Final report

Progressing superior tropical grasses and legumes in seasonally dry Queensland

Project code: B.NBP.0812

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Abstract

Seasonal deficits of yield and quality of native grasslands limits the profitability of beef growing and breeding enterprises in moderate rainfall areas of northern and central Queensland. Previous multi-site Department of Agriculture and Fisheries/Meat & Livestock Australia field testing (B.NBP.0766) identified superior pasture grasses (*Bothriochloa, Brachiaria, Chloris, Dichanthium, Digitaria, Panicum* and *Urochloa*) and legumes (*Centrosema, Clitoria, Desmanthus, Macroptilium* and *Stylosanthes*) for key beef production land-types and the potential for fertilised 'production paddock' systems to improve livestock growth. Under B.NBP.0812, superior lines were tested on basalt (Mt. Surprise), red earth (Charters Towers), duplex (Georgetown) and brown duplex (Moura) land-types as grass/legume swards using establishment and grazing more typical of commercial practice. Reliable establishment was achieved under a range of seasonal conditions. Fertilised mixed grass-legume systems produced high pasture yields on fertile red basalt (sulphur fertiliser) and infertile red earth (phosphorous plussulphur fertiliser) soils. Productive combinations of grasses and legumes were identified. Seasonal changes in forage quality emphasised the critical role of legume leaf in maintaining animal performance in the dry-season. Well-adapted and high-yielding grasses and legumes were also identified for red and black basalt soils near Charters Towers, a previously omitted land-type. Bio-economic analyses at paddock and property levels showed legume only and mixed grass-legume strip systems profitable on fertile and infertile land-types. For long term stylo adoption (broad-scale, no fertiliser) ***of only 20%*** of the properties (affecting 20% of total cattle), approximately 135 000 hd steers and weaners would benefit from sown legumes each year. At an extra 40 kg/hd/yr and a sale price of $4/kg, the gross benefit would be $21.6 M/yr ($108 M pa for 100% adoption).

The paddocks (approx..200-500ha) are relatively simple to implement with excellent establishment achieved using minimal cultivation and herbicide application even when there is poor rainfall after sowing. However, development requires planning to secure seed, fertiliser and equipment and the value proposition should be considered based on an assessment of current costs and expected market prices. Also, there are significant up-front costs and relatively short planting windows (wet season) which means they are best implemented progressively in stages. The costs are broadly half those of implementing leucaena pastures in north Queensland on a similar soil type. The skills and equipment required to develop the production paddocks are readily achievable by most beef producers, although some specific knowledge is required to minimise the risk failure.

The use of production paddocks should provide more resilience to enterprises in the seasonally dry tropics by increasing livestock growth rates and therefore cash flow (weaner/steer sales) through turning off animals earlier or achieving higher sale weights. This can in turn decrease the amount of nitrogen supplements required for growth during the mid- to late- dry season and improve profitability without increasing stocking rates beyond sustainable levels

Executive summary

Background

The seasonally dry tropics in north Queensland (north of Bowen and south of Cape York Peninsular) contains approximately 30% of the Queensland beef herd (Queensland Government, 2019) mostly selling weaners or young steers. The area contains approximately 3.9 million head (MLA 2011) (1.8 million breeders) with a turnoff of approximately 1.05 million head per annum. The volume and quality of feed from native pastures in the 5-7 month dry season is the key constraint on business productivity and profitability (Rolfe et al., 2016). Weaning branding rates and dry season animal growth rates are low and land condition is declining in many areas (Shaw et al., 2022).

The adoption of legumes, particularly stylos broadcast onto light textured and infertile soils, is a known historical method to increase animal growth rates and can support high stocking rates (Anon 1994a, 1994b) and increase business resilience and profitability (Bowen et al., 2019). Recent DAF / MLA studies have shown the potential for a range of legumes and grasses to produce high yields of herbage with significantly higher feed value than native grasslands found on a range of land-types in north Queensland (B.NBP.0766: Cox et al., 2019). Fertiliser phosphorous and/or sulphur was applied when soil levels were thought limiting for legume growth. A ‘production paddock’ system was proposed, whereby dedicated paddocks on more fertile soils would be sown to legumes with or without grasses and used to improve dry-season feeding of weaners, steers or heifers.

This project sought to answer two key research questions:

1. Is it sensible to develop legume-based ‘production paddocks’ within my enterprise and land-type and what are the potential costs and benefits of this?
2. What are the best combinations of grasses and legumes to sow and how do I establish them?

These questions followed producer enquiries at DAF field days and directly to DAF officers. A key focus was the ‘value proposition’ of the production paddocks given the development represents significant effort and up-front costs and the concept was at the relatively early stage of development.

The main target audience was beef producers in the project zone, DAF extension officers and other pasture researchers. The results will be used to develop commercial-scale demonstration sites and to foster adoption by DAF extension staff in the short term with broader adoption in the longer term. These will be used to refine management practices and complete more robust economic analyses using animal performance data to further promote adoption.

Objectives

The (abridged) objectives were as follows:

1. Develop on-property research sites to test combinations of promising grasses and legumes on a range of land-types. Manage as a dry-season ‘weaner’ or ‘grower’ paddock.
2. Measure establishment and seasonal performance of grass/legume combinations under grazing.
3. Estimate the financial benefit (or otherwise) of the sown-pasture system at a property level.
4. Promote the results to beef producers and seed companies.

