below minus five but increases to 798 mm during La Nina years when the average SOI is above plus five. The five-year mean average rainfall for the Condamine region varies from 532 mm (from July 2000 to Jun 2005) to 793 mm (from July 1953 to June 1958). The driest and wettest 15 year periods were 1909-23 and 1954-68. This variation has significant effects on pasture productivity, economic returns and estimated rates of soil carbon sequestration.

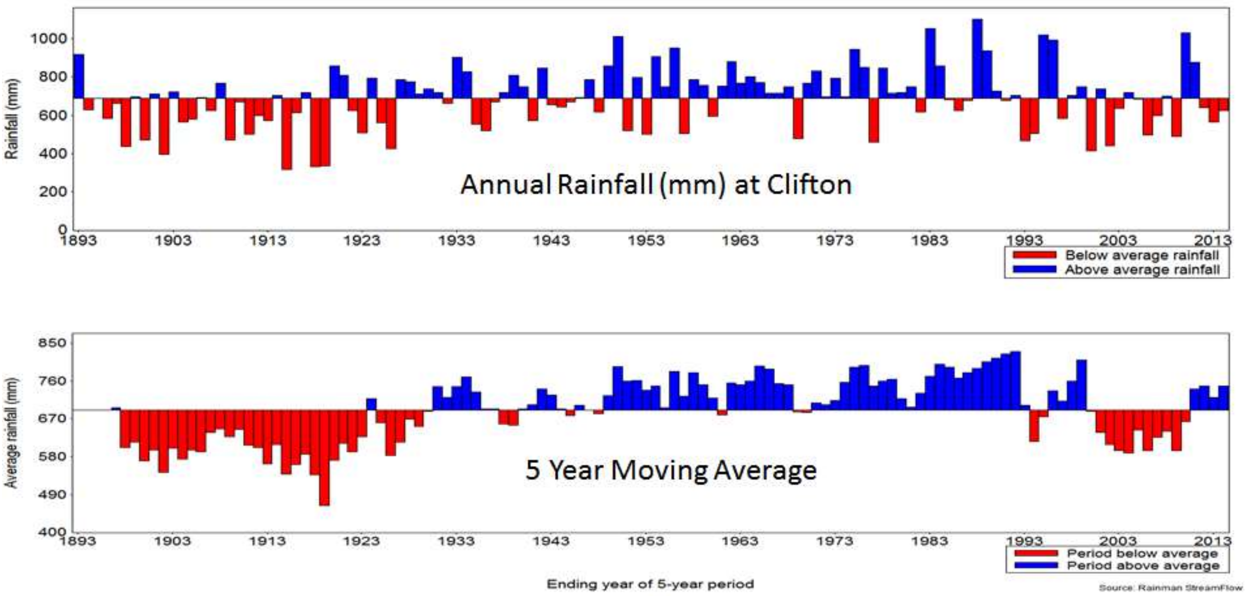


Figure 2.1 Example of rainfall variability in the Condamine region: (a) departure of annual rainfall from the long-term mean annual rainfall (690 mm for the period 1893 to 2014) at Clifton Post Office (upper diagram), and (b) departure of five year moving average of annual rainfall from the long-term mean (lower diagram) *(Source: Rainman Streamflow (Clewett et al. 2003) with updated data)*.

Weather conditions are usually more variable and arid in the north western plains area of the region and a little milder and less variable in the upland areas to the north of Bell and in the south east. Rainfall is higher but temperatures, evaporation and vapour pressure deficit are lower (Table 2.1).

Table 2.1 Long-term mean annual rainfall, temperatures and other climatic variables at the Project's 9 trial sites including vapour pressure (VP) deficit. (Data from the SILO Data Drill for the period 1 July 1894 to 30 June 2013).

| Site | Rainfall (mm/yr) | Max Temp (Deg C) | Min Temp (Deg C) | Pan Evap (mm/day) | Solar Radn (MJ/m$^2$/day) | VP Deficit (hPa) |
|---|---|---|---|---|---|---|
| **Western Sites** (Chinchilla area) | | | | | | |
| Leichardt Crossing | 640 | 27.0 | 12.1 | 5.2 | 19.6 | 16.9 |
| Canimbla | 618 | 26.8 | 12.1 | 5.2 | 19.5 | 16.6 |
| Oakleigh | 643 | 26.2 | 12.1 | 5.1 | 19.3 | 15.6 |
| **Central Sites** (Bell Jandowae area) | | | | | | |
| Oaklands | 638 | 25.7 | 11.5 | 5.0 | 19.2 | 14.8 |
| Cattle Camp | 679 | 24.7 | 11.0 | 4.8 | 19.1 | 13.2 |
| Roundview | 658 | 24.9 | 11.1 | 4.9 | 19.1 | 13.5 |
| **Eastern Sites** (Clifton-Ascot area) | | | | | | |
| Colliery Park | 708 | 24.6 | 11.7 | 4.7 | 18.8 | 13.3 |
| Parklyon | 683 | 23.6 | 10.6 | 4.4 | 18.7 | 11.2 |
| Mirrabooka | 735 | 22.7 | 10.3 | 4.2 | 18.6 | 9.7 |
| ***Mean*** | **667** | **25.1** | **11.4** | **4.8** | **19.1** | **13.9** |

It is generally more challenging from a climatic perspective to establish sown pastures in the more western areas.  Changes in climate across the region are shown by the following data.

- At the Chinchilla Post Office the median annual rainfall is 649 mm (ranging from 231 to 1589 mm) while the average maximum temperature in summer is 32.5 deg C with days over 35 deg C fairly common (usually about 14 days per year) and the average minimum in winter is 4.7 deg C.
- Average rainfall is similar at Bell (659 mm) but variability is slightly less.  Average summer maximum is lower (29.8 deg C) and the average minimum temperature in winter is 4.3 deg C.
- The trial sites around Clifton have the highest average annual rainfall (Table 2.1) and the lowest summer maximum temperature (28.6 deg C) with temperatures over 35 deg C seldom occurring. The average minimum temperature in winter is 4.1 deg C.

## 2.3. Weather Conditions During the Trial Period

Weather conditions across the Condamine region during the trial period were variable with extended periods of rainfall well below average; particularly in 2013 and 2014.  The dry periods were interrupted by some months of rainfall well above average as shown in Figure 2.2.  There was useful summer rain in 2012/13 and some useful late summer rain in March 2014.  However, rainfall in the 2013/14 summer (Dec-Feb) was very much below average and rainfall at many stations over the six months Aug 2013 to Jan 2014 had rainfall in the lowest decile.  These conditions continued throughout most of 2014. Conditions were generally hot and dry with regional rainfall more than 30 % below the long-term average for the 18 month period from May 2013 to Nov 2014. Mean maximum temperature for the period was 2 degrees above normal and rainfall totals for the 18 month period were among the lowest on record for many locations. Rainfall over the 2014/15 summer produced excellent growth of native and sub-tropical sown pastures across the region.  Winter rainfall during the trial period was poor and hence the growth of winter active forages was poor.

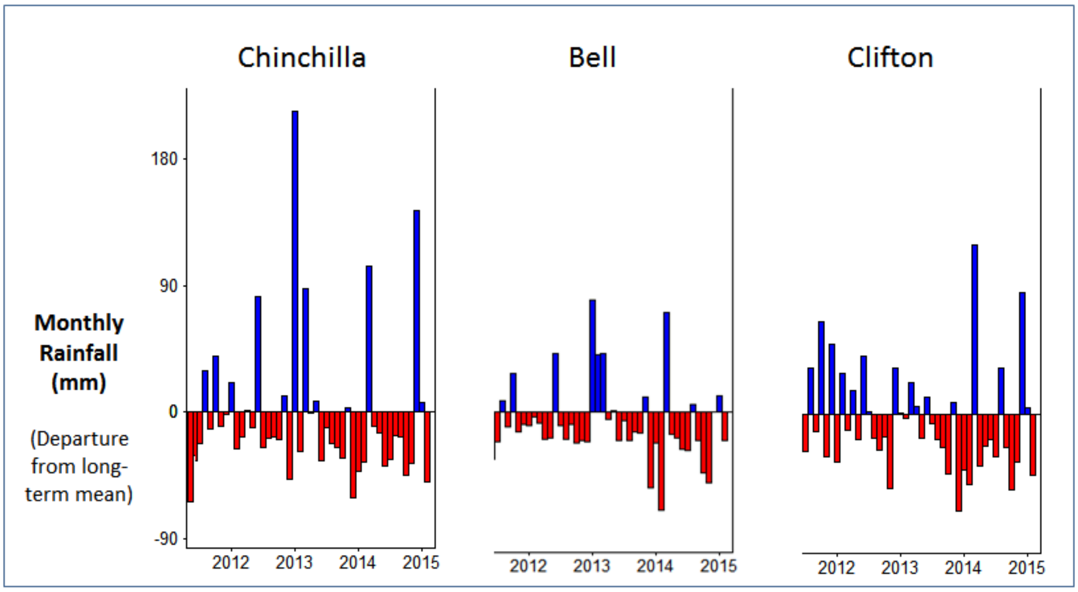


Figure 2.2   Departure of monthly rainfall from long-term mean monthly rainfall at Chinchilla, Bell and Clifton during the trial period from July 2012 to March 2015 *(source: Rainman Streamflow (Clewett et al. 2003))*.

## 2.4. Analysis of Data from Automatic Weather Stations

Data from the automatic stations were compared to rainfall records from nearby stations and also with daily weather records from the SILO data drill (Jeffries et al. 2001). Software was developed to join and match the hourly data from the auto weather stations to the weather data from the SILO data base regards daily values of maximum temperature, minimum temperature and rainfall. A full comparison of the SILO and auto weather station data was not feasible although preliminary investigations suggested:

- There were significant difficulties in downloading data from the automatic weather stations.
- Rainfall measurements from the automatic weather stations were often marginally less than observations at surrounding gauges. For a period of 3 months over the 2012/13 summer the average monthly rainfall at 3 sites for the automatic gauges was 90 mm per month. This compares with 138 mm received nearby in property gauges and 127 mm for ten nearby Bureau of Meteorology gauges. It is quite possible that the auto weather stations were under-recording rainfall events (particularly during high intensity storms) because rainfall bounced out of the shallow collecting devices.
- The daily temperature range of three automatic-weather stations was usually slightly greater than SILO data by a degree or two when tested over several months. It is likely that the temperature gauges in the auto weather stations were recording maximum temperatures that were slightly higher and minimum temperatures that were slightly lower than the SILO estimates.

On the basis of these observations, experiences and results it was concluded that the interpolations of the Bureau of Meteorology weather data provided by the SILO data base (Jeffries et al. 2001) were more accurate and reliable and therefore should be used as the weather input data to the GRASP simulations.

# 3. Field Observations

Field observations on the co-operator properties were conducted to inform both the bio-economic analyses and the project’s communications program. This section covers the detailed measurements of pastures in small exclosures at Colliery Park and Roundview using the abbreviated form of the Swiftsynd methodology (Day et al. 1997). Other observations included:

- Laboratory analyses of soil samples collected from all sites (0-10, 10-20, 20-30 cm) in 2012, 2014 and 2015 by David Hall. Samples were analysed for: texture, pH, nutrients (N, P, K, Ca, Na), soil carbon and organic matter. The 2014 samples were also analysed for water content at field capacity and wilting point to a depth of 60cm. Results are reported by Hall (2015).
- Pasture observations each year at all sites using the Botanal technique with 50 observations on each paddock at each recording. Observations were: species present, estimated ground cover, percent green and total standing dry matter yield. These results are reported by Paton (2015).
- Farm management practices and costs concerning land preparation for sown pastures, application of sprays, seed, fertilizer and manure and grazing management. These observations are generally reported by Alexander (2015), Capp (2015) and Elliot (2015).

## 3.1. Objectives

Measurement of pasture yield in grazed paddocks provides useful information but does not provide data required to calculate pasture growth rates. This occurs because growth rate is confounded by losses from the pasture due to grazing consumption and trampling loss. Pasture growth is a key calculation in the GRASP model and thus data from ungrazed pasture is required for calibration and testing model calculations. Data from ungrazed native pastures has been collected from many sites in Northern Australia relevant to the Condamine catchment. However, data for ungrazed sown grass-legume pastures is limited. This is particularly the case with sown pastures because pasture growth rates vary with the state of pasture rundown. The two grass legume sown pastures at Colliery Park (planted in 2007 and 2012) provided a good opportunity to observe growth rates in an ‘older‘ and ’newer‘ pasture and thus on different paths of the rundown curve. Data for pastures that have been subjected to high levels of grazing pressure for lengthy periods in the Condamine region were also required. The green couch pasture at Roundview had been heavily grazed and provided a useful site for observations on pasture growth without the confounding effects of grazing.

Objectives of pasture observations in 10m * 10m exclosures at Colliery Park and Roundview were to:

- record pasture growth, nitrogen content and cover
- provide field data from the trial sites for calibrating the GRASP model.

## 3.2. Pasture Observation Methods

The Swiftsynd methodology for sampling and measuring pastures in ungrazed exclosures is well established (Day et al. 1997) and was followed in the work reported here in the abbreviated Minisynd form. In summary the process was as follows.

- Swiftsynd exclosures were erected at two trial sites in October 2012; two 12*12 m exclosures at the Colliery Park trial site (in the paddock sown in 2007 at lat -27.97439 long 151.92320, and the paddock sown in 2012 at lat -27.97575 long 151.93123), and one 10*10 m exclosure at the

Roundview trial site (at lat -26.87587, long 151.45102) on a degraded couch grass pasture (see Figures in Section 7). Both of the pastures at Colliery Park were under-sown with an oats crop. Construction of another exclosure on a grass legume sown pasture at Roundview was planned (at lat -26.8730 long 151.4488) but management requirements and dry weather conditions did not permit establishment of the pasture until late December 2015 when a Leucaena pasture was sown. This operation was very successful and the Leucaena was well established by March 2015 but unfortunately was too late for measurements to occur.

- All exclosures were mowed to ground level in October each year (2012, 2013 and 2014) and the litter removed so that future yield measurements over the following summer would be of the total standing dry matter (TSDM) and litter.
- Measurements were taken at Colliery Park on 9 Apr 2013, 13 Feb 2014, 30 Apr 2014 and 24 Apr 2014 and at Roundview on 8 Apr 2013, 12 Feb 2014, 29 Feb 2014 and 18 Feb 2015.
- On each occasion the following observations were made from 4 quadrats (0.5 * 0.5m) in each exclosure: plant height, estimated cover of green, dead, litter and bare ground (no. rocks present), species present, and the fresh and dry weights of TSDM and litter. Bulked sub-samples were analysed for total nitrogen.
- Photographs were taken of the site and each quadrat at each sampling.

The Botanal observations were recorded in April each year and provided 'expert' estimates of pasture yield under grazed conditions from 50 quadrats (0.5 * 0.5 m) in transects across each paddock as described by Paton et al. (2013). The data was recorded for Colliery Park, Mirrabooka, Canimbla, Oakleigh, Cattle Camp and Roundview.

The live weight gains of 86 head of cattle were recorded every 2-3 months at Cattle Camp by the owner Harry Pickering for the period 3 May 2013 to 26 June 2014. A rotational system of grazing was used involving 30 paddocks and short periods of grazing (just a day or two in each paddock). The six paddocks at the trial site at Cattle Camp were part of the rotational system.

## 3.3. Pasture Observation Results

The grass-legume pasture under-sown to oats in 2012 at Colliery Park was well established by April 2013 with Premier Digit, Green Panic and Bambatsi as dominant grasses. Rhodes and creeping bluegrass were also present. Lucerne was variable and represented 10 to 100% of yield in quadrats. Cover inside the exclosure was consistent at 45 to 65% , litter and bare ground both averaged 20%, and pasture yield averaged 3020 kg/ha (1640 to clumps at 5536 kg/ha). Litter yield of the oats residue was 1864 kg/ha. The second exclosure at Colliery Park was not measured in the first year because of damage to fencing and subsequent grazing in January 2013. All measurements were subsequently completed in 2014 and 2015.

The grass legume pasture at Colliery Park planted in 2007 was dominated by Rhodes with significant proportions of bambatsi, Bissett creeping blue and Lucerne. Pasture yields in this exclosure were estimated to be greater than native pasture in surrounding paddocks but were consistently less than the yields in the 2012 planting: 320, 1280 and 3700 kg/ha in 2012, 2013 and 2014 respectively (see Table 3.1). In addition, nitrogen yields in the 2007 planted paddock were substantially less than the 2012 planted paddock. In regards to pasture rundown, this information was valuable for informing the calibration process concerning parameters in the GRASP model.

Green couch dominated the exclosure at Roundview for the life of the project. While percent cover was consistently high in all years, the pasture yields in April were substantially lower in 2013 and 2014 than in 2015. Yields in these years were estimated to be lower than in surrounding paddocks where buffel grass and green panic were growing and were lower than the yields at Colliery Park. However, in 2015 the growth of the green couch responded strongly to the favourable growing conditions from December 2014. This followed very hot dry conditions throughout most of 2014. The nitrogen content of the couch at Roundview averaged 2.1 % and this was substantially greater than the average nitrogen content (1.1 %) of the pastures at Colliery Park (Table 3.1). Although the green leaf of grass and legume were high at Colliery Park the high proportion of stem in those pastures reduced the overall nitrogen content. Further details of the results are described in section 7 and discussion of the results is given in section 4.3 where the pasture observations are compared to estimates from GRASP.