These objectives were achieved for four of the six sites, but late establishment of two sites meant results were limited to performance during establishment. Economic analyses were conducted for two scenarios on infertile and fertile land-types in north Queensland.

Methodology

On-property replicated experiments were developed on four properties to measure the productivity of fertilised grass x legume combinations on four different land-types: north Queensland – red basalt, red earth and duplex soils in moderate rainfall environments; central Queensland - brown clay soil. Replicated small plot experiments were also conducted to individually test a range of older and newer (under development) grasses and legumes on red and black (clay) basalt soils in a low rainfall environment in north Queensland. Measures included: herbage productivity (cover and biomass), changes in plant populations, feed quality, capacity to seed and acceptance to cattle and tolerance of grazing.
Bio-economic analyses were conducted to test the value proposition of introducing strips of either legumes or legumes+grasses into native grasslands on fertile (red basalt) and infertile (red earth) land types in north Queensland. Herbage yield and quality data from this and the pre-cursor project were used in combination with animal performance data from complementary studies. Current costs and averaged 5-year prices were used. Key messages were promoted through field days, beef industry events and Australia research conferences.

Results/key findings

A range of grasses and legumes were identified as being well-adapted and productive on red and black basalt soils in the low rainfall region near Charters Towers. Herbage yields for the best performing legumes were in the order of 6-9 T DM/ha over the growing season: grasses were slightly lower on the red soil and higher on the black soil. The best performing types were:

- red basalt: (legumes) *Stylosanthes seabrana*, *S. scabra* and *Macroptilium bracteatum* (grasses) *Bothriochloa insculpta, Brachiaria* spp.
- black basalt: (legumes) *Desmanthus* spp., *S. seabrana, Macroptilium atropurpureum, Clitoria ternatea* (grasses) *Dichanthium aristatum, Bothriochloa insculpta* followed by a range of moderate yielding types.

Establishment of grass and legume seeds was shown to be highly successful using simple cultivation and weed control systems in north and central Queensland. Low rainfall after sowing favoured legumes and high rainfall favoured grasses. Rapid plant development (and seeding) enabled sufficient herbage for grazing six months after sowing (i.e. in the dry first season) in years of moderate to high rainfall but not until the end of the following wet season if rainfall is poor after sowing.

Excellent herbage yields (typically 4-8 T DM/ha for the better-performing lines) were achievable over a growing season when grasses and legumes were grown in combination. Erect shrub legumes (*S. seabrana, S. sabra*) and some twining legumes (*Clitoria ternatea*) competed best with companion grasses, whereas stoloniferous grasses (*Urochloa mosambicensis*, *Bothriochloa insculpta* and *Digitaria milanjiana* (lesser extent)) and some giant types (*Brachiaria brizantha*) competed best.

Bio-economic analyses showed the introduction of 'production paddocks' using strips established in native pastures provided significant benefits for business profitability at paddock and business scales on fertile (red basalt) and infertile (red earth). Gross margins per hectare were increased 3 to 6-fold over native pastures depending on land-type or sowing choice. Grass+legume systems resulted in greater animal productivity and profitability than legume only systems even though they were more expensive to develop. The need to apply fertiliser phosphorus to infertile soils increased up-front and maintenance costs on the infertile soil and reduced profitability on a whole-of-property scale.

Benefits to industry

New field data and economic assessments were developed to support the development of legume-based 'production paddocks' in north Queensland. Adoption of these should improve the capacity for businesses to turn off weaners and steers and improve the health of female replacements for older or non-performing breeders without increasing stocking rates beyond sustainable levels. Key benefits at a business level include increased cashflow and the capacity to pay down debt. Although initial costs can be significant, the benefits of adopting legumes accrue over the long-term because (well-managed) stylo / native grass systems can remain productive over 30+ years.

Benefits to the beef industry accumulate as producers establish legumes to create productive long-term pastures. Improved weaner and steer turn off and growth rates will improve supply into the finishing sector and provide a greater range of options for different growth and marketing paths in north Queensland and other regions. The establishment of productive dry-season feed options across larger areas of the industry will also help insulate the industry from extended or unseasonable periods of low rainfall.

Future research and recommendations

Research, Development and Extension (RD&E) recommendations focus on the commercial testing and adoption of 'production paddock' systems in the seasonally dry tropics in northern Australia. High priorities to support wide-scale adoption in north Queensland, include:

Research and development

1. Demonstrations on commercial properties across regions and land-types to measure animal performance and validate the economic benefits estimated to date. These should have high levels of producer input and seek to address producer questions required for adoption.
2. Research to identify the most economically effective approach to fertilising legumes with phosphorous and/or sulphur across a range of soil fertility situations and use these to form industry recommendations.
3. Address seed-related impediments to successful adoption and pasture performance and use to make industry recommendations including:
    a. the efficacy of establishing coated vs uncoated seeds in seasonally dry environments and using different approaches to sowing, and
    b. rhizobium seed coating performance on different land-types and during typical establishment environments, particularly for legumes considered to not readily form useful associated with native soil rhizobia (*Desmanthus, Stylosanthes seabrana*).

Extension and adoption

4. Promote the adoption of legume production paddocks using regionally distributed commercial-scale demonstrations. Follow up with small-group extension and skills development focussed around the establishment of paddocks on new properties.
5. Coordinate a drive for adoption with the pasture seed industry to match the supply of seed with emerging demand and to gain consistency with messaging (cultivar selection for different landtypes, seed preparation and establishment methods).

6. As part of a broader program to encourage the adoption of legumes in north Queensland, it would be highly useful to benchmark the adoption of legumes at an industry level through field surveys conducted across land-types and use the information to focus adoption needs.

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1. Background

1.1 Beef industry issues related to this project

1.1.1 Key limitations to beef profitability within the study area

The principal focus area of this project (west of Bowen to the Northern Territory border and north to Cape York) contains approximately 30% of the Queensland beef herd with annual turnoff at the farm-gate in excess of $630 M (based on a 27% turnoff ratio and mid-2015 average cattle prices of $600 per head). The area contains approximately 3.9 million head (MLA, 2011) (1.8 million breeders) with a turnoff of approximately 1.05 million head per annum.

Breeder productivity (weaning and death rates) and heavier sale weights are recognised profit drivers for the northern beef industry (McLean et al., 2014). Historically, key beef enterprises within the project area include breeding for store sale (at 2.5–4.5 years) and growing steers (4-8 years). Weaner branding rates are approximately 45-70% (Partridge and Miller,1991).

A recent economic assessment of producer profitability and viability in the northern Gulf found managing a profitable enterprise to be highly complex with key factors being equity, lack of infrastructure and seasonal variability in feedbase (Rolfe et al., 2016). During the study period, many graziers had difficulty servicing debt, which averaged in excess of $3M per business. Financial losses were common for northern Australian beef producers and the average return on assets was poor at less than one per cent. Negative return on equity was also common where debt levels were high and businesses incurred significant interest costs. However, those managers who "respond to low rainfall years by selling-down or accumulating grass reserves appear to be in control and under less stress".

1.1.2 Feed-base limitations to beef production in seasonally-dry Queensland

The project area is characterised by moderate annual rainfall (600-800 mm) with an extended dry season (winter). Rainfall varies considerably between years and is linked to cycles in the southern oscillation index. The principal grazing resources are natural grasslands comprising approximately 40% blackspear grass, 35% *Aristida – Chrysopogon* and 20% bluegrass-browntop communities in north Queensland plus a significant area of the *Bothriochloa – Chloris –Aristida* community in central Queensland (Tothill and Gillies, 1992). The productivity of these grasslands is variously compromised by timber regrowth, soil erosion and incursion of unpalatable weeds resulting in considerable areas being in 'B' (degrading, but recoverable) or 'C' (degraded, difficult to restore) condition. Low biomass annual (grader – *Themeda quadrivavlis*) and perennial (early flowering types of Indian couch – *Bothriochloa pertusa*) grasses have become dominant in key land-types.

Seasonal variation in the quantity and quality of feed available is the principal limitation to growing and breeding livestock in north Queensland (Rolfe et al., 2006). Average annual liveweight gains are typically below 130 kg/head and average stocking rates around 1AE :10 ha)(Partridge and Miller, 1991). Reproductive performance is also limited by the native feed resource, with branding rates commonly ranging from 40 to 65%. Enterprises on *Eucalypt* woodland on light-textured soils in central and southern Queensland face similar challenges. These areas support approximately 510,000 head of cattle with an annual liveweight gain of 130 kg/hd. In comparison, cattle grazing on sown grass pastures (mostly tropical coast and tablelands) often gain in excess of 180 kg annually with stocking rates of 1AE:2ha or less (English et al., 2009).

1.1.3 Legume based 'production paddocks' require testing

Historical research and associated industry co-funded property demonstrations on infertile soils in north Queensland have demonstrated the capacity for sown legumes to increase annual liveweight gain in the 600-800 mm zone in north Queensland from 50-140 kg/ae at 5-25 ha/ae on sown pastures to 130-200 kg/ae at a stocking rate of 4.5-2 ha per ae, depending on input levels (Partridge and Miller, 1991). Research in the Northern Territory (Katherine) and sub-coastal Queensland (near Townsville and Mareeba) also report significant benefits of liveweight gain and stocking rates through using well adapted legumes such as stylos (Coates et al., 1997). Significant gains can be achieved even when legumes are a relatively low proportion of the diet (McLeod and Cook, 2004).

Queensland Government pasture demonstration site research in north Queensland showed the potential for unfertilised stylo to increase weaner liveweight gain by 45% between May and August on infertile soils compared to native pastures if no fertiliser was used and by 90% when phosphorous plus sulphur fertiliser were applied (Anon, 1994a). The fertilised stylo treatment also resulted in a tripling of stocking rate. Similar results were achieved for steers grazing stylo/native grass pastures on infertile (soil available P < 2 mg/kg) soils (Anon, 1994b). In a series of replicated studies in north Queensland during the 1980s stylo production was shown to respond significantly to P application with significant residual benefits for legume and grass production by initial applications of 40 kg P/ha (Shaw et al., 1994).