Table 3.1 Pasture measurements recorded from the Swiftsynd exclosures at Colliery Park and Roundview from April 2013 to February 2015 (TSDM is Total Standing Dry Matter)

| Trial Site | Treat ment | Date | Height (cm) | TSDM (kg/ha) | Litter yield (kg/ha) | TSDM % dry matter | % Cover (green +dead) | % Green in TSDM | % N of TSDM | N yield (kg/ha) | Grass leaf % N | Legume leaf % N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Colliery Park | 2007 | 20140213 | 11 | 960 | 320 | 48 | 58.8 | 65 | 1.10 | 10.6 | -- | -- |
| | planting | 20140430 | 35 | 3140 | 240 | -- | 79.0 | 55 | 0.51 | 16.0 | 1.20 | 3.50 |
| | | 20150224 | 70 | 3800 | 360 | 40 | 46.0 | 64 | 0.50 | 19.0 | -- | -- |
| Colliery Park | 2012 | 20130409 | 39 | 4724 | 1864 | 33 | 58.0 | 48 | 0.83 | 39.2 | 1.1 | 3.5 |
| | planting | 20140213 | 14 | 1280 | 140 | 42 | 41.3 | 90 | 2.10 | 26.9 | -- | -- |
| | | 20140430 | 49 | 4420 | 110 | -- | 85.0 | 85 | 1.10 | 48.6 | 1.90 | 5.10 |
| | | 20150224 | 47 | 7500 | 1040 | 40 | 65.0 | 88 | 0.46 | 34.7 | 0.4** | 1.4** |
| Roundview | Control | 20130408 | 10 | 2330 | 480 | 36 | 94.0 | 40 | 1.80 | 41.9 | 2.6 | -- |
| | | 20140212 | 5 | 840 | 320 | -- | 47.5 | 55 | 2.40 | 20.2 | -- | -- |
| | | 20140429 | 9 | 1200 | 0 | -- | 97.5 | 78 | 2.00 | 24.0 | 2.70 | -- |
| | | 20150218 | 17 | 4080 | 20 | 44 | 78.7 | 79 | 1.20 | 49.0 | -- | -- |

** % N of stem + leaf

# 4. Bio-economic Analyses

## 4.1. Introduction and Objectives

Interpretation of data from field sites and extrapolation to other locations can be challenging because of changes in seasonal conditions and many location specific characteristics concerning soils, pastures and management regimes. Analysis of the data using computer models and simulation experiments can help to overcome these challenges by providing estimates for discussion of changes in the performance of an agricultural system with changes in seasonal conditions, location and management. Changes relevant to this study are changes in soil carbon, pasture and livestock productivity, economic returns and greenhouse gas emissions.

The GRASP (Grass Production) model (McKeon *et al.* 1990 and 2008, Clewett et al. 1997, Day *et al.* 1997 and Rickert *et al.* 2000) has been routinely used for analysis of grazing systems (e.g. McKeon *et al.* 2000, 2008, Clewett *et al.* 2007, Scanlan *et al.* 2011a,b). It was developed as a robust daily time-step model for simulating the growth and condition of grazed and un-grazed native pastures in Northern Australia through time periods of just a few seasons to more than 100 years. Weather inputs to GRASP are daily values of rainfall, solar radiation, minimum and maximum temperature, vapour pressure and synthetic pan evaporation.

Significant benefits from GRASP have accrued from estimating changes over time in pasture productivity, land condition and the live-weight gain of cattle due to the impacts of weather events, soil/pasture characteristics and grazing management including the influence of grazing pressure via changes in stocking rate. Key components of GRASP are shown in Figure 4.1. Outputs from GRASP can be very useful as inputs to discussion with farmers, particularly discussions about how management and the run of seasons (good, average or poor) over 10 or 15 years can affect land condition and economic returns. The computing framework of GRASP gives it strong advantages as a tool for biophysical and economic analyses. Some strengths of the model are:

- GRASP provides robust water balance accounting regards rainfall, runoff, deep drainage and water loss via soil evaporation and plant transpiration.
- The main driver of pasture growth in GRASP is via transpiration and this is adjusted for the effects of light interception, temperature, potential growth rate, nitrogen availability, land condition and tree competition. Pasture quality and senescence / detachment rates are calculated so that estimates of dry matter yield as green leaf and stem, standing dead leaf and stem and litter can be made. Root dry matter is not calculated.
- Animal live-weight gain (calculated as a function of age, weight and intake) and feedback effects of grazing on the pasture are calculated so that simulation experiments can be run to assess the influence of stocking rate and pasture spelling on both the pasture and animals.
- Use of GRASP has often had a biophysical focus but it has also been used to generate information for assessing impacts of grazing pressure and/or pasture renovation on land condition and economic returns (McKeon *et al.* 2000, Clewett 2007, Donaghy *et al.* 2007, Star and Donaghy 2010). Output from GRASP has been used in tandem with economic models such as CSIRO's ENTERPRISE spread sheet (Macleod and Ash 2001, Macleod *et al.* 2010) for calculating whole farm herd dynamics and economic returns involving multiple paddocks, breeders and cattle turnoff.

- Methods for calibrating GRASP from field data and conducting simulation experiments involving multiple combinations of locations and management regimes are well documented (Clewett and McKeon 2008, Scanlan *et al.* 2008).

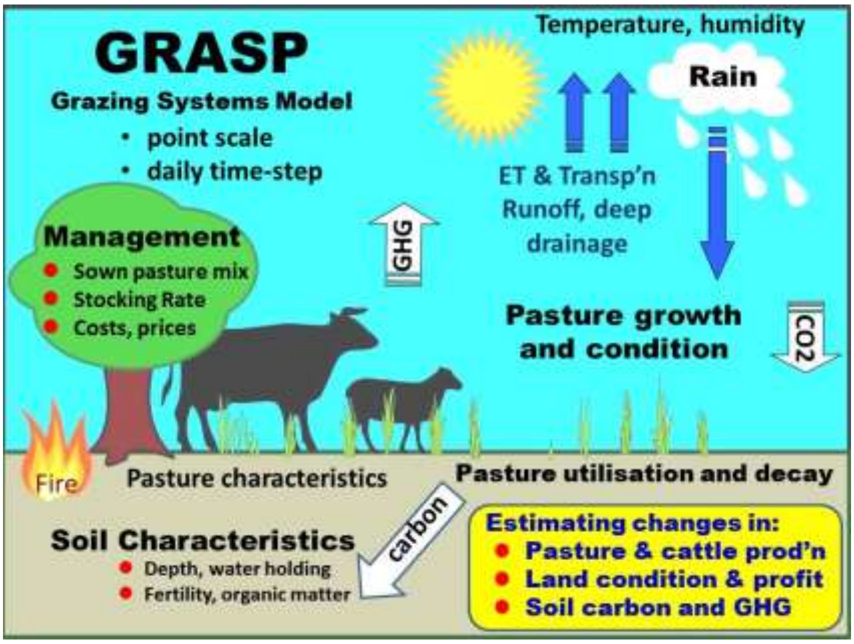


Figure 4.1 Key components of the ***GRAS**s **P**roduction (GRASP) model (McKeon et al. 2008)* (based on the original diagram from Greg McKeon pers. comm. 2008).

The three principal objectives of the bio-economic analyses were to:

1. provide interpretation of data from the field sites including the influence of seasonal conditions on sown pastures across four land resource areas of the Condamine region
2. estimate the effects of changes in agricultural practice (such as use of grass or grass legume pastures, use of fertilizers and/or manure and changes in grazing pressure) on soil carbon, greenhouse gas emissions, productivity and economic returns
3. review the significance of results to industry concerning the value of sown pastures.

The main land resource areas proposed for analysis were:

(a) Basaltic Uplands using Botanal and Swiftsynd data from Colliery Park as well as Botanal data from Cattle Camp and Mirrabooka to substantiate parameters in the model and test outputs

(b) Brigalow Lands including the Brigalow uplands and Brigalow plains using Botanal and Swiftsynd data from Roundview as well as the Botanal data from Oakleigh to test outputs (Oaklands is also part of this land type)

(c) Alluvial Plains using Botanal data from Canimbla to test outputs from simulation runs.

By focussing on the above land resource areas the results will cover a high proportion of lands in the Condamine Catchment that are suited to either pasture renovation, or conversion of marginal cropping lands to permanent pasture.

## 4.2. Methods for Bio-economic Analyses

A version of GRASP for sown pastures has been developed (Clewett 2015 in preparation) and was used in this study. It includes several additional modules for:

- Establishment of sown grass or grass-legume pastures into either existing pastures or retired cultivation land
- Estimating the effects of pasture rundown on the productivity of pastures and livestock due to changes in soil nitrogen availability
- Estimating effects of legumes on pasture growth and animal performance, and also the effects of nitrogen fertilizer and manures on pasture growth
- A soil carbon module base on the RothC model of Coleman and Jenkinson (1999) for calculating changes in soil carbon
- An emissions module for calculating changes in methane emissions from livestock and emissions of nitrous oxide due to application of fertilizers or manure
- An economics module for calculating economic costs and returns from grazing systems.

### Weather data

Long-term daily weather data from SILO (Jeffrey *et al.* 2001) was used as input to GRASP. Farmers often use 10 to 15 year planning horizons and hence the long-term daily data from 1890 to 2015 enabled many sequences of weather conditions over 10 to 15 years to be examined in the simulation experiments described below.

### Parameters

The base set of parameters used as input to GRASP was the parameter set for native pastures in Northern Australia. However, this base set was adjusted for sown pastures in the Condamine region and also in accord with soils, land types and pastures at the trial sites using several parameter settings from Land Type parameter sets for Southern Queensland supplied by the Queensland Department of Agriculture and Forestry. Soil parameters were based on trial site observations and published data for the land resource areas (Maher 1996, Harris *et al.* 1999 and Dalgliesh 2012) particularly data for the Basaltic Uplands in the eastern and central areas of the Condamine region, the Brigalow Uplands and plains in central areas, and the Alluvial Plains in western parts of the region. Estimates of bulk density and water holding capacity were derived from field texture, depth and wilting point observations with equations by Pawcer (cited by Littleboy 1997).

The standard native pasture parameter set was used in some circumstances where a benchmark of pasture growth and soil carbon sequestration rates were required. In this case the growth of sown pasture was evaluated in relation to the native pasture benchmark.

### Rundown and legumes, N, manure

Total soil nitrogen that is annually available for uptake is an important parameter in GRASP describing soil fertility and for estimating pasture growth. In the GRASP native pastures model this parameter stays constant from year to year and is typically about 20 kg N/ha. However, in the GRASP model for sown pastures it is a variable that can more than double nitrogen availability so that the influence of pasture rundown (Peck et al. 2012) and the contributions of nitrogen from legumes (up to 10 kg N/ha), fertilizer and manure may be estimated. Sown pastures are often most productive in their first few years of growth due to increased availability of nitrogen (Graham et al. 1985, Peck *et al.* 2011,2012).

Several reviews (Myers and Robbins 1991, Peck et al. 2011), show that pasture rundown is common in sown pasture grazing systems. The increased productivity in the initial years (defined here as the "initial lift") and duration of the rundown period depends on several factors including levels of soil disturbance, fertility of the site and the presence of legumes in the sown pasture. Rundown in sown Brigalow pastures can continue for 20 years (Radford 2007), whereas it may last only one or two years with minor disturbances. In order to assess the value of sown pastures and particularly the value of legumes to pasture productivity, economic returns and carbon sequestration it was necessary to calibrate parameters describing the initial lift in productivity and rate of rundown in sown pastures and the nitrogen contribution of legumes. Estimates were also required for the contribution of legumes to increases in live weight gain, the longevity of legumes regards drought and grazing pressure, and the influence of nitrogen fertilizer and manures on pasture growth. The availability and influence of phosphorous and other nutrients on pasture growth were recognised but not incorporated in the modelling.

Parameters and equations for adapting GRASP to simulate sown pastures with legumes / fertiliser / manure inputs were derived using several key resources including Peake *et al.* (1990), Myers and Robbins (1991), Gramshaw (1995), Day et al (1997), Middleton (2001), Peoples and Baldock (2001), Lloyd et al. (2007, 2012), Ngome and Mtei (2010), and Star and Donaghy (2010) and Peck *et al*. (2011, 2012) and Lawrence et al. (2014).

## Soil Carbon model

The version of GRASP for sown pastures estimates changes in soil carbon by incorporating the RothC soil carbon model (version 26.3)(Coleman and Jenkinson 1999) . RothC has been shown to provide useful and reasonably accurate estimates of changes in soil organic matter in Australia including Brigalow soils in Queensland (Ranatunga et al. 2001, Skjemstad et al. 2004) and the performance of RothC is similar to other models such as APSIM and Century (Ranatunga et al. 2001, Parton et al. 1992).

RothC estimates the effects of soil type, temperature, moisture content and plant cover on the rates of breakdown in several carbon pools on a monthly basis. These pools are decomposing plant material, microbial biomass and humus. Existing routines in the GRASP model were used to estimate soil water content and plant cover and the monthly contribution of plant biomass to the soil carbon pool. This was estimated as 90% of monthly losses in Total Standing Dry Matter (TSDM) and was guided by the findings of Delal et al. (1995, 2005, 2008), Chan et al. (2008, 2010), Luo et al. (2010) and Sanderman et al. (2010). The initial level of inert soil carbon was estimated from initial levels of total soil carbon but subsequent changes (e.g. those due to fire) were not calculated. Parameters in the model were those proposed by Coleman and Jenkinsen (1999) except: (a) the monthly contribution of plant biomass to the soil carbon pool was guided by the findings of Kuzyakcov and Domanski (2000) and Dalal et al. (2005) for pastures and set at 90% of TSDM losses, and (b) the coefficient for estimating the moisture modifying factor for carbon losses was based on the findings of Farina et al. (2013) who showed it was important to adjust this equation in the semi-arid conditions of Australia.

## Emissions models

GRASP uses feed intake to estimate annual live weight gain. Changes in methane emissions from cattle due to changes in stocking rates and intake were estimated using the revised CSIRO data for tropical forage. Young cattle grazing a range of tropical forages (buffel, stylo, Rhodes, Mitchell, black spear, lucerne, creeping blue) were found to have an average methane emission of 19.6 g/hd/day per kg of dry matter intake (Kennedy and Charmley 2012). This is significantly less than previous findings which are now considered incorrect (Hunter 2007). The Kennedy and Charmley (2012) findings did not vary greatly with species (+ or - 2 g/hd/day per kg of dry matter intake) and thus this relationship was used to estimate methane emissions.

Emission of nitrous oxide from soils due to application of fertiliser or manure can vary widely from less than 0.2% to more than 10% in some circumstances depending on concentration, placement and environmental conditions (temperature, soils, moisture) (Dalal et al. 2003, De Klein et al. 2006). Nitrous oxide was estimated using the IPCC AR4 (De Klein et al. 2006) default value method of 1% of applied N, and then converted to Nitrous oxide by multiplying by 44/28. Nitrous oxide losses from legumes and livestock urine and faeces were estimated using the IPCC AR4 (2006) default value.

## Economics model

Economic returns were estimated in GRASP for a steer growing enterprise in which young cattle were purchased at 280 kg live weight in July each year and then sold 12 months later as heavy steers. Operating costs in relation to pasture establishment (land preparation, seeding, fertilizer, and manure), cattle purchase and grazing costs, and marketing (transport, yard fees, MLA fees) were taken into account. Labour costs were excluded. Gross margins per hectare and per head and net present value were calculated with trading margins on cattle purchase and selling prices taken into account. Trial site collaborators provided details on the timing of operations, rates for seeding, fertilizer and sprays, costs and prices.

## Methods for conducting Simulations Experiments

A series of four simulation experiments were conducted as follows.

**The first simulation experiment** was designed to compare estimates of pasture production at each of the trial sites to actual observations of pasture production recorded in the Swiftsynd and Botanal observations. For this simulation the model was set to start in the year 2000 and to then calculate pasture yield (total standing dry matter) each day until mid-February 2015 when the final observations were recorded. This enabled comparison of estimated and observed data. This experiment was run repeatedly as part of the model calibration process. Parameters were adjusted until the fit with observed data was reasonable. This was a matter of judgement rather than attempting to minimise an objective function (e.g. least squares fit) that could push the calibration process too far by suggesting inappropriate values for parameters.

**The second simulation experiment** was designed as a preliminary investigation to assess the influence of climate variability (temporal and geographic) on pastures across the Condamine region. It was conducted in parallel with the first experiment and was completed before the above calibration process had been completed. Pasture growth at each of the 9 trial sites was simulated for the period 1 Jul 1894 to 30 June 2013 by dividing this period into 8 shorter periods of 15 years with simulations starting in

1894, 1909, 1924, 1939, 1954, 1969, 1984 and 1999. A prior spin-up period of 2 years was also included to settle the model. Results from this spin-up period were discarded. Each simulation started with native pasture in years 1 and 2, pasture renovation began in August of year 3 and the sown pasture was planted the following Feb-March. Light grazing commenced after 90 days provided pasture growth exceeded 2000 kg/ha and full grazing resumed after 1 year. Grazing pressure was adjusted each year at the start of July to utilize 35% of the Total Standing Dry Matter (TSDM).

**The third simulation experiment** was designed to evaluate the effects of location, seasonal conditions and grazing pressure (stocking rate) on returns from sown grass and grass-legume sown pastures over a decade. Grazing pressure was imposed by adjusting stock numbers each year in accordance with expected levels of productivity and pasture rundown. This maintained about the same level of pasture utilisation from year to year and from site to site. This enables valid comparisons between sites. This simulation was conducted as a factorial experiment with the following treatments:

> **Factor 1:** This tested 7 trial sites with 3 paddocks at each trial site (native pasture, sown grass pasture and sown grass-legume pasture). At Cattle Camp sown pasture + manure was substituted for the native pasture, and at Oakleigh sown pasture + nitrogen fertilizer was substituted for the sown grass-legume pasture.
>
> **Factor 2:** This tested 5 grazing pressures at 1, 10, 25, 30 and 35 % utilisation of pasture growth.
>
> **Factor 3:** This tested 11 sets of seasonal conditions. The model was run for each decade since 1900 giving 11 decades of different seasonal conditions. For each decade the model had an initial "spin up period" of three years and then the sown pasture was "sown" for each decade in 1900, 1910, 1920 ……. 1990, 2000).

**The fourth simulation experiment** was designed to evaluate the use of pastures to build soil carbon over an extended period (50 years) rather than single decades as used in the previous experiment. The 50 year simulation was repeated four times (starting in 1901, 1921, 1941 and 1961) to overcome the influence of variation in seasonal weather conditions. Observed values of soil carbon (0-30 cm) at each of the trial sites were used as starting levels of soil carbon when estimating the monthly mass balance of soil carbon and the annual soil carbon sequestration rate. Soil carbon sequestration rates were then averaged for each decade of the 50 year period. A grazing pressure of 25% utilization of the expected annual pasture growth was used. Comparisons were made of existing pastures versus sown grass and sown grass-legume pastures with percent legume in the pasture maintained at 15% of pasture biomass.