The above studies show considerable potential for the development of fertilised legume and grass 'production paddocks', a term used in this report to describe discreet paddocks managed with moderate intensity for key stock classes (weaners, steers and heifers). The principal role of these paddocks is to improve animal nutrition during the dry season when herbage yield and feed quality become limiting to animal growth. Such systems provide a perceived opportunity to improve weaner growth, increase steer growth rates and increase first conception and re-conception rates in seasonally dry areas. Since beginning B.NBP.0812 the Queensland Government completed a series of economic options analyses using bio-economic modelling (field measurements combined with regional production data, biological growth models and economic analysis) to compare a range of interventions graziers could use to increase profitability and manage and respond to drought (Drought and Climate Adaptation (DCAP)). Based on historical research on infertile soils, these analyses showed the adoption of stylos and the fertilising of stylos to be the best intervention to increase beef business profitability in the Gulf of Carpentaria region (Bowen et al., 2019).

Through well-resourced federal and state government evaluation programs during the 1970s and 1980s, a wide range of legumes were tested for persistence and herbage yield in a range of soil types and growing environments in the seasonally dry zone of north Queensland and more broadly (Clem and Hall, 1994; Clements et al., 1984; Edye et al., 1998; Hall, 1985; Hall and Walker, 2005). These were assessed primarily for adaptation for extensive pasture systems. Prior to 2014 there had been no systematic or independent appraisal of grasses or legumes for production paddocks in north Queensland and almost no pasture plant evaluation for some 20 years and there remained few options for key land types in the seasonally dry tropics (Bell et al., 2016; Walker et al., 1997). During this time new tropical pasture varieties were developed from a range of sources including reselection from old plant evaluation sites, importing elite varieties and fast-tracking accessions from the Australian Pastures Genebank which had previously been tested but not released (Cox, 2013). This was supported by seed production by the Queensland Government at Walkamin. There had been no systematic adaptation testing of these lines or measurements of herbage yields and feed quality, key information required for the adoption and management of legume-based sown pastures.

1.1.4 B.NBP.0766 Promising pastures for the seasonally dry tropics

B.NBP.0766 (2014-2018), the pre-cursor project to B.NBP.0812, sought to identify grasses and legumes which could be used within 'production paddock' systems on a range of land-types. Twenty-nine legumes (from *Centrosema, Clitoria, Desmanthus*, *Macroptilium* and *Stylosanthes*) and 30 grasses (from *Brachiaria, Chloris, Dichanthium, Digitaria, Heteropogon, Panicum* and *Urochloa*) were assessed in replicated small plots at 12 sites within the 600-900 mm median annual rainfall belt in a broad arc from Normanton to Emerald. The selected lines included relatively recent cultivars and promising lines yet to be commercialised and were compared with older well-adapted cultivars, where options were available (Fig. 1).

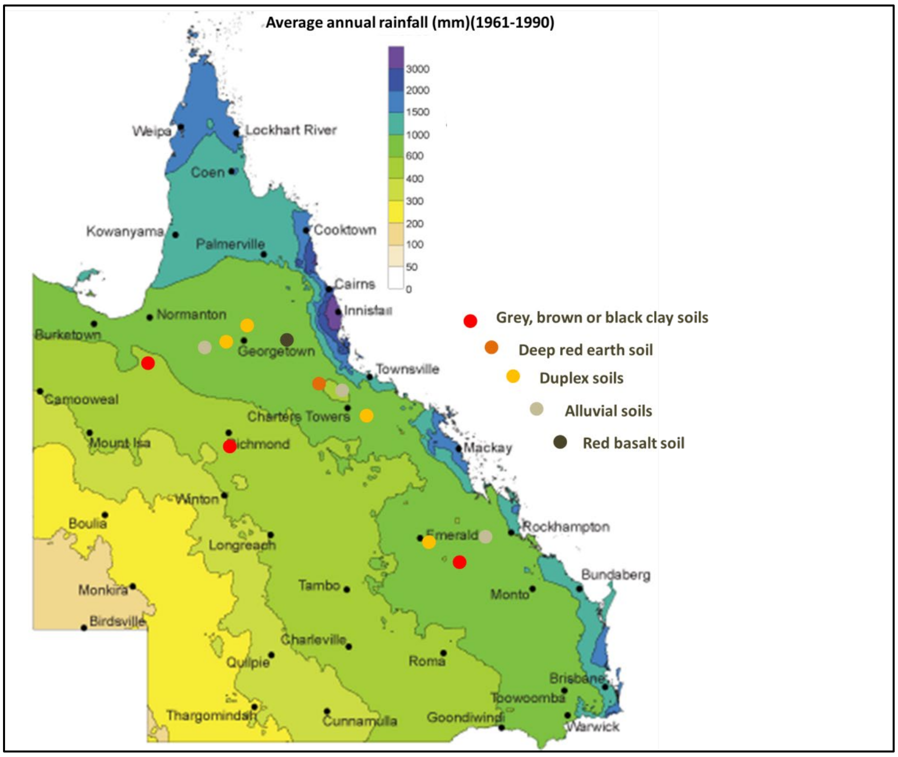
The sites represented a range of moderate to high fertility soil types and were conducted on commercial beef properties. Each site comprised replicated (3) small plots for each grass and legume line within 1-2 ha fenced areas which were grazed early to mid. – dry season (to coincide with first or second round weaning). Each were sown to maximise establishment under rain-fed conditions and fertiliser phosphorous and sulphur only was applied where considered limiting to growth. The plants were assessed for establishment performance, changes in cover, reproductive development, end of season biomass, the capacity to stay green into the dry season, and acceptance to cattle. Herbage samples collected mid- and end- of the wet season were collected at two sites and analysed for standard feed quality indices and mineral contents.

The research was completed over a historically dry period, with rainfall at many sites in the 20-30% decile range for the early years of the project, particularly in north Queensland. This resulted in establishment failure at some sites, particularly western and light-textured soil sites, requiring repeated sowings. It did, however, enable the assessment of the grasses and legumes under 'tough' growing conditions: this selection pressure was useful for identifying plants which persist well under prolonged dry conditions, and was, overall, considered useful as performance at these sites could be compared with plant performance at sites where conditions were more favourable for growth.

Grasses and legumes suitable for red basalt (Mt Surprise), red earth (Charters Towers) and sandy duplex (Georgetown and Ravenswood) in north Queensland and brown clay (Moura), alluvial (Gogango) and brown duplex (Emerald) in central Queensland were identified. These are summarised by land-type in Appendix 10.1 along with key growth characteristics. These included older cultivars and lines which had not been commercially released. Some were readily available at the onset of B.NBP.0812 whereas commercial failure restricted supply of other established cultivars (Appendix 10.2). Early stage seed increase was required for promising lines which were yet to be commercialised. Repeated failed establishment on the grey and black soils of north-west Queensland meant clear options were not identified.

Whereas B.NBP.0766 was useful for identifying suitable grasses and legumes for fertilised systems in a range of land-types, it did little to address yield expectation and under commercial management. Critically, the various grasses and legumes were managed separately whereas there would presumably be competitive effects between different grasses and legumes in commercial pastures. Also, the only data useful for bio-economic analyses related to infertile soils and stylos and were based on historical studies: herbage yield and quality data under more commercially relevant situations were needed to complete analyses useful for graziers.

Fig. 1 Distribution of experimental sites as related to mean annual rainfall and soil group. Original map sourced from the Australian Bureau of Meteorology.



1.2 Research questions and adoption targets for B.NBP.0812

1.2.1 Research program

B.NBP.0812 was primarily a research project to assess the potential for legume-based production paddocks in the seasonally dry tropics. There were two research questions from a beef producer's perspective:

1. Is it sensible to develop legume-based 'production paddocks' within my enterprise and land-type and what are the potential costs and benefits of this?
2. What are the best combinations of grasses and legumes to sow and how do I establish them?

To address these questions the research team sought to:

1. Develop replicated experiments on commercial beef properties representing a range of growing environments and soil fertility levels to measure herbage yields when well-adapted grasses and legumes are grown in combinations and managed as a 'weaner' paddock.
2. Measure changes in feed quality between pasture components (grasses and legumes) over growing seasons.
3. Use herbage yield and feed quality data from B.NBP.0766 and B.NBP.0812 to complete bio-economic analyses to determine the benefits (or otherwise) of developing 'production paddocks' on fertile (high phosphorous) and infertile soils.

The experimental sites were on key land types (red basalt, sandy duplex, red earth and brown clay) used in B.NBP.0766, on the same or nearby properties. They were to be of a larger scale than for the small-plot assessments and to employ practically feasible methods of establishment and pasture management. The establishment of research sites was planned to be conducted over two seasons, beginning in 2019-20. In addition to the four grass x legume combination studies, two small plot experiments were to be established on red and black basalt soils north-west of Charters Towers similar to those experiments used to test broad ranges of grasses and legumes in B.NBP.0766. This was a key land class not accounted for in the previous study, having significantly lower rainfall than the red basalt site near Mt. Surprise. It also provided an opportunity to test a wide range of grasses and legumes for heavy clay (vertisol) soils as attempts in north-west Queensland were unsuccessful (multiple failed establishments due to drought).

1.2.2 Promotion and adoption

A key objective was to generate new information for, and to promote, the adoption of legume-based sown-pasture systems through the development of on-property field demonstrations across regions and to use these to complete regionally useful economic analyses on the benefits (or otherwise) of investing in the establishment of sown pastures. The key regions serviced by the project represented the Gilbert River/Etheridge (Georgetown), Gilbert River / upper Burdekin (Mt Surprise), lower Burdekin (3 sites Charters Towers) and Fitzroy (Moura) catchments. Producers in the northern regions focus on primarily on weaner production and live export cattle whereas more grower operations are completed in central Queensland.

The principal target audience was beef producers in the seasonally dry tropics zone in an arc from Georgetown to Charters Towers. However, it wasalso extended to Moura, because the research was regionally targeted towards their needs and historical research on the adoption of legumes (mostly stylos), albeit in extensive production systems, has demonstrated the capacity to significantly improve animal performance in thisregion as well. The producer audience, plus agribusinesses and regional NRM groups, were to be engaged through DAF field days and workshops using the demonstration sites to and presentations at regional BeefUp days to promote awareness of the potential to develop production paddocks, with follow-up through assisting producers with enquiries on a one-on-one basis (DAF pasture and beef extension). The research also targeted beef producers in seasonally dry zones of northern Australia through more broadly-targeted media events (BeefWeek 2021, sown pastures and newsletter articles). The results were also to be promoted to researchers, extension officers and producers at key conference events (e.g. NABRUC, AAAP).