## 4.3. Results (Experiment 1): Comparison Model Estimates to Field Data

This section describes and discusses the comparison of pasture yields estimated by GRASP following model calibration to observed values of pasture yield that were obtained from:

- The Swiftsynd exclosures in two grass-legume paddocks at Colliery Park and one green couch paddock at Roundview and these provided observations of pasture yield in ungrazed conditions
- Botanal observations at all pasture sites and this provided estimates of pasture yield under grazing.

Estimates of pasture yield from GRASP were found to account for 74% of the variation in observed pasture yield in the Swiftsynd exclosures and 50% of the variation in the Botanal observations (Paton

2015) (Figures 4.2 to 4.6). When combined the estimates from GRASP accounted for 50% of the variation in observed yields.

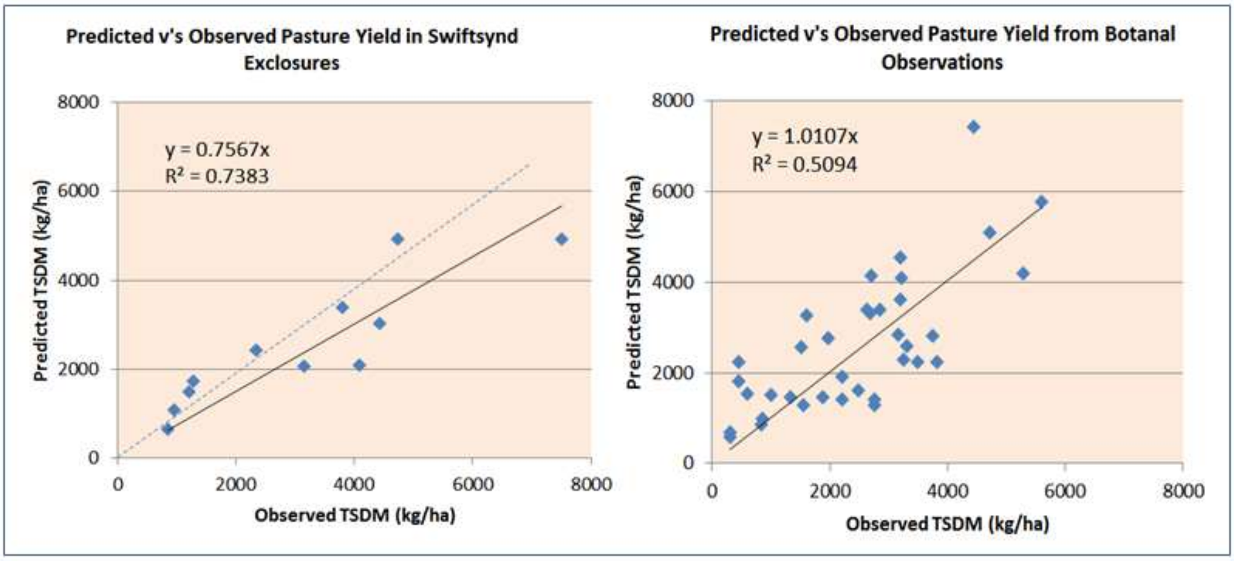


Figure 4.2 Regression analysis comparison of GRASP estimates of pasture yield to observed pasture yields from: (a) Swiftsynd exclosures (not grazed), and (b) Botanal observations (grazed paddocks)

Observed values of pasture yield from the exclosures at Colliery Park and Roundview are compared to the predicted time series of monthly estimates of pasture yield from GRASP in Figure 4.3. Further photos are shown in section 7. Predicted and observed values were reasonably close on most occasions, however, in February 2015 the predicted values for Roundview and the 2012 planted pasture at Colliery Park were significantly less than was observed. Several reasons for this are possible. For example, some evidence suggests that rainfall at the sites (Dec 2014 and Jan 2015) was more than estimated by SILO leading to more growth than expected, or perhaps the very hot dry conditions during 2014 led to additional mineralisation of nitrogen and this promoted additional growth. The yield estimated by GRASP at Roundview was similar to the observed yield outside the exclosure (Figure 4.6) which had not been grazed since the previous October (and thus well before the start of growth in December 2014). Because of the above uncertainties it was decided to not attempt further calibration of the model.

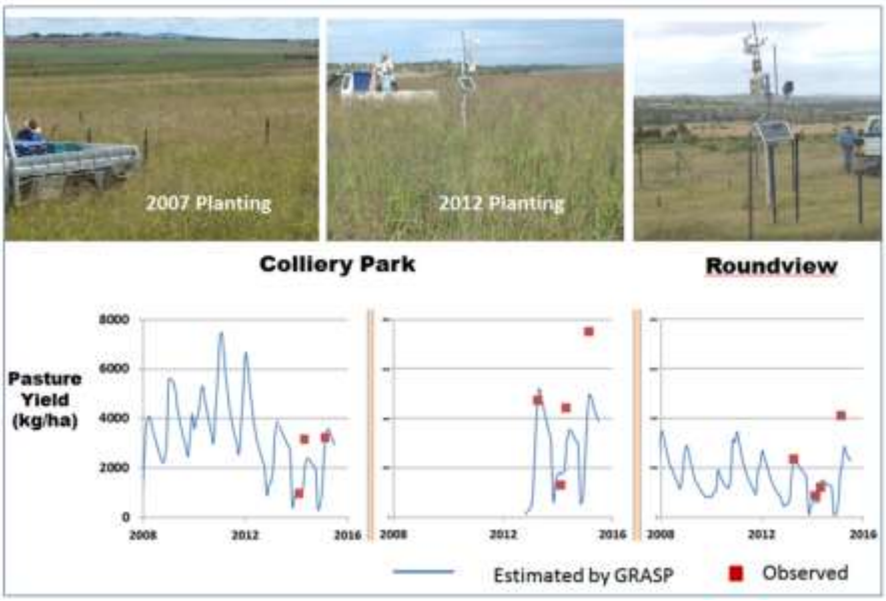

Figure 4.3 Time series comparison of GRASP estimates of pasture yield to observed pasture yields from Swiftsynd exclosures (not grazed)

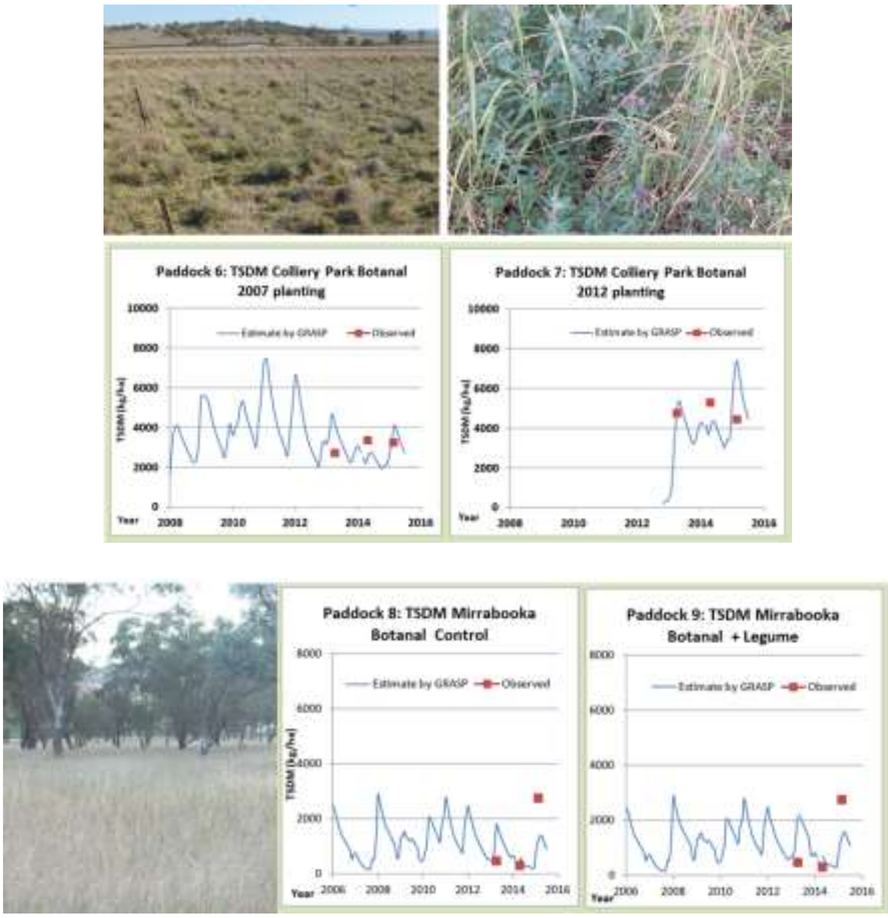


Figure 4.4 Comparison of GRASP estimates of pasture yield to observed Botanal estimates of pasture yield (Paton 2015) from grazed paddocks with data from: (a) Colliery Park and (b) Mirrabooka.

Botanal pasture yield observations of the two grazed pastures at Colliery Park showed that the new grass-legume pasture planted in 2012 had consistently more dry matter than the pasture planted five years earlier in 2007 (Figure 4.4). Mean yields were respectively 4813 and 3076 kg/ha in the 2012 and in the 2007 paIntings (Paton 2015). This data highlights the significance of pasture rundown where land use change occurs and in this case it was the conversion of crop land to permanent pasture. The data from Colliery Park greatly assisted calibration of parameters in the GRASP model describing pasture rundown. On average, the drop in pasture yield due to rundown from the new to the older pasture was 1736 kg/ha. A similar drop was estimated by GRASP (1951 kg/ha).

Pasture growth at Mirrabooka was initially impacted by high grazing pressure in the first two seasons. However, very dry conditions forced spelling of the paddock from July 2014 and it was then left ungrazed until the final observations were recorded in February 2015. The rapid recovery and resilient nature of the Mirrabooka native pasture paddock is shown in Figure 4.4.

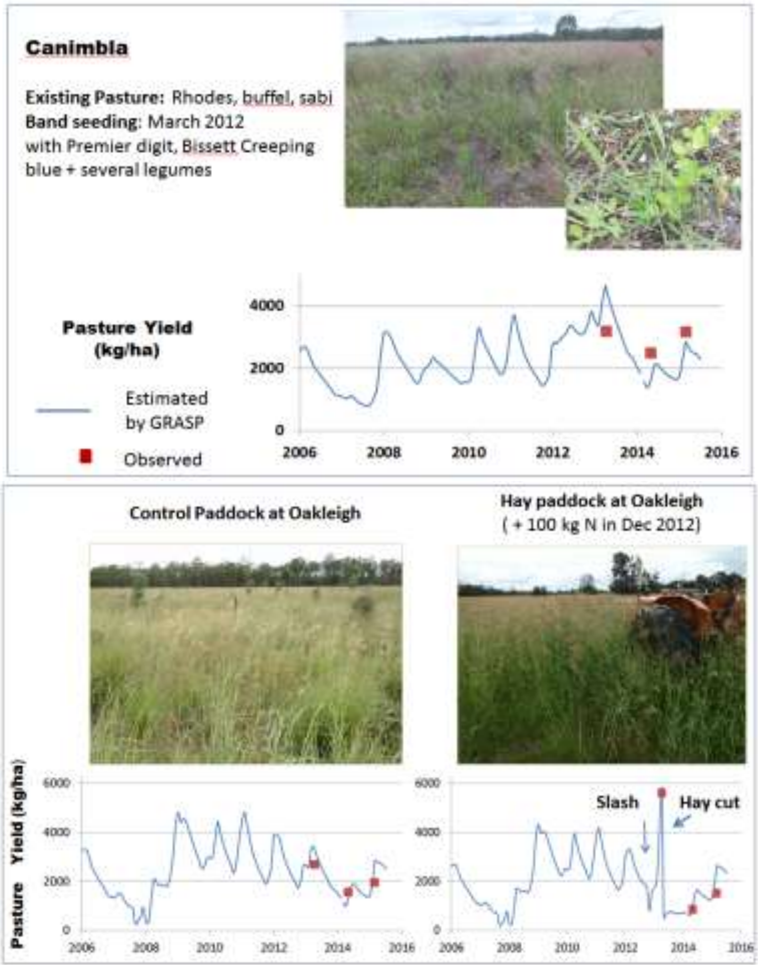


Figure 4.5 Comparison of GRASP estimates of pasture yield to observed Botanal estimates of pasture yield (Paton 2015) from grazed paddocks with data from: (a) Canimbla and (b) Oakleigh.

Pastures observations at Canimbla (Figure 4.5) showed very little evidence of pasture rundown following the pasture planting in 2013 and provided a sharp contrast to the data from Colliery Park. At Canimbla the sown grass-legume pasture was planted using a band seeder to direct drill pasture seed into an existing pasture. Planting occurred in strips that were sprayed to kill the existing pasture in the same operation. This caused some change in the existing pasture but overall there was limited opportunity for mineralisation of soil nitrogen. Consequently there was limited opportunity for a lift in production .

Observations at Oakleigh (Figure 4.5) provided data concerning effects of nitrogen fertilizer on the productivity of an existing Rhodes grass sown pasture. Nitrogen was applied at 103 kg/ha in December 2013 and then harvested for hay in the following March when the observed and predicted yields were 5597 and 5763 kg/ha. The estimated nitrous oxide loss from this pasture was 2.8 kg/ha and was estimated using the IPCC (De Klein et al. 2006) default value of 1% of applied nitrogen.

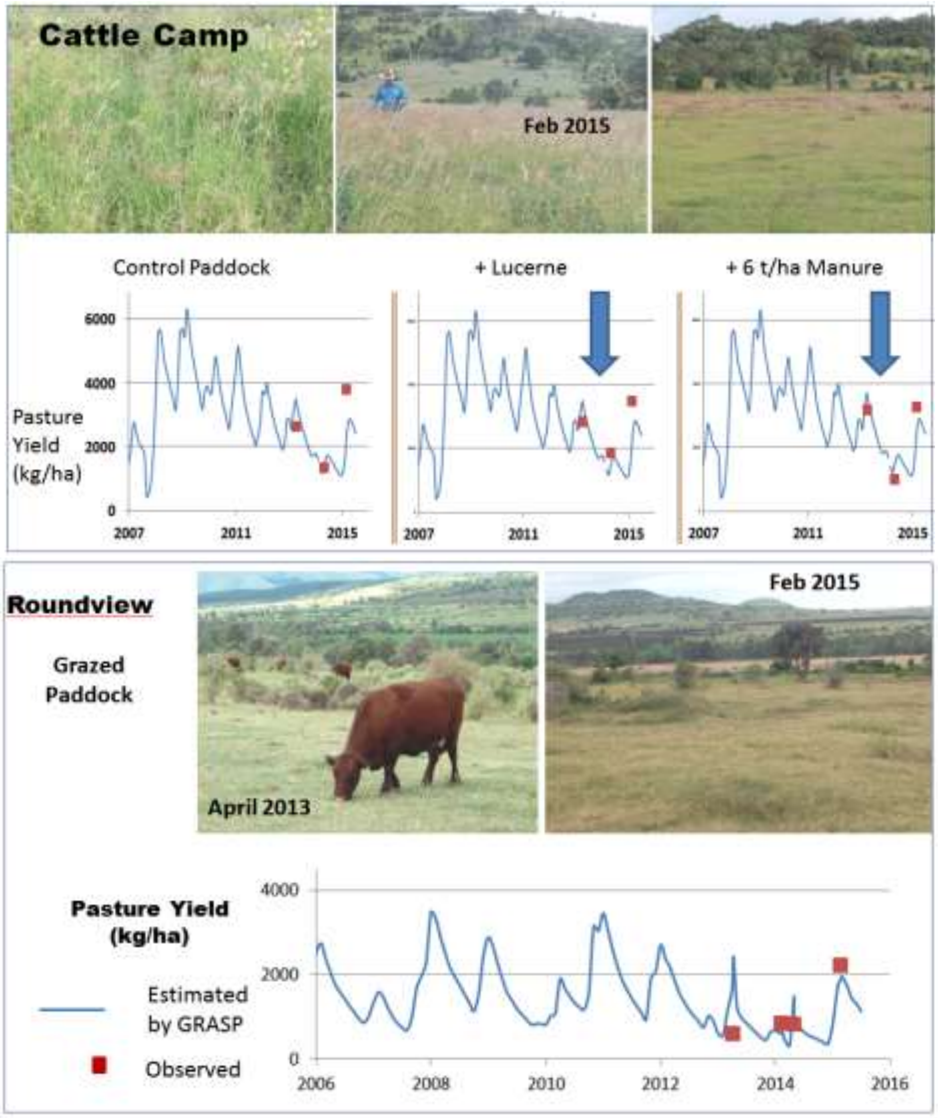


Figure 4.6 Comparison of comparison of GRASP estimates of pasture yield to observed Botanal estimates of pasture yield (Paton 2015) from grazed paddocks with data from: (a) Cattle Camp , and (b) Roundview.

Observations at Cattle Camp centred on a sown grass pastures established in 2007 that compared: (a) sod-seeding with a legume (Lucerne) in 2013, (b) application of chicken manure broadcast at 6 t/ha, and (c) no treatment as a control. Productivity of the site was estimated to be very similar to Colliery Park. The mean observed yield at the end of summer after grazing was 2603 kg/ha and was estimated by GRASP to be very similiar (2405 kg/ha) (Figure 4.6). Yields of the “control”, “plus legume” and “plus manure” after grazing at the end of the project in February 2015 were 3811, 3483and 3261 kg/ha respectively (Paton 2015).

Application of manure at 6 t/ha (3.5% nitrogen at $28.30/t) was expensive, gave no obvious change in productivity at any stage and was according to the land owner “*a complete waste of time*”. Botanal observations in April 2014 and February 2015 of pasture yield did not show significant change from the control paddocks and were actually slightly less in the manure paddocks (Paton 2015). Because of the weather conditions and broadcasting of the manure it is possible that the nitrogen was lost to the atmosphere. Most of this would be as ammonia. Use of the IPCC (2006) default calculation of 1% losses of applied nitrogen to nitrous oxide suggests approximately 3.3 kg/ha of the 210 kg N/ha applied would be lost to nitrous oxide. This is equivalent to 983 kg $CO_2$e/ha.

Botanal observations showed that Lucerne was successfully established throughout the paddock and formed 22% of the pasture yield (Paton 2015). However, after two years there was no evidence as yet that the legumes were contributing to increased growth of grasses. GRASP was therefore calibrated to restrict legume contributions to grass growth until after two years.