The research results (plant adaptation and herbage yield and quality under a range of management scenarios), and bio-economic analyses arising from these, are to be used to guide upscaling and accelerated adoption of production paddocks over the next 5-10 years. As a result of the research, DAF has already developed a large-scale replicated demonstration experiment at DAF Spyglass (Charters Towers) to capture the relative animal production benefits of different legume systems and provide more robust data for producer options analysis being developed regionally by DAF. Similar large-scale sites using best-bet options are planned to practically demonstrate and measure the effect of different management methods (establishment, fertiliser application, grazing strategies) on profitability. Overall system performance and practical learnings will be incorporated into DAF beef extension resources and training workshops. One-on-one mentoring for the adoption of production paddocks (and the use of legumes in general) provide the opportunity to produce case studies for further learning (modification of recommendations) and promotion.

2. Objectives

2.1 Project purpose

This project targets improved nutrition of livestock within grass-fed beef breeding and growing operations in the seasonally dry tropics (mostly 600-900 mm aar) of northern and central Queensland. It extends MLA/DAF project B.NBP.0766 in which DAF staff conducted independent small-plot assessments of a wide range of promising, but previously untested, new tropical pasture legumes and grasses in replicated small-plot studies and compared with older types (where present). The principal aim of B.NBP.0812 was to further the development of the 'production paddock' approach by testing *combinations* of the better-performing legumes and grasses in larger, replicated field plots using grazing management more typical of 'weaner' or 'grower' paddocks. There was a greater emphasis on measuring plant growth rather than adaptation as for the previous project. The research questions at the onset of the project were:

1. How much quality fodder is produced by combinations of promising tropical pasture legumes and grasses for 'weaner' or 'grower' livestock systems over and between years?
2. Are they superior to older varieties (if present)?
3. What are the best combinations of grasses and legumes to achieve and maintain a productive grass/legume balance?
4. What are the costs/benefits of developing sown pastures using these technologies on key land-types?

Perhaps short pithy answers to the questions posed. The paragraph below speaks to intent and approach, but a short summary of the outcome against questions would be good.
The field measurements were designed to understand plant performance within a grass/legume pasture, and included ease of establishment, plant persistence and recruitment, plant productivity (biomass) and feed quality. Animal preference (utilisation) and regrowth after grazing was also to be assessed to provide insights into future grazing management strategies. The measures were to be related to profitability at paddock and whole-of-business levels and land types representing soils of high and low fertility in the seasonally dry tropics were chosen for this. Each experiment was to become a regional focal point to raise awareness of the development of legume-based production paddocks and renew interest in the adoption of legumes in general. These were also to be points of practical demonstration and discussion for graziers. The ultimate long-term aim was to generate reliable information for graziers to assist sensible decision making when considering and implementing sown pastures.

2.2 Project objectives

The specific objectives of the project were to:

1. Confirm key legumes and grasses for each land-type (using results from B.NBP.0766) and conduct seed increase at DAF Walkamin to provide seed for assessment as grass/legume combinations (Year 1).
2. Develop on-property research sites and involve beef producer and resource management groups and DAF extension staff with final plant selection and site management practices (Years 2 and 3[1]).
3. Prepare and sow replicated plots of grass/legume mixtures with management to optimise establishment (light grazing). Measure establishment and year one (seasonal) productivity (cover and biomass), seeding and acceptance to cattle (Years 2 and 3[1]).

4. Measure seasonal performance of grass/legume combinations under grazing as a 'weaner' or 'grower' paddock, including: productivity (cover and biomass), changes in plant populations, feed quality, capacity to seed and acceptance to cattle and tolerance of grazing (Years 3 and 4).
5. Estimate the financial benefit (or otherwise) of the sown-pasture system at a property level and extend to the broader region (Year 4).
6. Promote the results to beef producers and seed companies using the research sites for demonstration and contributing independent information for DAF and MLA extension (Years 3 and 4).

[1] some sites were established prior to the development of B.NBP.0812 due to delays in contracting.

2.3 Success in meeting project objectives

The project objectives were broadly achieved. Research sites were developed to compare the productivity of various combinations of grasses and legumes at four locations in north and central Queensland each represent a key beef production land-type (rainfall, soil type (fertility)). Two experiments were also established to compare the persistence and productivity of a wide range of legumes and grasses in a key land-type (red and black basalt-derived soils in a low rainfall environment north-west of Charters Towers) which had not been included in B.NBP.0766. These were all on properties managed for commercial beef production and included one DAF property.

The experiment sites were originally scheduled to be sown during the 2018-19 and 2019-20 wet seasons following scoping and infrastructure development. The five north Queensland sites were sown between February 2018 and February 2020, with one for small plot assessments sown early to progress the research. Establishment of the central Queensland site was delayed, however, until February 2021 due to extended drought and the need to accumulate soil moisture ahead of sowing. The staggered nature of the sowings means that the sites were at different stages of development when this report was compiled. Pasture productivity and composition (persistence) studies in dry-land environments are best conducted over the longer term, so it recognised there is a need to continue active management of the research sites until at least five years of data have been collected.

Field data covering establishment, changes in cover, herbage yield and quality and acceptance to cattle were all collected as proposed. These were compiled, analysed and key results are described in this report. The field data for the later planted sites best represent the establishment phase of production paddocks whereas the earlier-sown experiments also provide estimates of persistence and yield.

Economic analyses were conducted in the final year of the project to compare the adoption of production paddocks in north Queensland using fertilised legumes or legumes+grass established in strips compared with the native pastures alone. Land-types with soils of high and low (phosphorus) fertility were selected and the analyses were conducted at paddock and then whole-of-business levels. The analyses were conducted by DAF agricultural economists using methods developed for the DAF Drought and Climate Adaptation Program (DCAP) and field data from B.NBP.0812 (grass+legume) and B.NBP.0766 (legume only). Economic analyses were not completed for central Queensland because the site was established late in the project.

Although principally a research project, the research team has attempted to engage the beef industry through a range of activities and events. These included field days, DAF beef extension workshops, beef industry events (BeefUp and Beef Week) and media (newsletter articles, podcast).

One-on-one mentoring of north Queensland producers seeking to introduce fertilised legume systems was also undertaken towards the end of the project.

Seed production was undertaken at DAF's Walkamin Research Facility to provide seeds of promising, but not commercialised, grasses and legumes to provide seed for establishing the experiments and first commercial seed crops. Seed production was most intensive in the first few years of the project, but some lines were maintained until 2022. Seed was provided to seed companies for the establishment of seed crops of most lines in the latter two years of the project.

This section demonstrates activities but not outcomes/deliverables against objectives. Pithy statements on what was the result against objective.

3. Methodology

3.1 Project scope and timing of the research and extension activities

B.NBP.0812 was primarily an applied research project to test the potential to develop legume-based 'production paddocks' in seasonally dry areas of (mostly) north and central Queensland. It built on the results from the previous multi-site, small-plot appraisal of grasses and legumes undertaken in north-west, north and central Queensland in B.NBP.0766.

There were two levels of plant evaluation experimentation within this project. All were conducted on commercially managed beef properties. The first and key activity of the project was to identify the best combinations of promising grasses and legumes identified during B.NBP.0766 and to do this on land-types similar to those used in B.NBP.0766. This recognised that previous assessments using small, grass-only or legume-only plots are not typical of most pasture systems. The assessments were also completed on a larger scale using management techniques more typical of commercial practice. The second level of experimentation was to undertake small plot testing of a wider range of grasses and legumes on basalt soils north-west of Charters Towers, an important environment not assessed during B.NBP.0766, using methods similar to those of the previous project. Both components of this research were undertaken between 2018 and 2022.

Seed production of newer lines considered to have significant potential if commercialised was undertaken by the project team at the DAF Walkamin Research Facility (north Queensland) to ensure a supply of seed for plant evaluation and the production of pre-commercial seeds for on-going development. The seed production of some lines commenced prior to the onset of B.NBP.0812 through the DAF seed production program but was extended to newer crops between 2018 and 2020. Some lines were maintained thereafter to provide a reserve of seed for commercial adoption.

Bio-economic analyses were completed initially on paddock and later whole-property levels during 2021 and 2022 as more mature data became available from the grass x legume assessments. These tested the benefit of introducing legume based 'production paddocks' using strips of either legumes alone or legumes+grass on two contrasting land types (high and low soil phosphorous) in north Queensland (Mt Surprise and Charters Towers regions).

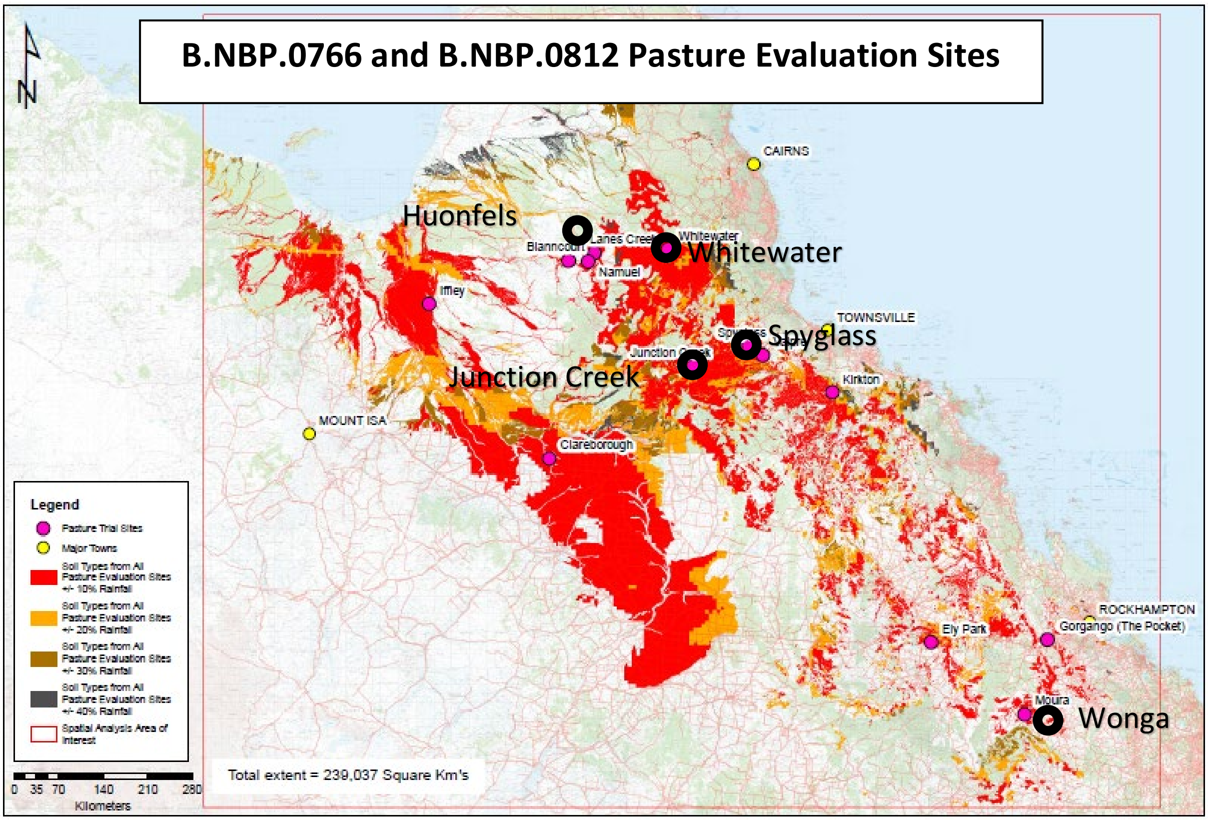
Extension activities were undertaken over the entire duration of the project, and included field days, presentations at Beef Industry events (BeefUp, Beef Week), media articles and resources and conference papers and presentations.