Live weight gain observations at Cattle Camp on 86 head of cattle gave an average daily live weight gain of 0.58 kg/hd/day for a 12 months period (Pickering, 2015 pers. comm.). This gave an annual gain of 212 kg/hd/year. Some supplements were used. Seasonal values were very even for autumn, winter and spring and were 0.66, 0.64 and 0.62 kg/hd/day respectively. Surprisingly the summer value (0.44 kg/hd/day) was very low but intake may have been significantly affected because of feed shortages during the 2013/14 summer. Cattle management during the summer was difficult because it was abnormally hot and dry and significant rain to boost pasture growth did not occur until March 2014.

## 4.4. Results (Experiment 2): Climate Impacts on Condamine Region Pastures

This experiment evaluated the temporal and geographic influence of climate variability on pastures across the Condamine Region and used an average set of soil and pasture parameters for a sown grass legume pasture so that soil and pasture characteristics were not confounding the results.

Climate conditions were highly variable during the 120 year simulation period and there were long periods when average rainfall was considerably below or above the long-term mean. The regional average pasture growth across all years and all sites was 3835 kg/ha for sown grass pastures, and varied from 3635 kg/ha for the dry 1909-23 period, to 4063 kg/ha for the wetter 1954-68 period (Table 3). The large variation in wet and dry periods is often associated the NinoThe El Nino/Southern Oscillation and this has been shown to have significant impacts on pasture growth (Clewett and Clarkson 2007).

Results here use a generalised set of parameters for sown grass pastures on clay soils with stocking rates adjusted in July to utilize 35% of pasture yield (TSDM) present on 1st May. Estimated pasture growth marginally decreased (10%) from east to west in association with the drop in rainfall, increase in maximum temperatures and increase in aridity (see Table 4.1). Climatically, Mirrabooka and Colliery Park have the highest potential for growth being about 4% above the regional average, however, soil constraints and tree competition at Mirrabooka significantly reduce productivity.

Table 4.1 Influence of climate variability and location on mean values for rainfall, runoff, transpiration, soil evaporation and pasture growth for the 8 simulation periods and 9 trial sites.

| **Simulation Period** | **Rainfall** | **Runoff** | **Transp'n** | **Soil Evap** | **Pasture Growth** | **TSDM** |
|---|---|---|---|---|---|---|
| Start yr - End yr | mm/yr | mm/yr | mm/yr | mm/yr | kg/ha | 30th June |
| 1894 to 1908 | 673 | 14 | 313 | 305 | 3823 | 2431 |
| 1909 to 1923 | 616 | 13 | 272 | 291 | 3635 | 2380 |
| 1924 to 1938 | 680 | 14 | 330 | 296 | 3816 | 2483 |
| 1939 to 1953 | 680 | 16 | 329 | 283 | 3887 | 2580 |
| 1954 to 1968 | 721 | 19 | 339 | 289 | 4063 | 2545 |
| 1969 to 1983 | 691 | 18 | 319 | 290 | 3856 | 2397 |
| 1984 to 1998 | 669 | 15 | 310 | 292 | 3859 | 2424 |
| 1999 to 2013 | 643 | 15 | 309 | 273 | 3743 | 2383 |
| **Mean** | 672 | 15 | 315 | 290 | 3835 | 2453 |

| **Location** | **Rainfall** | **Runoff** | **Transp'n** | **Soil Evap** | **Pasture Growth** | **TSDM** 30th June |
|---|---|---|---|---|---|---|
| | mm/yr | mm/yr | mm/yr | mm/yr | kg/ha | kg/ha |
| Leichardt Crossing | 640 | 18 | 280 | 296 | 3625 | 2365 |
| Canimbla | 618 | 13 | 273 | 299 | 3539 | 2343 |
| Oakleigh | 643 | 14 | 300 | 290 | 3782 | 2459 |
| Oaklands | 638 | 12 | 300 | 291 | 3771 | 2415 |
| Cattle Camp | 720 | 16 | 347 | 292 | 3960 | 2523 |
| Roundview | 658 | 14 | 311 | 289 | 3850 | 2435 |
| Parklyon | 708 | 16 | 344 | 283 | 4010 | 2518 |
| Colliery Park | 683 | 16 | 325 | 289 | 3938 | 2487 |
| Mirrabooka | 735 | 19 | 356 | 281 | 4043 | 2532 |
| **Mean** | **672** | **15** | **315** | **290** | **3835** | **2453** |

## 4.5. Results (Experiment 3): Influence of Pasture Rundown, Use of Legumes and Grazing Pressure on Returns from Sown Pastures

This section evaluates bio-economic returns from sown grass and grass-legume pastures. A generalised view was achieved by conducting the experiment at several locations to address spatial changes due to differences in soil, pasture characteristics and management practices , and also over 11 decades to both remove and assess the influence on results from temporal variation in weather conditions.

The main focus was on how pasture rundown, legumes and grazing pressure cause changes in productivity (pastures and livestock), soil carbon sequestration rates and economic gross margins. In addition, management practices using nitrogen fertilizer and manure were examined. Green-house gas emissions were also estimated as methane emissions from livestock and nitrous oxide livestock urine and faeces, and from the application of nitrogen fertilizer and/or manure, and nitrogen fixation by legumes. Further details of methods are given in section 5.2.

Grazing pressure is specified in GRASP as the annual percent utilisation of pasture and is calculated as the amount of pasture eaten by livestock divided by the quantity of pasture that grows during the year. Grazing pressure is adjusted in GRASP by changing the stocking rate. Higher stocking rates increase grazing pressure. The five grazing pressures investigated here were: 1, 10, 25, 35 and 50 % utilisation.

Results are examined for the three main land types: Basalt uplands, Brigalow lands, and alluvial plains and are presented in two main sections: (1) effects of pasture rundown and legumes on pasture productivity, and (2) effects of grazing pressure on pasture and livestock productivity, soil carbon sequestration and economic returns.

### 4.5.1. Effects of Grazing Pressure on Productivity, Soil Carbon, Methane Emissions and Economic Returns

The mean annual growth of pastures across all sites, pastures, grazing pressures and climatic conditions was estimated to be 3076 kg/ha. This mean was substantially higher on the more fertile clay soils of the Basalt Uplands: 3779 kg/ha at Colliery Park and 4017 kg/ha at Cattle Camp. Lower pasture growth was estimated for the lighter and less fertile loam soils of the Brigalow Uplands at Roundview (2837 kg/ha) and Oaklands (2580 kg/ha), and Alluvial Plains at Canimbla (2648 kg/ha).

Sown grass pastures and sown grass-legume pastures were estimated to increase pasture growth by 27 and 46 % respectively in the first decade after planting when compared to existing grass pastures at the trial sites or typical native pastures that could grow at the trial sites. These results were for the first decade after planting and are the mean values for the 11 decades tested. Higher plant growth from sown pastures increased the soil carbon sequestration rates at all grazing pressures. These results are shown in Table 4.2 for all simulated levels of grazing pressure. The grazing pressures shown in this table are shown in two ways: (1) the designed level applied in July each year to set stock numbers for the next 12 months based upon the expected level of pasture production over the next 12 months, and (2) the actual level of pasture utilisation resulting from the seasonal conditions experienced over the previous 12 months. The results in Table 4.2 show the designed level was a little conservative as the mean actual level was 2 to 3% below the designed level when averaged across all 11 decades.

Table 4.2 Effects of grazing pressure on mean annual pasture production, carbon sequestration, cattle performance, cattle methane emissions and economic returns on the means for native or existing sown pasture, sown grass pastures and sown grass legume pastures

| | Grazing Pressure % Utilisation Designed level and actual rate in brackets | Existing or Native pasture | Sown Grass Pasture | Sown Grass /Legume Pasture |
|---|---|---|---|---|
| **Pasture Growth** (kg/ha/yr) | 5 % (4.2) | 2795 | 3542 | 4464 |
| | 15% (12.9) | 2699 | 3415 | 4091 |
| | 25 % (22.2) | 2573 | 3256 | 3690 |
| | 35 % (32.0) | 2371 | 3044 | 3268 |
| | 50% (47.5) | 1928 | 2475 | 2531 |
| **Carbon sequestration** (t/ha/yr) | 5 % (4.2) | 392 | 527 | 964 |
| | 15% (12.9) | 369 | 498 | 859 |
| | 25 % (22.2) | 332 | 454 | 730 |
| | 35 % (32.0) | 251 | 379 | 565 |
| | 50% (47.5) | 4 | 53 | 154 |
| **Stocking Rate** (AE/100ha) | 5 % (4.2) | 4.0 | 4.4 | 5.4 |
| *(mean adult equivalents* | 15% (12.9) | 11.9 | 13.0 | 15.4 |
| *for 12 month period)* | 25 % (22.2) | 19.6 | 21.3 | 24.1 |
| | 35 % (32.0) | 27.0 | 29.2 | 31.6 |
| | 50% (47.5) | 36.4 | 38.7 | 39.4 |
| **Live weight gain** (kg/head/yr) | 5 % (4.2) | 175 | 180 | 207 |
| | 15% (12.9) | 167 | 172 | 197 |
| | 25 % (22.2) | 157 | 163 | 184 |
| | 35 % (32.0) | 144 | 152 | 166 |
| | 50% (47.5) | 114 | 122 | 127 |
| **Live weight gain** (kg/ha/yr) | 5 % (4.2) | 8.0 | 9.2 | 12.9 |
| | 15% (12.9) | 22.8 | 26.2 | 35.1 |
| | 25 % (22.2) | 35.7 | 41.1 | 51.8 |
| | 35 % (32.0) | 45.7 | 53.2 | 62.4 |
| | 50% (47.5) | 49.6 | 59.3 | 62.8 |
| **Methane emissions** (kg/ha/yr) | 5 % (4.2) | 2.4 | 2.7 | 3.7 |
| | 15% (12.9) | 7.1 | 8.0 | 10.6 |
| | 25 % (22.2) | 11.6 | 13.2 | 16.3 |
| | 35 % (32.0) | 15.5 | 17.8 | 20.6 |
| | 50% (47.5) | 18.8 | 22.1 | 22.9 |
| **Gross Margin** ($/head/yr) | 5 % (4.2) | 163 | 36 | 157 |
| | 15% (12.9) | 181 | 153 | 273 |
| | 25 % (22.2) | 157 | 149 | 262 |
| | 35 % (32.0) | 124 | 128 | 212 |
| | 50% (47.5) | 59 | 69 | 111 |
| **Gross Margin** ($/ha/yr) | 5 % (4.2) | 7.6 | 1.8 | 9.6 |
| | 15% (12.9) | 25.2 | 23.2 | 47.7 |
| | 25 % (22.2) | 36.4 | 37.6 | 72.7 |
| | 35 % (32.0) | 40.4 | 44.5 | 78.6 |
| | 50% (47.5) | 26.9 | 32.7 | 53.6 |

There was substantial variation in plant growth and carbon sequestration rates caused by differences between sites and this is shown in table 4.3. There was also significant temporal variation caused by pasture rundown and variable climatic conditions and these issues are addressed in the next section.

Tables 4.2 and 4.3 show that as grazing pressure increased, the increases in stocking rate were initially beneficial because of estimated increases in live weight gain per unit area without large penalties to live weight gain per head or to pasture growth and condition. However, at higher stocking rates the negative effects of grazing pressure were estimated by GRASP to outweigh advantages and thus cattle and economic performance rapidly declined.

Grazing pressure was estimated to have direct effects on the live weight gain of cattle because of reduced diet selection as grazing pressure increases and also because of restrictions on intake when pasture availability becomes limiting. Increases in grazing pressure were also estimated to have negative feedback effects on both pasture growth and pasture condition. Direct effects on growth occur because of reduction in cover and leaf area which then reduces transpiration and photosynthetic capacity. It also increases the proportion of soil moisture lost to soil evaporation. The effect on pasture condition is by selective grazing and reducing the competitive ability of more palatable or nutritious species (such as legumes and the better grasses) which then allows weeds to invade and prevail.

Cattle methane emissions were calculated on the basis of dry matter intake and were found to generally increase as grazing pressure increased (Table 4.4). However, at very high grazing pressures cattle intake was severely restricted causing losses in cattle live weight particularly during decades with low rainfall. Pastures collapsed in the simulations during extended drought periods at the very high grazing pressures and did not recover. Once pastures had collapsed under high grazing pressure the productivity and economic returns were low. Expected pasture growth was low, carbon sequestration rates became negative, stocking were low and methane emissions fell.

The effects of sown pastures on rates of carbon sequestration and methane emissions enable comparison of these rates in terms of green-house gas carbon dioxide equivalents ($CO_2$e).

Soil carbon sequestration rates were converted to $CO_2$e by multiplying by 44/12 (atomic weight ratio), and methane emissions were converted to $CO_2$e by multiplying by 34 as recommended by the IPCC AR5 report (Myhre et al. 2013). Previously the methane conversion rate was 25 (IPCC AR4 2006) but was upgraded to 34 in the IPCC AR5 report to account for carbon feedback effects. The comparisons in Table 4.4 show that sown pastures should be beneficial to reducing green-house gases because:

- the mean annual $CO_2$e sequestered by sown grass pastures is 412 kg/ha more than for native pastures and thus much higher than the corresponding increase in $CO_2$e from methane emissions of 58 kg/ha $CO_2$e.
- the difference is greater for sown grass-legume pastures with an increase in carbon sequestration of 1411 kg/ha $CO_2$e compared with the much lower increase of 127 kg/ha $CO_2$e for methane emissions.

Further green-house gas emissions were calculated concerning the loss of nitrogen to nitrous oxide. Estimates of $CO_2$e nitrous oxide losses based on the IPCC AR4 (De Klein et al. 2006) default value of 1% nitrogen losses to nitrous oxide were: (1) an additional mean annual loss of 2 and 12 kg/ha $CO_2$e respectively for sown grass and grass-legume pastures due to nitrous oxide losses from the urine and faeces of the extra livestock carried on sown pastures compared to native pastures, and (2) an additional mean annual loss of 52 kg/ha $CO_2$e from nitrous oxide due to nitrogen fixation by legumes in sown grass-legume pastures. These estimates were based on: nitrogen fixation of 3.0 kg/ha per 100 kg of pasture (shoots and roots), a mean nitrogen yield of 26 kg/ha in grass-legume pastures, 25%

utilisation of forage, 1% loss of nitrogen to nitrous oxide, the nitrous oxide atomic ratio of 44/28, and a nitrous oxide global warming potential of 298.

The above estimates suggest that sown grass and grass legume pastures in the Condamine region could have a positive influence on reducing green-house gases because the benefits of carbon sequestration were estimated to outweigh increases in green-house gas emissions. At commercial grazing pressures the mean annual net benefits are 351 kg/ha $CO_2e$ for sown grass pastures, and 1174 kg/ha $CO_2e$ for sown grass-legume pastures.

Table 4.3 Estimated effects of grazing pressure on sown grass-legume pastures at four trial sites across three land resource areas concerning mean annual productivity, economic returns, soil carbon and livestock emissions. Data are the means from 121 years (11 periods of 11 years).

| Grazing Pressure | Average Stocking Rate*** | Pasture Growth | Final Pasture Cond'n | Live weight Gain of Beef Cattle | | Gross Margin | Soil Carbon Increase | Cattle Methane Emissions |
|---|---|---|---|---|---|---|---|---|
| % Util | hd/100ha | kg/ha | | kg/hd/dy | kg/ha | $/ha | kg/ha | kg/ha |
| **(a) Basalt Uplands at Colliery Park** | | | | | | | | |
| 10 % (low) | 22.0 | 4999 | good | 0.56 | 45.6 | 61.3 | 1034 | 13.1 |
| 25 % | 34.9 | 4514 | good | 0.52 | 67.2 | 92.3 | 883 | 20.3 |
| 35 % (high) | 46.4 | 3173 | declining | 0.36 | 83.7 | 64.4 | 685 | 25.7 |
| **(b) Basalt Uplands at Cattle Camp** | | | | | | | | |
| 10 % (low) | 21.5 | 4859 | good | 0.56 | 44.7 | 73.7 | 1018 | 14.0 |
| 25 % | 34.0 | 4351 | good | 0.53 | 65.7 | 112.2 | 877 | 21.4 |
| 35 % (high) | 45.0 | 3076 | declining | 0.37 | 80.9 | 97.0 | 710 | 26.4 |
| **(c) Brigalow Lands at Roundview** | | | | | | | | |
| 10 % (low) | 13.2 | 4003 | good | 0.53 | 26.1 | 32.3 | 1017 | 7.8 |
| 25 % | 21.8 | 3684 | good | 0.51 | 40.9 | 53.9 | 913 | 12.7 |
| 35 % (high) | 30.5 | 2851 | declining | 0.40 | 64.1 | 59.6 | 807 | 17.2 |
| **(d) Brigalow Lands at Oaklands** | | | | | | | | |
| 10 % (low) | 14.2 | 3278 | good | 0.53 | 27.6 | 34.4 | 657 | 8.3 |
| 25 % | 22.8 | 3040 | good | 0.49 | 41.3 | 52.7 | 574 | 12.9 |
| 35 % (high) | 30.8 | 2099 | declining | 0.36 | 52.7 | 38.1 | 473 | 16.7 |
| **(e) Alluvial Plains at Canimbla** | | | | | | | | |
| 10 % (low) | 17.2 | 3672 | good | 0.51 | 32.5 | 38.5 | 730 | 10.1 |
| 25 % | 26.5 | 3145 | good | 0.48 | 46.3 | 55.6 | 542 | 15.1 |
| 35 % (high) | 34.4 | 1612 | declining | 0.25 | 37.4 | 17.6 | 275 | 17.9 |
| **Means** | | | | | | | | |
| 10 % (low) | 17.6 | 4202 | good | 0.54 | 35.3 | 48.0 | 891 | 10.6 |
| 25 % | 28.0 | 3762 | good | 0.50 | 52.3 | 73.3 | 758 | 16.5 |
| 35 % (high) | 37.4 | 2490 | declining | 0.35 | 63.8 | 55.4 | 590 | 20.8 |
| **Mean** | **27.7** | **3485** | | **0.46** | **50.5** | **58.9** | **746** | **16.0** |

*** Young cattle purchased at 280 kg and sold 12 months later

Table 4.4 Estimated effects of grazing pressure on mean annual carbon sequestration and methane emissions (and their difference) for sown pastures relative to the rates for native/existing pastures ***.

| **Grazing Pressure** | **Sown Grass Pasture** | | | **Sown Grass Legume Pasture** | | |
|---|---|---|---|---|---|---|
| **% Utilisation** Designed and actual | Additional Carbon Sequestered $CO_2e$ (kg/ha/yr) | Additional Methane Emissions $CO_2e$ (kg/ha/yr) | **Difference** $CO_2e$ (kg/ha/yr) | Additional Carbon Sequestered $CO_2e$ (kg/ha/yr) | Additional Methane Emissions $CO_2e$ (kg/ha/yr) | **Difference** CO2e (kg/ha/yr) |
| 5 % (4.2) | 492 | 11 | 481 | 2096 | 45 | 2051 |
| 15% (12.9) | 472 | 33 | 439 | 1796 | 119 | 1677 |
| 25 % (22.2) | 448 | 56 | 392 | 1461 | 162 | 1299 |
| 35 % (32.0) | 469 | 79 | 390 | 1154 | 171 | 983 |
| 50% (47.5) | 178 | 110 | 68 | 550 | 138 | 411 |
| Mean | 412 | 58 | 354 | 1411 | 127 | 1284 |

*** Values shown are additional and relative to native/existing pastures because the sequestration rates for native pasture have been deducted from the sown pasture rates. Methods for calculating $CO_2$ equivalents are described in the text.

The optimum commercial grazing pressure in terms of maximum economic return per hectare was estimated to be 25 to 30% utilisation and this was consistent across trial sites and land types as shown in Tables 4.2 and 4.3. This is also shown in Figure 26 where the influences of grazing pressure on gross margin/ha are compared for existing pastures, sown grass pastures and grass-legume pastures. This data was presented to colleagues at peer review meetings and to several producer field days where it drew considerable discussion concerning the resilience of pastures to grazing pressure. An outcome from the discussions was to slightly adjust the model to decrease the effect of grazing pressure on the rate of decline in pasture productivity and condition. This shifted the economic optimum grazing pressure from 25 towards 30% utilization. The optimum grazing pressure found for legume-based pastures was estimated to be slightly lower than for sown grass pastures.

Economic returns were maximised at all sites from use of sown grass-legume pastures. Legumes were estimated to provide much larger returns than the cost of adding a few dollars to the cost of establishment. The main costs for establishment were in land preparation, the planting operation and the cost of grass seed. While the mean annual benefit of legumes was 47 % of the gross margin (adding 24 $/ha) the mean cost of seed was just 15 % of establishment costs (120 $/ha).

The mean economic return from sown grass pastures was generally higher than for native/grass but not always as demonstrated in Figure 4.7 at Oaklands and Canimbla. Use of the low-cost band seeder to establish a sown grass pasture at Canimbla was cost negative because productivity gains were very low. In this case the grasses sown were similar to the existing pasture and thus the increased benefits from cattle were less than the costs of establishment. However, if legumes could also be established with the band seeder as is assumed in Figure 4.7, then increased returns from the grazing system would occur.

In contrast to Canimbla, the seedbed preparation at Oaklands for sown pastures was thorough but a comparatively expensive operation as land use was changed from cropping back to pasture. A small lift in production was expected to be followed by a longer-term pasture rundown phase but economic returns were estimated to be worse with sown grass, compared to native pasture, and best for when a grass-legume pasture was used.

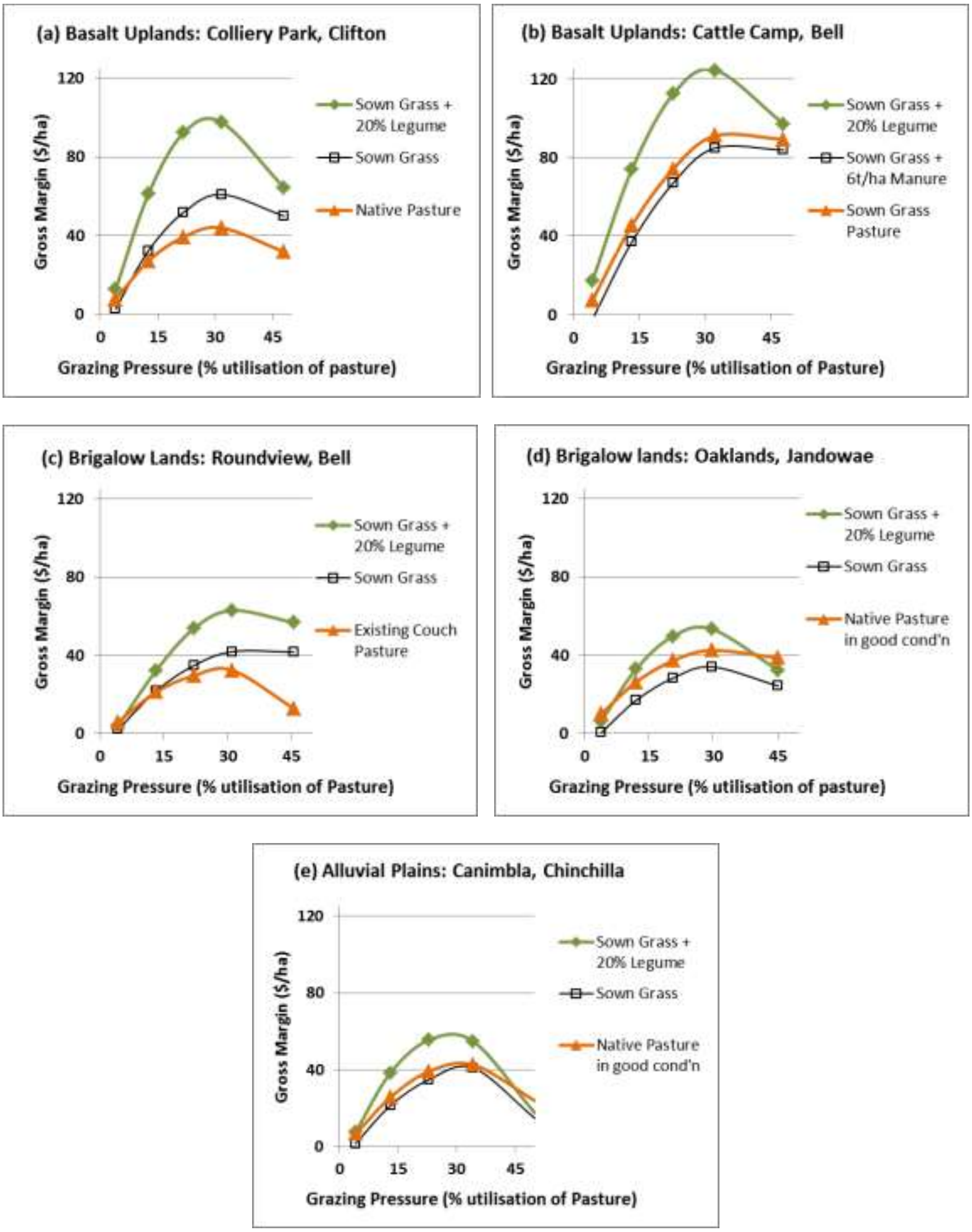


Figure 4.7 Effects of grazing pressure on mean annual gross margins from native or existing sown pasture, sown grass pastures and sown grass legume pastures at two basalt uplands sites (Colliery Park and Cattle Camp), two sites on Brigalow lands (Roundview and Oaklands) and one site on Alluvial plains (Canimbla).

### 4.5.2. Effects of Pasture Rundown and Legumes on Pasture Productivity

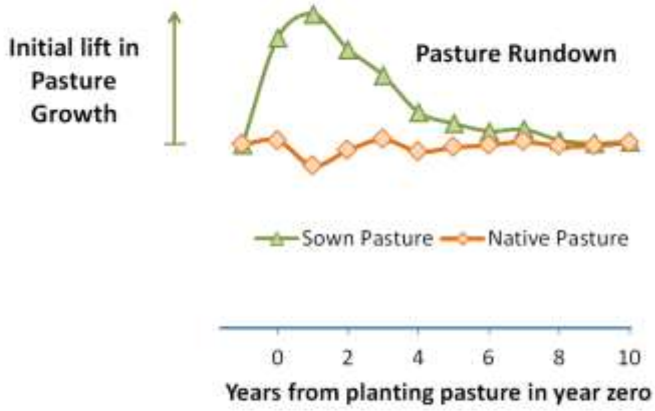


Figure 4.8 Typical characteristics of sown pasture growth relative to the annual growth of native/ existing pastures showing (a) the initial lift in pasture productivity that occurs after planting and (b) the pasture rundown phase that can be just a few years to more than 20 years in some cases.

**Initial Lift and Rundown Characteristics of Pastures**

As shown previously, sown grass and grass-legume pastures were estimated to increase mean annual pasture growth by 673 kg/ha/yr (27 %) and 1135 kg/ha/yr (46 %) respectively compared to the growth of native or old existing sown pastures when averaged across all trial sites. These are mean values over an 11 year simulation period and include the initial lift in productivity that is usually evident in sown pastures and their subsequent decline (Figure 4.8). This decline known as pasture rundown occurs because of declining nutrient availability, particularly nitrogen (Peck et al. 2011).

There were substantial differences between trial sites in pasture productivity and rundown. The highest yielding pastures on the more fertile Basalt Uplands at the Colliery Park and Cattle Camp trial sites were estimated to have an initial lift of 83 % in productivity (2696 kg/ha/yr). This was followed by declining productivity over the next 7 years until there was little difference between sown grass pastures and native pastures in good condition (Figures 4.10 and 4.11).

In contrast pasture yields were limited at Mirrabooka by shallow soils, trees and high grazing pressures, and at Roundview by the dominance of couch grass and high grazing pressure. Similarly, band seeding at Canimbla and the direct drilling of legumes into native pasture at Mirrabooka were not successful because of competition from the existing grass pasture, and thus in these cases, sown pasture did show any advantage in productivity. Results from Canimbla and Mirrabooka highlight the importance of using effective pasture establishment practices.

Substantial lifts in productivity were estimated for Roundview and Oaklands because both of these sites had a significant phase of cropping, seedbed preparation and fallowing before pasture establishment. However, and because of the lighter and less fertile soils at Roundview and particularly Oaklands the initial lift in productivity was less than estimated for Colliery Park and Cattle Camp. The initial lift at Roundview was 2111 kg/ha/yr but in this case the comparison is with the existing couch grass pasture that was in poor condition with its underlying soil characteristics of low infiltration/high runoff, shallow roots and low productivity (2108 kg/ha/yr mean pasture growth). The low fertility soils at Oaklands were estimated to have an initial lift of 1128 kg/ha/yr when compared to a native pasture in good condition (2427 kg/ha/yr mean pasture growth). The rundown period for sown grass pastures at Roundview and Oaklands were 5 and 4 years respectively.

### Influence of Climate Variability on Rundown

Climate variability was estimated to have a substantial influence on pasture productivity and hence on the transparency of being able to accurately observe pasture rundown. (Figure 4.9). This Figure shows large drops in the estimated values of pasture growth that are primarily caused by low rainfall and drought conditions. However, drops in pasture growth are not counter-balanced by large increases in growth due to high rainfall as might be expected. This occurs because the lack of nitrogen availability is predominantly the main factor constraining yield in high rainfall years.

### Graph 1—CV effect on Growth

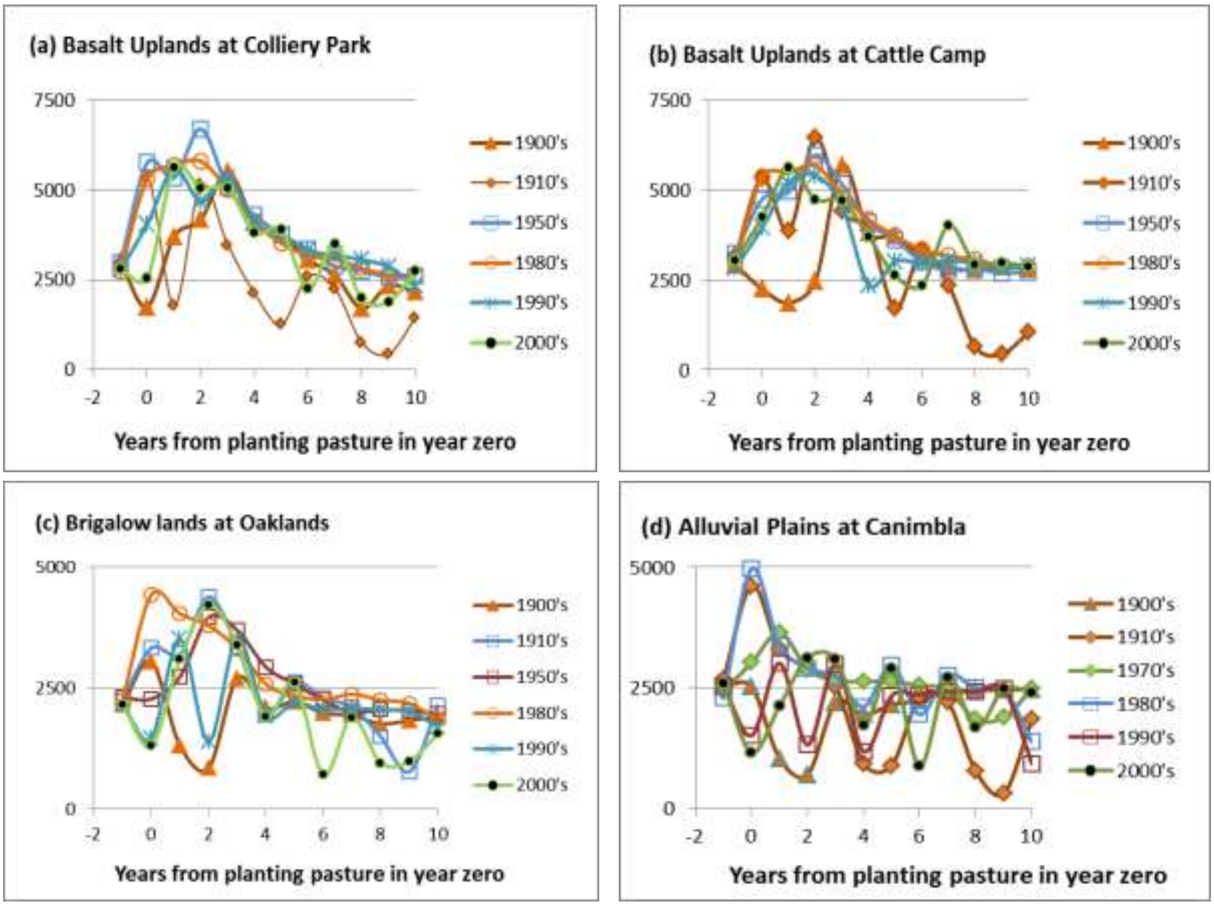


Figure 4.9 Effects of climate variability from six decades on the annual growth (kg/ha) of sown grass pastures at four trial sites across three land resource areas and several management regimes as described in the text.

## Influence of Legumes on Pasture Rundown and Productivity

The influence of legumes to counter the effects of pasture rundown depended on several factors. Firstly, the size of the initial uplift in pasture growth due to renovation compared to the contribution of legumes. On the more fertile sites the initial uplift was constrained to provide a maximum of 15 kg/ha/yr of nitrogen uptake for sites converting crop land to pasture. This was reduced to 3 kg/ha/yr at Canimbla where disturbance from the band seeding operation was minimal. In contrast, legumes provided an additional 1.5 kg/ha/yr of nitrogen per 100 kg/ha/yr of growth up to a maximum of an additional 10kg/ha of nitrogen uptake. Secondly, the contribution of legumes depended on the success of initial establishment (20 % at Colliery Park and 15 % at the other sites) and the rate of decline due to aging, diet selection and grazing pressure.

The estimated mean effects of pasture rundown on sown grass and sown grass-legume without the influence of adverse climate variability and pasture establishment failures are shown in Figures 4.10 and 4.11 for pasture growth and economic returns. These figures show mean values across 11 decades.

The pasture growth and gross margin data in Figures 4.10 and 4.11 illustrate several key concepts that include the following.

- Pasture rundown is a central concept to the use of sown pastures in grazing systems, and therefore needs to be included in farm management planning processes, particularly the magnitude of the initial uplift and the duration of the rundown phase
- Legume contributions of nitrogen to foster additional grass growth were important at all sites. They were estimated to have less influence than pasture rundown at Colliery Park and Cattle Camp, however, the estimated contributions by legumes at the other less fertile trial sites were equally or more important than rundown especially for the low cost band seeding practice at Canimbla.
- Legumes are a relatively minor cost when establishing a sown pasture but they contribute greatly to the profitability of sown pastures. This highlights the value of developing technologies to improve the reliability and resilience of agricultural practices to successfully establish and maintain palatable legume-based sown pastures.
- Pasture rundown and legumes have a significant influence on carbon sequestration rates and this is investigated in more detail in the following section over a longer time frame (50 years) than used in this experiment.

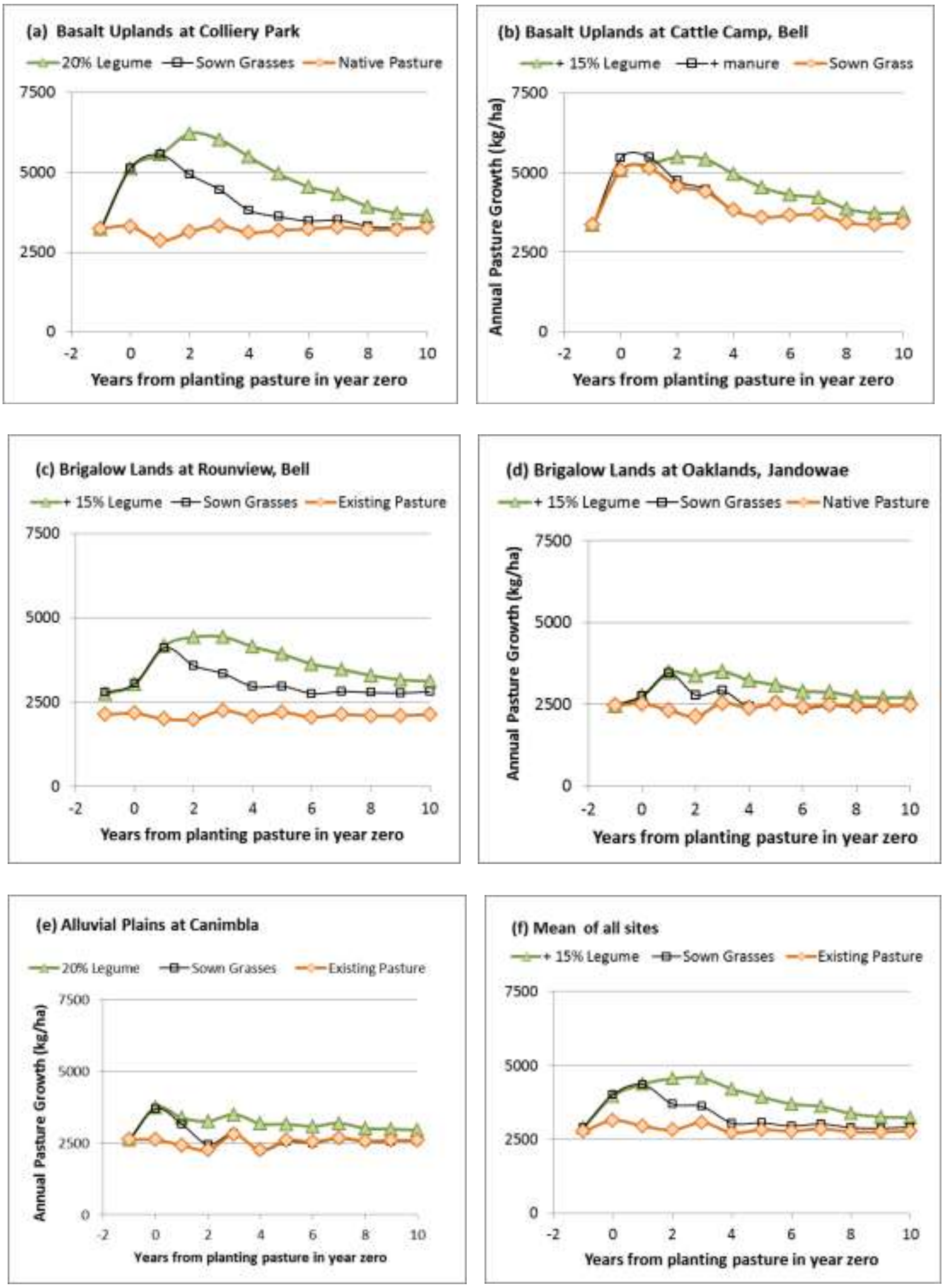


Figure 4.10 Estimated effects of pasture rundown on the mean annual growth (kg/ha/yr) of sown grass and grass-legume pastures at five trial sites (and the mean of those sites) across three land resource areas and several management regimes as described in the text. Data are the means from 11 decades.

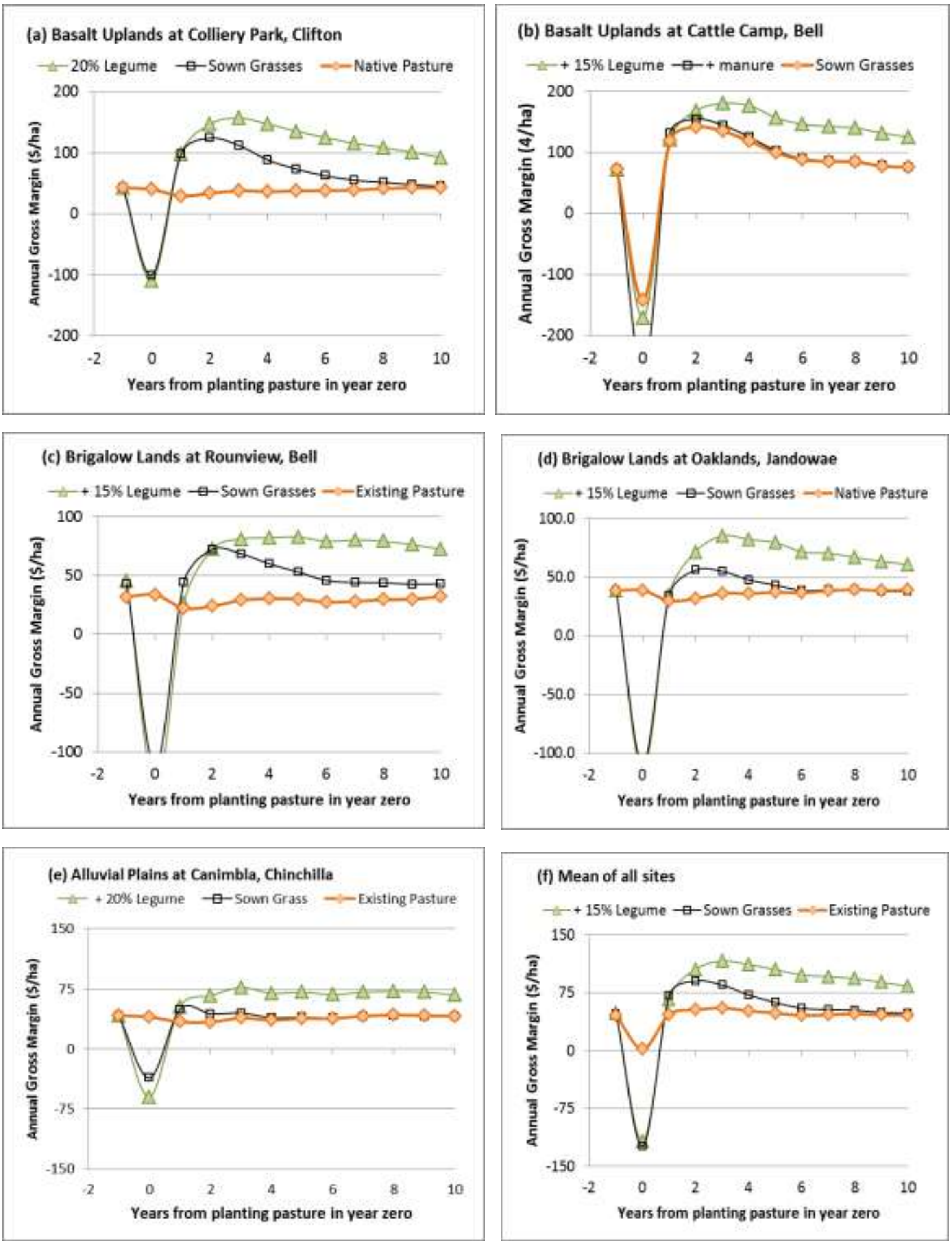


Figure 4.11 Estimated effects of pasture rundown on the mean annual gross margin ($/ha) of sown grass and grass-legume pastures at five trial sites (and the mean of all five sites) across three land resource areas and several management regimes as described in the text. Data are the means from 11 decades and there are differences in y axis scale.

## 4.6. Results (Experiment 4): Soil Carbon Sequestration

The mean observed starting value of soil carbon (0-30 cm) across all trial sites was 1.13% (David Hall, 2014 pers. comm.). Values ranged from 0.63 to 0.88 % carbon (31 to 35 t/ha) on light sandy soils of the Brigalow and Alluvial plains to an average of 1.68 % carbon (52 t/ha) for the black cracking clays of the Basalt uplands with some values up to 2.16%. Estimated bulk density at the trial sites for the 0-30 cm soil layer were calculated from soil texture and ranged from 1.03 g/cm$^3$ for the clay soils at Colliery Park to 1.57 g/cm$^3$ and 1.68 g/cm$^3$ for the sandy loams at Roundview and Oaklands. The starting values of soil carbon for each of the trial sites that were used for estimating carbon sequestration in the simulations are shown in Table 4.5.

Estimated soil carbon sequestration rates were found to vary across the Condamine catchment depending on starting level of soil carbon, paddock history, type of pasture, length of time from establishment of sown pastures and seasonal weather conditions. The mean carbon sequestration rate for all pastures across all sites and all simulation periods was 117 kg/ha/year in the 0-30 cm soil layer. There were substantial differences between decades in sequestration rates but the overall means of the four simulation periods were similar: 125, 119, 118 and 104 kg/ha/year respectively for the simulation periods 1901 to 1951, 1921 to 1971, 1941 to 1991 and 1961 to 2011. The large differences estimated between trial sites and management regimes overshadowed differences between land types. Overall means for the Basalt uplands, Brigalow lands and Alluvial plains were estimated to be 117, 129 and 98 kg/ha/year (see Table 4.5).

Soil carbon sequestration rates were estimated to be much higher in the first decade after planting a sown pasture than in later decades. This reflected changes in pasture productivity associated with pasture rundown and the progress of soil carbon levels towards new equilibrium conditions. In sown grass pastures the average for the first decade was 459 kg/ha/year compared with 10, 15 and -36 kg/ha/year over the last three decades.

Native pastures in good condition and sown grass pastures were estimated to have very similar pasture productivity after 10 years (Figure 4.10). Thus it was not surprising that these two pasture systems were also found to have similar soil carbon levels after 50 years. The existing sown grass pasture at Oakleigh was estimated to sequester about the same as a replacement sown grass pasture.

Grass-legume pastures had the highest carbon sequestration rates. They were estimated to sequester an average of 595 kg/ha/year for the first decade after sowing and 113 for the second. This was followed by an average of 32 kg/ha/year over the last three decades (see Table 4.5). Differences in climate and site characteristics had significant impacts on pasture productivity and hence on the above estimates. For example, the range in sequestration rates for the first decade was 360 to 971 kg/ha/year. The data indicate that higher levels of soil carbon will persist if a legume can be maintained as an effective component in the pasture.

The two pastures with the highest sequestration rates were estimated to be the sown grass-legume pastures at Colliery Park and Roundview. These pastures had an average of 971 and 774 kg/ha/year for the first ten years and average gains of 237 and 224 kg/ha/year respectively for the overall 50 year simulation period. These high sequestration rates possibly reflect low starting values of soil carbon and thus soils in poorer condition being rundown through cropping and sheet erosion. Pasture productivity was similar at Cattle Camp to Colliery Park (Figure 4.10) but the starting value of soil carbon at Cattle Camp was 9 t/ha higher and hence the soil carbon sequestration rates were substantially less. Table 4.5 shows the carbon sequestration rate at Cattle Camp was 60% of the Colliery Park rate. This suggests the soils at Cattle Camp to be in better condition in terms of soil organic matter. The above sequestration rates for sown grass-legume pastures in the first decade are significantly more than estimated for the previous experiment where the effects of grazing pressure reduce the percent legume in the pasture. In this experiment the percent legume in the pasture was held constant and thus extra nitrogen was estimated to be available for pasture growth which then enabled higher carbon sequestration rates.

Table 4.5 Mean soil carbon sequestration rates over five decades for the nine trial sites for either native or existing pastures, sown grass pastures and sown grass-legume pastures. Values are means for four simulation periods of 1901 to 1951, 1921 to 1971, 1941 to 1991 and 1961 to 2011.

| Land Type | Trial Site and pasture *** | Starting Soil Carbon | Rate of Change in Soil Carbon Each Decade (kg/ha/year in top 30 cm soil) | | | | | Mean |
|---|---|---|---|---|---|---|---|---|
| | | t/ha | 1st Decade | 2nd Decade | 3rd Decade | 4th Decade | 5th Decade | kg/ha/yr |
| **Basalt Uplands** | Park Lyon SGP | 56.3 | 625 | -38 | -44 | -35 | -64 | 89 |
| | Colliery Park NP | 49.4 | 389 | 137 | 53 | 40 | -20 | 120 |
| | Colliery Park SGP | 49.4 | 706 | -14 | -9 | 12 | -36 | 132 |
| | Colliery Park SGLP | 49.4 | 971 | 62 | 67 | 74 | 10 | 237 |
| | Mirrabooka EP | 46.4 | 258 | 88 | 64 | -69 | 58 | 80 |
| | Mirrabooka SGLP | 46.5 | 360 | 96 | 69 | -78 | 73 | 104 |
| | Cattle Camp SGP | 58.4 | 492 | -14 | -44 | -34 | -53 | 69 |
| | Cattle Camp SGLP | 58.4 | 729 | 43 | 15 | 21 | -11 | 159 |
| | Catlle Camp NP | 58.4 | 269 | 92 | 1 | -17 | -42 | 60 |
| | **Mean** | **53** | **533** | **50** | **19** | **-10** | **-9** | **117** |
| **Brigalow Lands** | Oakleigh EP | 35.5 | 307 | 164 | 62 | 48 | 17 | 119 |
| | Oakleigh SGP | 35.3 | 430 | 101 | 35 | 38 | 6 | 122 |
| | Oaklands SGP | 31.4 | 370 | 113 | 31 | 38 | -1 | 110 |
| | Oaklands SGLP | 31.4 | 470 | 167 | 55 | 59 | 17 | 153 |
| | Roundview EP | 33.6 | 202 | 98 | -50 | -10 | -17 | 45 |
| | Roundview SGLP | 33.6 | 774 | 167 | 63 | 71 | 44 | 224 |
| | **Mean** | **33** | **425** | **135** | **33** | **41** | **11** | **129** |
| **Alluvial Plains** | Canimbla EP | 38.5 | 276 | 103 | 55 | 26 | -25 | 87 |
| | Canimbla SGLP | 38.5 | 495 | 154 | 77 | 88 | -10 | 161 |
| | Leic't Crossing SGP | 26.7 | 281 | 54 | 36 | 35 | -124 | 56 |
| | Leic't Crossing SGLP | 26.7 | 365 | 103 | 49 | 46 | -129 | 87 |
| | **Mean** | **33** | **354** | **103** | **54** | **49** | **-72** | **98** |
| | Mean EP | 45.3 | 279 | 104 | 25 | -6 | -9 | 78 |
| | Mean SGP | 41.9 | 459 | 52 | 10 | 15 | -36 | 100 |
| | Mean SGLP | 40.6 | 595 | 113 | 56 | 40 | -1 | 161 |
| | **Mean** | **42.4** | **463** | **89** | **30** | **18** | **-15** | **117** |

*** NP=native pasture, EP= existing pasture, SGP = Sown grass pasture, SGLP = sown grass legume pasture

Sequestration rates on existing pastures were variable. At Roundview and Mirrabooka the estimated soil carbon levels on existing pastures showed little change. For the couch grass pasture at Roundview there was an estimated net gain of soil carbon at an average rate of 45 kg/ha/year but this varied from a loss of 8 kg/ha/year for the 50 year simulation period from 1961 to 2011 to a gain of 66 kg/ha/year for the simulation period from 1941 to 1992. It was concluded that soil carbon at this site had reached near equilibrium conditions again after its conversion from cultivation in the 1970s to a green couch permanent pasture. Both losses and gains in soil carbon were also estimated for the native pasture at Mirrabooka with fluctuations correlating to seasonal conditions. During prolonged dry periods there were estimated losses of up to 192 kg/ha/year over a decade while there were also gains of up to 353 kg/ha/year averaged over a decade during wetter than average periods.

Differences in observed levels of soil carbon from the first sampling in 2012 to the second sampling in 2014 were typically ± 0.3 % C in 10 cm soil layers across the 9 trial sites and there was an average gain of 0.18% in the 0-30 cm layer (data from David Hall, 2014 pers. comm.). Most sites showed gains in carbon but differences ranged from losses of 1% to gains above 1% for the 0-30 cm soil layer (see Table 1.3).

Gains of over 0.1% C in a single year for the 0-30 cm soil layer represent very large increases in soil carbon of about 4 t/ha which may occur as a pasture moves from drought to an exceptional year at the start of a pasture development phase and/or with additional nitrogen fertilizer but is unlikely in the normal course of events. In comparison, the rates of carbon sequestration reported in Table 4.5 are quite small when expressed as a percent change in soil carbon. For example, the estimated mean rates of change for the first decade (463 kg/ha/year) in the 0-30 cm soil layer is equivalent to an increase of just 0.01 % C per year (assuming an average bulk density of 1.35 g/cm$^3$). These results highlight the difficulty of measuring and interpreting changes in soil carbon over short time periods.

A strong linear relationship ($R^2 = 0.83$) was found between observed values of total soil nitrogen and soil carbon when the 2014 data from all trial sites was pooled (Figure 4.12) and a very similar relationship was found for the 2012 data. Importantly, the carbon to nitrogen ratio was 14:1. This data suggests that it is not possible to substantially increase soil carbon unless soil nitrogen is also increased and that 1000 kg of nitrogen is required to lift soil carbon by 14 t/ha (an increase of 0.35% carbon). For grazing systems the most effective way to increase soil nitrogen is via legumes. However, most leguminous pastures cannot lift soil nitrogen rapidly. Inputs of 1000 kg/ha are likely to take many decades.

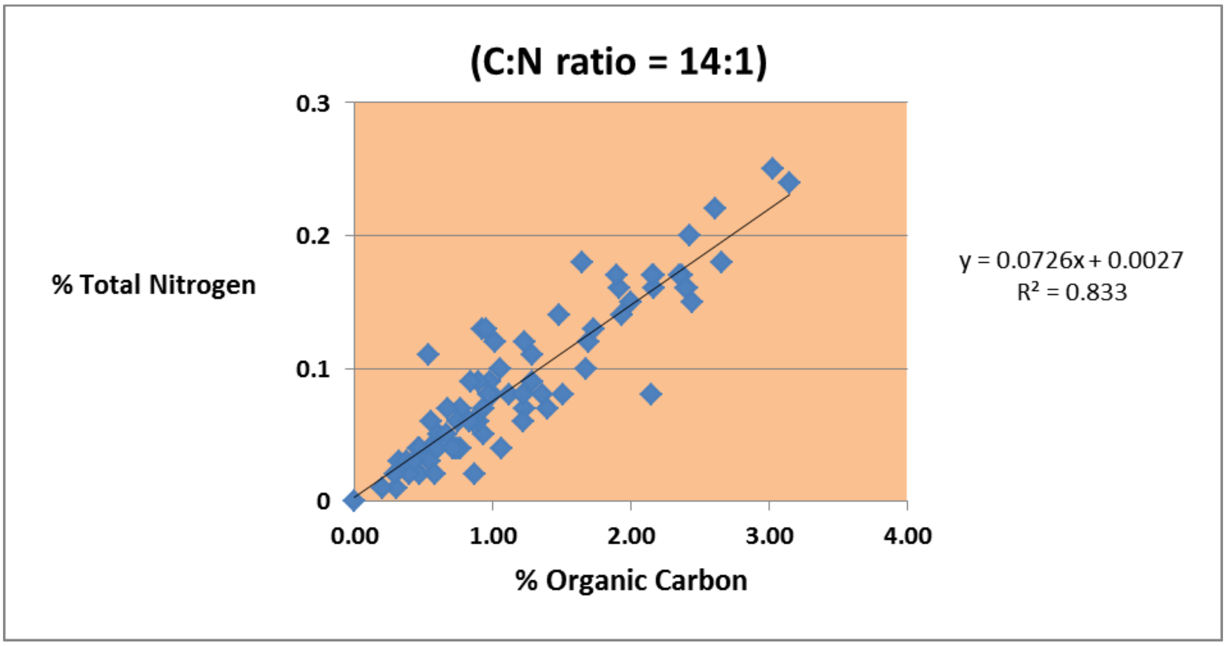


Figure 4.12 Observed relationship between total soil nitrogen and soil carbon using the April 2014 data from all trial sites. (*source: David Hall, 2014 pers. comm.)*

# 5. Communication of Results

## 5.1. Bus tour and Farm Walks

Presentations were made to the bus tour and farm walks on 14th June and 2nd Aug 2014. Discussions focussed on the trial objectives, soil characteristics and infiltration, soil health and the role of soil carbon, use of the weather stations, establishment of sown pastures, weed control, benefits of legumes in cattle nutrition and building soil health, grazing management, production and economics of sown pastures, proposed bio-economic analyses using GRASP and the role of forage crops. Photos from these events are shown in Figures 5.1 and 5.2.

Cattle Camp discussion s– 14 June 2014 Bus Trip

Figure 5.1 Discussions of sown pasture production and the role of forage at Roundview, Cattle Camp and Oaklands on 14th June and 2nd Aug 2013


Figure 5.2 Measuring infiltration rates of soils at Roundview, and discussion of sown pasture production, economic returns and soil carbon at Cattle Camp on 2nd Aug 2013

## 5.2. Peer Review Presentations

A presentation about the project with preliminary results was given to about 50 people at the NCCARF '*Climate Adaptation Future Challenges 2014'* Conference at Broadbeach (Clewett et al. 2014). A copy of the factsheet prepared for this presentation is shown in Figure 5.3

A peer review presentation was given to nine colleagues on 12th March 2015. This 90 minute presentation focussed on reviewing the methods used in the project to apply the GRASP model to sown pastures. The meeting involved several of GRASP's main authors. A key outcome from the meeting was to change some of the parameter settings affecting the influence of grazing pressure on pasture growth.

## 5.3. Field Days

The background, objectives and results of the bio-economic modelling were presented to producers at four field days in March 2015 at Chinchilla, Bell, Jandowae and Clifton. The theme and title of the 45 minute presentations was "*Legumes boost returns from sown pastures*". The main points were:

- Degraded crop and grazing lands are improved through establishment of legume-based sown pastures with bonus payoffs in production, carrying capacity, economic returns, and GHG emissions and sequestration rates.
- Sown pastures are usually most productive in the first few years after planting and then gradually decline in productivity (known as "pasture rundown" ) in the following years because of nutrient limitations mainly nitrogen
- Maintaining legumes in pastures increases soil nitrogen, pasture growth and cattle production.
- Legumes can help to offset pasture rundown.
- While droughts cause significant losses in some years, nitrogen is limiting in most years.
- Stocking rates should aim to utilise 25 to 30 % of pasture growth.
- Increased pasture production builds soil carbon which improves soil health.

All presentations were similar in approach but had results relevant to each local area.  A two-page factsheet was prepared for each field day with locally relevant data (see example in Figure 5.4 for the field day at Clifton).

Many questions were asked by producers concerning the methods and results particularly in relation to the impacts of grazing pressure on pastures, cattle performance, economic returns and soil carbon.  The main outcome and feedback from discussions concerned the optimum grazing pressure, seasonal adjustments in grazing pressure, and the response of pasture to grazing pressure.

Interactions with landholders highlighted the need for further extension activities that focussed on farming practices that help to overcome risks including the risks that are linked with agronomy, grazing management, financial issues and climate variability.

# Improving Risk Management & Soil Carbon with Sown Pastures

Jeff Clewett[1], Christian Capp[2], Col Paton[3], David Hall[4] and David George[5]

**In "Future Challenges" National Climate Adaption Conference, Gold Coast, 30 Sept – 2 Oct 2014**

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Combating climate change has opportunities and challenges for agriculture. There is opportunity to build soil fertility by storing more carbon in the soil as organic matter. This improves productivity and also sequesters greenhouse gases from the atmosphere.

However, given the likelihood of more adverse climate conditions in the future there will also be an on-going challenge in farming to maintain sustainable production and profits. Adaptations to manage climate risk will be needed such as converting marginal cropland to permanent pasture (Condamine Alliance 2012).

**Condamine Catchment**

This paper highlights our on-farm work with sown pastures concerning the effects of climate and management on production, profits and soil carbon in the Condamine region of Southern Queensland.

Current field trials on 7 properties address sub-tropical sown grass and grass-legume pastures established on both old cultivations and pastures needing renovation. Carbon levels in these soils (0-10 cm) are low and range from 0.4% on sandy loams to 2.0% on clay soils.

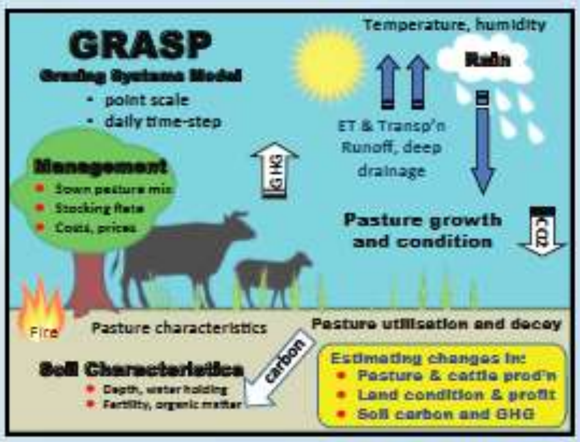
| Paddock Location | History | Landform | Soil Type | Soil Carbon (0-30cm) | |
|---|---|---|---|---|---|
| | | | | % | t/ha |
| Site 1: Clifton | Old cultivation sown to pasture | Basalt uplands | Cracking clay | 1.64 | 51 |
| Site 2: Clifton | Renovated native pasture | Basalt uplands | Cracking clay | 1.47 | 46 |
| Site 3: Bell | Renovated couch grass pastures | Brigalow uplands | Sandy clay loam | 0.70 | 34 |
| Site 4: Bell | Old cultivation sown to pasture | Basalt uplands | Cracking clay | 1.78 | 58 |
| Site 5: Jandowae | Cultivation to be sown to pasture | Brigalow uplands | Sandy clay loam | 0.62 | 31 |
| Site 6: Jandowae | Old cultivation sown to pasture | Brigalow plains | Clay loam | 0.77 | 35 |
| Site 7: Chinchilla | Old cultivation sown to pasture | Alluvial plains | Clay loam | 0.83 | 38 |

**Table 1:** Regional variation of paddocks being used to test the value of sown pastures

Agroclim Australia   Condamine Alliance   Australian Government

Figure 5.3 Brochure prepared for 'Climate Adaptation Future Challenges 2014' Conference (Clewett et al. 2014).

A modified version of the GRASP computer model is being used to assess impacts of climate variability, climate change and management on the growth and condition of sown pastures, cattle live weight gains, economic returns, Green House Gas (GHG) emissions and soil carbon.




## Conclusions

Results show significant annual and decadal fluctuations in pasture productivity. They highlight the benefits of legumes and the importance of adjusting stock numbers to manage risk. Results are relevant to some 0.3 M ha in the region and show that changes in short-term carbon sequestration rates are dependent on environment and management regimes. They can be negative due to drought, pasture rundown and / or over-grazing.

**Table 2** Estimated effects of grazing pressure on average annual productivity, profitability and carbon flux from grazing sown pastures in the Condamine region of Southern Queensland (pastures sown in year 3 of an 18 year simulation period (1996 - 2013). Data are averaged for 3 locations.

| Grazing pressure: % utilisation of growth | | Pasture growth (kg/ha/yr) | Final cond'n of pasture | Live weight gain of beef cattle (kg/hd/yr) | Live weight gain of beef cattle (kg/ha/yr) | Gross margin ($/ha/yr) | Soil carbon increase (kg/ha/yr) | Methane from cattle (kg/ha/yr) |
|---|---|---|---|---|---|---|---|---|
| Low | 19 | 3892 | Good | 169 | 43 | 50 | 398 | 15 |
| Medium | 28 | 3707 | Good | 159 | 58 | 72 | 373 | 21 |
| High | 36 | 2934 | Poor | 146 | 56 | 68 | 269 | 21 |

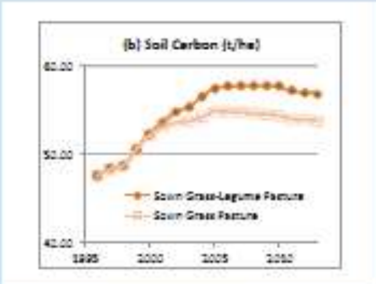




**Figure 1:** Estimated effects of climate variability, pasture rundown and presence of legumes on: (a) growth of sown pastures and (b) carbon sequestration. Data show annual values averaged across several soil types and locations in the Condamine region for the period 1995 to 2013 (pastures sown in year 3).

**References and funding**


1. Condamine Alliance (2012). "Increasing soil carbon in degraded cropping and grazing Land". Project Plan for Project AOTGR1-137. See Condamine Alliance website www.condaminealliance.com.au

2. McKeon, G.M. for the GRASP Modelling Team (2008). Improving Grazing Management Using the GRASP Model. Final Report on Project NBP.338. Meat and Livestock Australia, North Sydney 82 pp.



3. Australian Government funding support via the Department of Agriculture's Action on the Ground Program is acknowledged.


Figure 5.3 *(continued)* Brochure prepared for *'Climate Adaptation Future Challenges 2014'* Conference (Clewett et al. 2014).

# LEGUMES BOOST RETURNS FROM SOWN PASTURES

FIELD REPORT / DR JEFF CLEWETT / AGROCLIM AUSTRALIA

## Summary of findings

- Maintaining legumes in pastures increases soil nitrogen, pasture growth and cattle production.
- Legumes can help to offset pasture rundown.
- While droughts cause significant losses in some years, nitrogen is limiting in most years.
- Stocking rates should aim to utilise about 25% of pasture growth.
- Increased pasture production builds soil carbon which improves soil health.

## Overview

The Condamine Alliance Action on the Ground project has been trialling on farm practices to increase sequestration of carbon in the soil by enhancing biomass and/or productivity through the incorporation of perennial pastures in farming systems. Funded by the Australian Government, nine local trial sites were established in Chinchilla, Jandowae, Bell and Clifton districts. The trials explored a variety of soil types and land management practices on degraded cropping and grazing land.

Three sites in the Clifton area:
Parklyon, Colliery Park and Mirrabooka trialled:

- sowing legumes and grasses into native pasture
- converting old cropping land to permanent pasture by sowing legumes and grasses
- adding manure to crop rotations to increase organic matter and nitrogen.

## Methodology

Soil and pasture field observations and a version of the GRASP computer model for sown pastures were used to assess results (Figure 1). GRASP used data from the trial sites with long-term weather records to estimate the impacts of seasonal conditions and management on pasture production, cattle live weight gains, economic returns, Green House Gas (GHG) emissions and changes in soil carbon. Economic returns were based on pasture establishment costs and growing yearling steers. Results are relevant to some 0.3 million hectares of the Condamine region.


Source: McKeon, G.M. for the GRASP Modelling Team (2008).

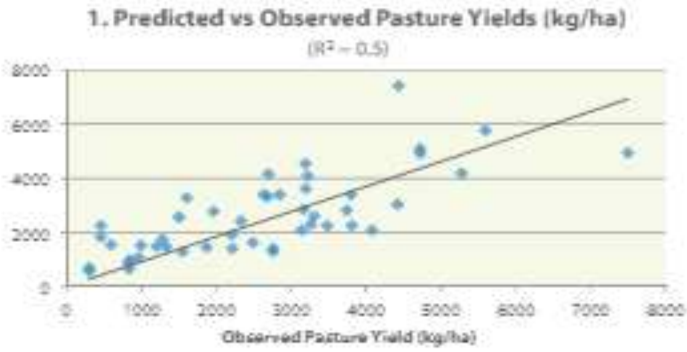
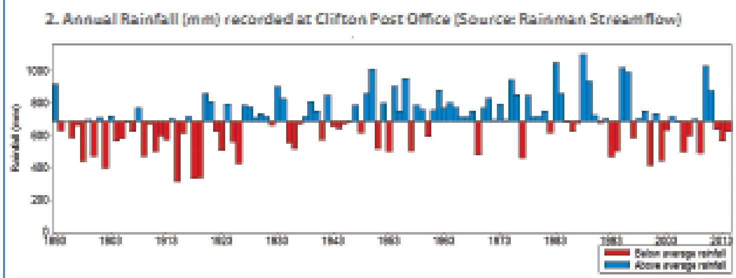
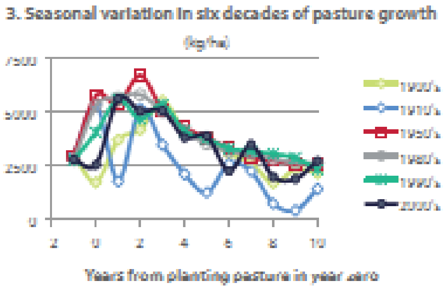



Figure 5.4   Factsheet prepared for Clifton Field Day on 26 March 2015

# Climate Variability

The significant impacts of rainfall variability on pasture growth and cattle production were clearly evident when GRASP was used to assess weather records from each day over the last 120 years (Figure 2: Figure 3). This was particularly evident during droughts but not so much during the wetter years because nitrogen supply became the main limiting factor. Lack of nitrogen restricts pasture growth in most years and hence the interest in legumes.




# Stocking Rate

Adjusting grazing pressure to seasonal conditions is important. Where possible grazing pressure should adjust seasonally to use up to 25% of the feed that grows each year. Lower levels generally increase live weight gains per head but reduce economic returns. Higher levels can increase short term economic returns but if persistently used are likely to cause detrimental effects on pasture condition and reduce live weight gains per head. This leads to lower gross margins and reduced soil carbon. The following analyses from GRASP show estimated effects of grazing pressure on returns from sown grass/ legume pasture at Colliery Park (data are averaged over ten decades).

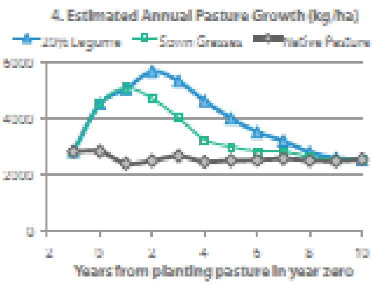
| Grazing Pressure | | Pasture Growth | Final pasture cond'n | Live weight gain of beef cattle | | Gross Margin | Soil Carbon increase* | Cattle methane emissions |
|---|---|---|---|---|---|---|---|---|
| (% utilisation) | | (kg/ha) | | (kg/hd/dy) | (kg/ha/yr) | ($/ha) | (kg/ha/yr) | (kg/ha/yr) |
| Too Low | 10% | 4853 | good | 0.56 | 35.9 | $45.29 | 1004 | 19 |
| Okay | 25% | 3590 | good | 0.47 | 56.6 | $65.57 | 510 | 25 |
| Too High | 35% | 2836 | poor | 0.37 | 55.1 | $45.00 | 78 | 29 |

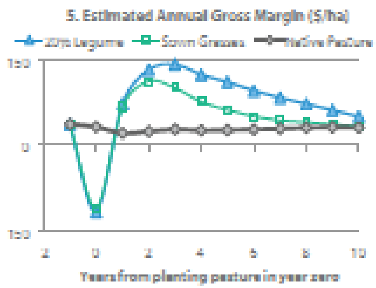
* Over the initial ten year period after planting

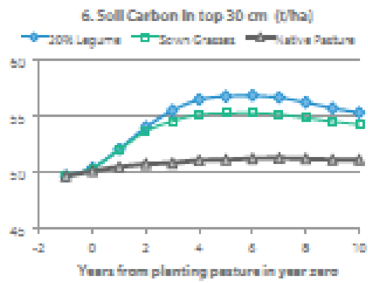
# Pasture Rundown

Pasture rundown has large effects on the growth of sown pastures. Young pastures take advantage of extra nitrogen availability caused by land disturbance but this lift in nitrogen supply normally reduces over time. Legumes can maintain the supply of extra nitrogen and thus provide significant benefits to grasses and diet quality. GRASP analyses for Colliery Park in the graphics below compare three pasture types with estimates averaged over 10 decades across pasture growth (Figure 4), annual gross margin (Figure 5) and soil carbon (Figure 6). The pastures compare:

- a Queensland blue grass native pasture in good condition growing on undulating cracking clay soils clear of trees
- a grass pasture (Rhodes, bambatsi, green panic, Premier digit and Bissett creeping blue) under sown to oats and thus replacing cultivation on the same land type as above
- the same grass pasture under sown to oats but with lucerne in the sown pasture mix. The lucerne successfully establishes as 20% of pasture yield and is then estimated to gradually decrease over time. This data shows the value of legumes for increasing pasture production (and cattle live weight gains) leading to increased economic returns and soil carbon.




**Prepared by:**

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**Further Reading and Acknowledgements:** Condamine Alliance AOTG Soil Carbon Project Final report.

Figure 5.4 *(continued)* Factsheet prepared for Clifton Field Day on 26 March 2015

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# 7. “Swiftsynd” Pasture Measurements

### Introduction
This section provides supporting information to the methods and results described in section 3 concerning pasture observations from the Swiftsynd exclosures at Colliery Park and Roundview. The objective was to measure pasture characteristics (height, cover, species, yield and quality as measured by total % N) in the absence of grazing (i.e. within exclosures) in the control and treatment paddocks at Roundview and Colliery Park.

### Methods
Pasture sampling from the exclosures at Colliery Park and Roundview were carried out in accordance with the proposed methods (Paton et al. 2013) and as summarised in section 3. The dates of harvest were:

- Roundview: 8 April 2013, 12 Feb 2014, 29 April 2014 and 18 Feb 2015
- Colliery Park: 9 April 2013, 13 Feb 2014, 30 April 2014 and 24 Feb 2015

In 2013 data was not recorded in the Colliery Park exclosure (2007 planted pasture) because of damaged fencing and stock grazing.

### Results
Details of data for dry matter yield, pasture height, cover and species composition for 2013 are shown in the following section. Results for 2014 and 2015 are summarised in table 3.1 in section 3. All data for % nitrogen are shown table 3.1. Photographic results for all years are shown below.

### Swiftsynd Pasture Observations for April 2013

**Table 7.1** Pasture Yield data for Roundview and Colliery Park, April 2013

| | Wet (g) | Dry (g) | % Dry Matter | Dry Matter (kg/ha) |
|---|---|---|---|---|
| **Roundview Exclosure** (8 April 2013) | | | | |
| **Standing Leaf and Stem** | | | | |
| Quadrat 1 | 124 | 55.7 | 45 | 2,228 |
| Quadrat 2 | 160 | 59.2 | 37 | 2,368 |
| Quadrat 3 | 188 | 57.5 | 31 | 2,300 |
| Quadrat 4 | 190 | 60.6 | 32 | 2,424 |
| **Mean** | | | **36** | **2330** |
| **% green/dead** | | | | 40/60 |
| **Litter** (bulked over 4 quadrats) | | 12 | | **480** |
| **Colliery Park Exclosure** (9 April 2013) | | | | |
| **Standing Leaf and Stem** | | | | |
| Quadrat 1 | 192 | 64 | 33 | 2,560 |
| Quadrat 2 | 190 | 58.6 | 31 | 2,344 |
| Quadrat 3 | 130 | 41 | 32 | 1,640 |
| Quadrat 4 | 402 | 138.4 | 34 | 5,536 |
| **Mean** | | | **33** | **3020** |
| **% green/dead** | | | | 48/52 |
| **Litter** (bulked over 4 quadrats) | | 46.6 | | **1,864** |

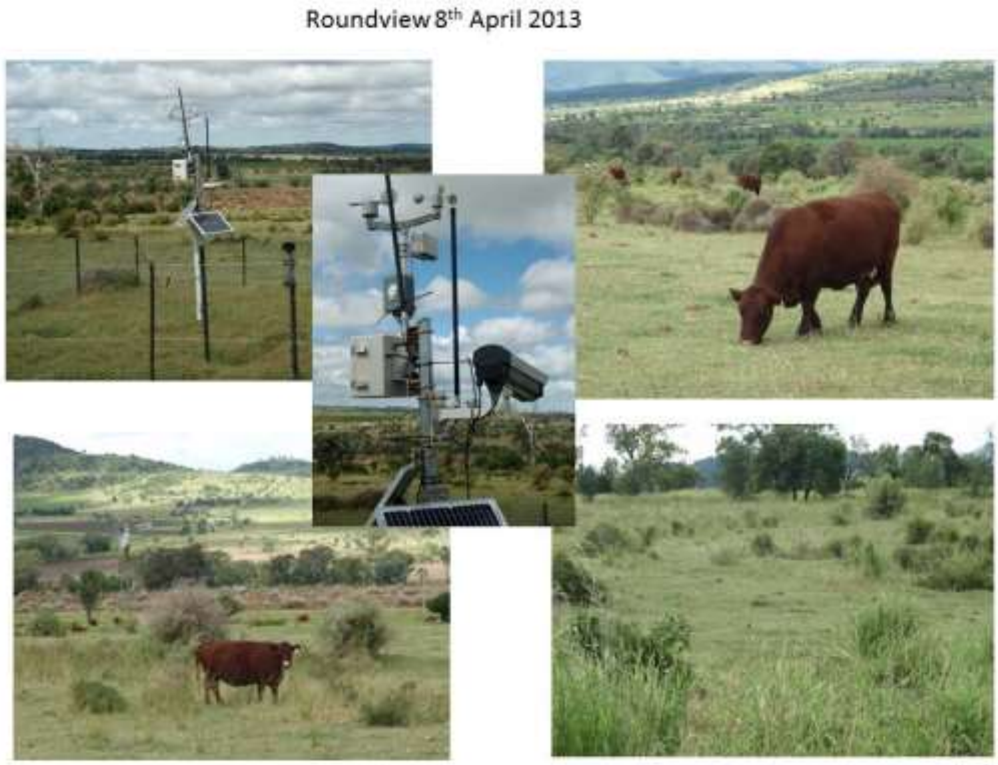


**Figure 7.1** Photos from the control paddock at Roundview showing the exclosure, automatic weather station and camera, and cattle grazing the couch grass and clumps of green panic.

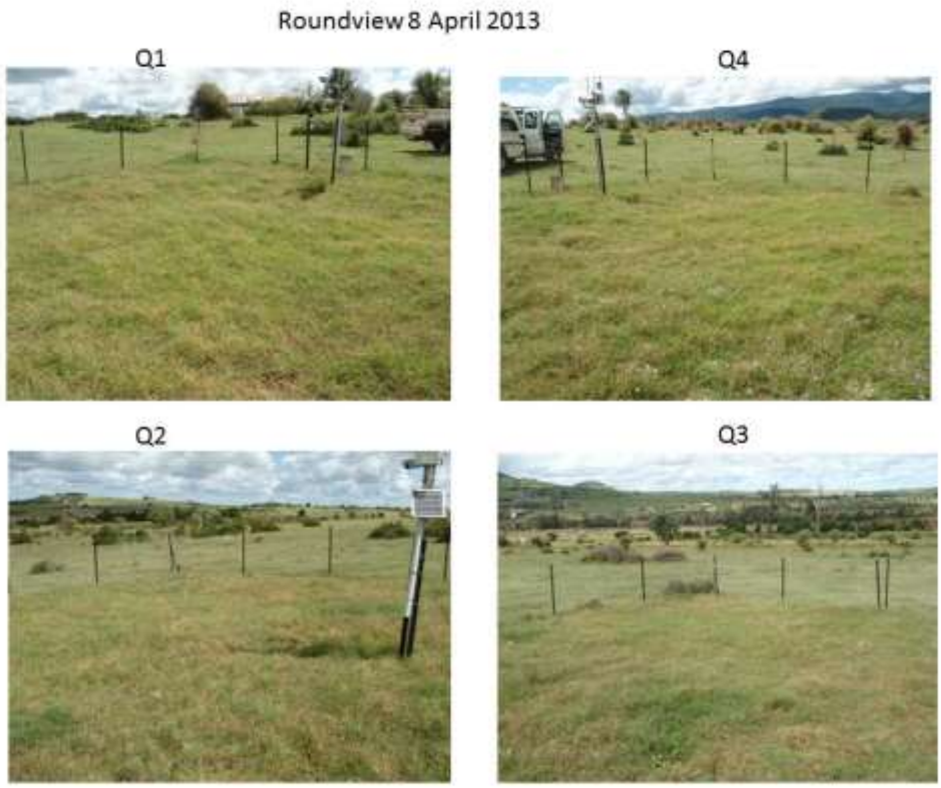


**Figure 7.2.** Photos of the exclosure in the control paddock at Roundview on 8 April 2013 (average yield is 2330 kg/ha). Q1= NW corner, Q2=SW corner, Q3=SE corner and Q4=NE corner.


**Figure 7.3** Photos of quadrats after cutting in the exclosure in the control paddock at Roundview on 8 April 2013. Q1= NW corner, Q2=SW corner, Q3=SE corner and Q4=NE corner.


**Figure 7.4.** Photos from the one-year old pasture paddock (planted April 2012) at Colliery Park showing the pasture inside and outside the exclosure, a view towards the 5 year old paddock and cattle grazing the adjacent native pasture paddock.

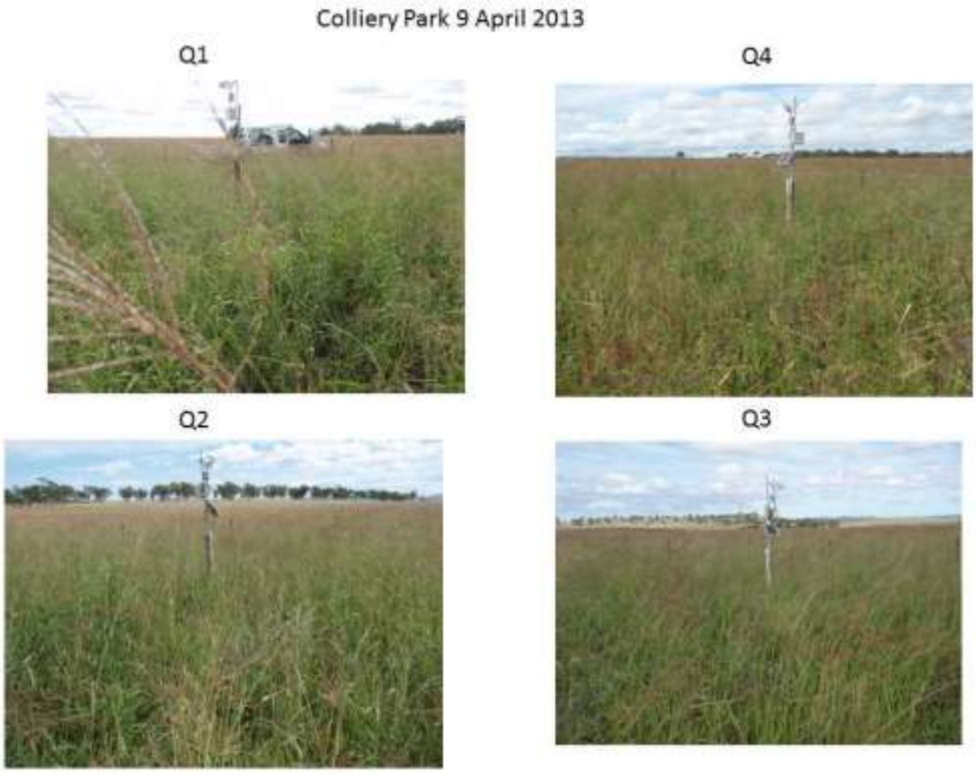


**Figure 7.5.** Photos of the exclosure in the 2012 planted pasture paddock at Colliery Park on 9 April 2013 (average yield is 3020 kg/ha). Q1= NE corner, Q2=NW corner, Q3=SW corner and Q4=SE corner.


**Figure 7.6.** Photos of the quadrats before cutting in the 2012 planted pasture paddock at Colliery Park on 9 April 2013 (average yield is 3020 kg/ha). Q1= NE corner, Q2=NW corner, Q3=SW corner and Q4=SE corner.

**Table 7.2.** Results from Roundview Swifsynd H2 Harvest (8 April 2013) re pasture height, cover and species composition, quadrat area = 0.25m, dominant grass = green couch, sub-dominant grass = nil, sown legume = nil)

| | Quadrat 1 | Quadrat 2 | Quadrat 3 | Quadrat 3 |
|---|---|---|---|---|
| Pasture Height | | | | |
| Height 1 | 9 | 10 | 10 | 10 |
| Height 2 | 10 | 12 | 9 | 9 |
| Mean | 9.5 | 11 | 9.5 | 9.5 |
| | | | | |
| Cover (% total cover) | | | | |
| Green | 70 | 80 | 65 | 85 |
| Dead | 29 | 15 | 20 | 10 |
| Bare | 1 | 0 | 5 | 0 |
| Litter | 0 | 5 | 10 | 5 |
| Rocks | 0 | 0 | 0 | 0 |
| Total | 100 | 100 | 100 | 100 |
| | | | | |
| Species Composition (% of total yield) | | | | |
| Dominant grass | | | | |
| Spp No | 26 | 26 | 26 | 26 |
| % | 90 | 95 | 95 | 97 |
| Sub-dom grass | | | | |
| Spp No | 31 | - | - | - |
| % | 4 | - | - | - |
| Other grasses | | | | |
| Spp No | - | - | - | 16 |
| % | - | - | - | 1 |
| Dicots | | | | |
| Spp No | 50 | 39 | 50 | 50 |
| % | 6 | 5 | 5 | 2 |
| Sown legumes | | | | |
| Spp No | - | - | - | - |
| % | - | - | - | - |

**Species:** 16 = small burr grass, 26 = green couch, 31 = buffel, 39 = Maynes Pest, 50 = other forbes

**Table 7.3.** Results from Colliery Park Swiftsynd H2 Harvest (9 April 2013) in 2012 planted paddock re pasture height, cover and species composition, quadrat area = 0.25m, dominant grass = Green Panic, sub-dominant grasses = Digit blue grass and Rhodes, sown legume = Lucerne, other species = Bambatsi, creeping blue grass and oats litter.

| | Quadrat 1 | Quadrat 2 | Quadrat 3 | Quadrat 3 |
|---|---|---|---|---|
| Pasture Height | | | | |
| Height 1 | 52 | 27 | 42 | 43 |
| Height 2 | 45 | 35 | 30 | 40 |
| Mean | 48.5 | 31 | 36 | 41.5 |
| | | | | |
| Cover (% total cover) | | | | |
| Green | 35 | 55 | 45 | 55 |
| Dead | 10 | 10 | 10 | 10 |
| Bare | 35 | 25 | 20 | 10 |
| Litter | 20 | 10 | 25 | 25 |
| Rocks | 0 | 0 | 0 | 0 |
| Total | 100 | 100 | 100 | 100 |
| | | | | |
| Species Composition (% of total yield) | | | | |
| Dominant grass | | | | |
| Spp No | 27 | 24 | - | 23 |
| % | 70 | 50 | - | 75 |
| Sub-dom grass | | | | |
| Spp No | - | 25 | - | 24 |
| % | - | 35 | - | 15 |
| Other grasses | | | | |
| Spp No | - | - | - | - |
| % | - | - | - | - |
| Dicots | | | | |
| Spp No | - | 50 | - | - |
| % | - | 5 | - | - |
| Sown legumes | | | | |
| Spp No | 64 | 64 | 64 | 64 |
| % | 30 | 10 | 100 | 10 |

Species List**:** 23 = Premier digit, 24 = bambatsi, 25 = creeping blue, 27 = green panic
35 = other naturalised grass, 50 = other forbes, 64 = lucerne

### Swiftsynd Pasture Observations for Feb 2014


**Figure 7.7.** Photos of the exclosure in the control paddock at Roundview on 12 Feb 2014 (average yield is 840 kg/ha). Q1= NW corner, Q2=SW corner, Q3=SE corner and Q4=NE corner.

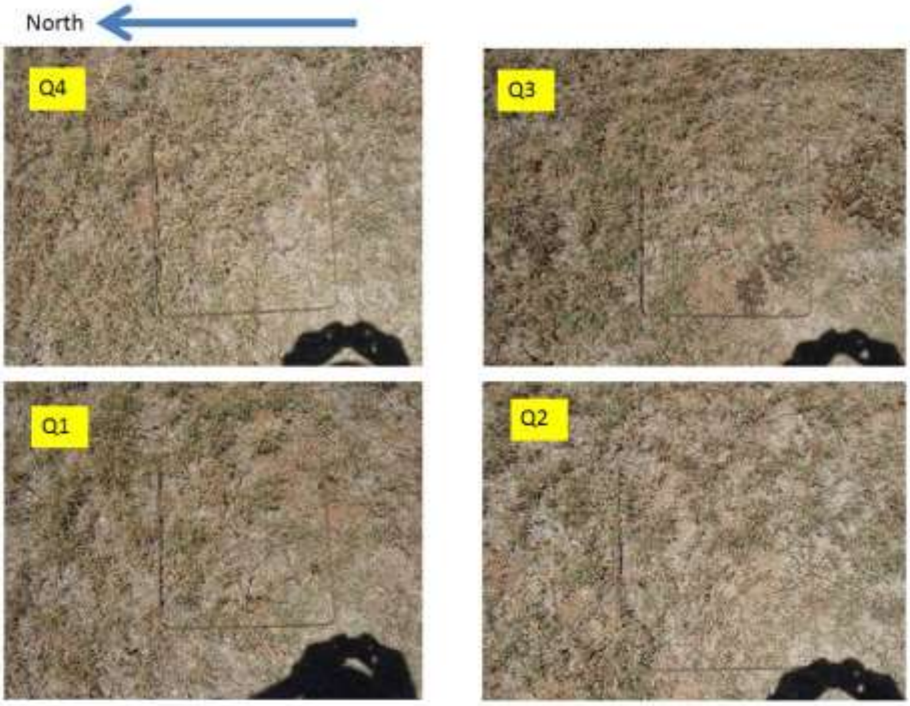


**Figure 7.8** Photos of quadrats after cutting in the exclosure in the control paddock at Roundview on 12 Feb 2014 (average yield is 840 kg/ha). Q1= NW corner, Q2=SW corner, Q3=SE corner and Q4=NE corner.


**Figure 7.9** Photos of the exclosure in the two-year 2012 planted pasture paddock at Colliery Park on 13 Feb 2014 (average yield is 1280 kg/ha). Q1= NE corner, Q2=NW corner, Q3=SW corner and Q4=SE corner.


**Figure 7.10** Photos of the quadrats before cutting in the 2012 planted pasture paddock at Colliery Park on 13 Feb 2014 (average yield is 1280 kg/ha). Q1= NE corner, Q2=NW corner, Q3=SW corner and Q4=SE corner.


**Figure 7.11** Photos of the exclosure in the 2007 planted pasture paddock (planted 2007) at Colliery Park on 13 Feb 2014 (average yield is 960 kg/ha). Q1= NE corner, Q2=NW corner, Q3=SW corner and Q4=SE corner.


**Figure 7.12** Photos of the quadrats before cutting in the 2007 planted pasture paddock at Colliery Park on 13 Feb 2014 (average yield is 960 kg/ha). Q1= NE corner, Q2=NW corner, Q3=SW corner and Q4=SE corner.

## Swiftsynd Pasture Observations for April 2014

**Figure 7.13** Roundview exclosure Control Paddock 29 April 2014

**Figure 7.14** Colliery Park 2012 Planting, 30 April 2014

**Figure 7.15** Colliery Park 2012 Planting, 30 April 2014 Stocktake site

**Figure 7.16** Colliery Park 2007 Planting, 30 April 2014 (Yield is noticeably less than 2012 planting

## Swiftsynd Pasture Observations for February 2015

**Figure 7.17** Roundview Couch grass exclosure in control paddock and Leucaena planted Dec 2014 in legume paddock 18 February 2015

**Figure 7.18** Colliery Park exclosure 2012 Planting, 24 February 2015

**Figure 7.19** Colliery Park Exclosure 2007 Planting, 24 February 2015