3.1.1 Selection of evaluation sites

Distribution of sites

B.NBP.0812 includes six evaluation sites. They are are located near Georgetown (1 site, Gilbert River catchment), Mt Surprise (1 site, Einesleigh/Gilbert), Charters Towers (3 sites, Burdekin) and Moura (1 site, Fitzroy) (Table 1). They all represent key land-types for beef breeding and growing enterprises. They include red (2) and black basalt, duplex (2) and red earth soil types within the seasonally dry tropics of north Queensland. The north Queensland sites have a 6+ month winter dry season, whereas the central Queensland site (brown clay) has a greater winter rainfall component. Mean annual rainfall ranges from 600 to 800 mm. The location of the sites is presented in Fig. 2 along with the sites assessed in B.NBP.0766. The condition of the sites prior to development varied between sites (Fig. 3).

Fig. 2 **The location of B.NBP.0812 sites (discs) in relation to B.NBP.0766 sites.** Shaded areas represent the area of adaptation (all sites) based on soil, rainfall and vegetation mapping (map by N. Gobius).



Sites for grass x legume assessments

'Whitewater' (red basalt, Mt Surprise)

'Whitewater', , represents the red basalt soils near Mt Surprise in north Queensland. The site lies within a new ~50 ha paddock in uncleared woodland with similar structure to that used in the previous project (*Eucalyptus* and *Corymbia* spp., *Heteropogon contortus, Bothriochloa pertusa*). Of note is a high population of grader grass (*Themeda subquadripara*), an annual early-flowering grass which rapidly loses feed quality in the dry season. The site has excellent all-year access (and exposure). The site was surveyed during the 2018 wet season and wallaby and rabbit-proof fencing (mesh) installed six months later to reduce the risk of unplanned grazing affecting experimental results. Water infrastructure was installed during 2020 to enable controlled grazing of the ~ 6 ha experimental site. Experimental areas were surveyed during the early wet season and comprised four blocks which were allocated to three replicates (one replicate comprising two adjacent blocks).

'Spyglass' (red earth, Charters Towers)

Five possible sites at this DAF research station were inspected and soil samples taken from two. A strong history of pasture development at 'Spyglass' meant that grasses (buffel (*Cenchrus ciliaris*) and sabi (*Urochloa mosambicensis*)) and legumes (Wynn cassia (*Chamaecrista rotundifolia*) and shrubby stylo (*Stylosanthes scabra*)) are variously present across the station. The stylo and buffel were of particular concern because a range of stylos are to be evaluated and buffel can be extremely dominant and difficult to control once established. The chosen site provided the best compromise having very little shrubby stylo or buffel, but Wynn cassia and some sabi grass. The site had also been cultivated in the previous wet season (twice) in anticipation of pasture renovation (cancelled due to insufficient rainfall after cultivation). This would have reduced soil seed levels by promoting germination: early season rainfall in September had caused the germination of Wynn cassia seeds. The site has excellent exposure, being opposite the main buildings, and good stock access through a series of laneways linked to weaner and steer paddocks.

'Huonfels' (sandy duplex, Georgetown)
'Huonfels' is adjacent to the 'Lanes Creek' property used in B.NBP.0766 . Soil samples were collected from four sites. The final ('quarry') site was chosen because of uniformity and a relatively low population of stylos. The most common grasses include: *Heteropogon contortus, Aristida* spp., *Urochloa mosambicesis* and *Bothriochloa pertusa*, and forbs include low populations of *Stylosanthes scabra* and *Sida* sp. Bloodwoods (*Corymbia*) are the dominant tree. The site has excellent road access, , and access to livestock through a recently developed laneway.

'Wonga' (brown clay, Moura)
This site was selected as an alternative to 'Unumgar' used during B.NBP.0766: it is nearby and on the same land-class. The site is immediately adjacent to the Moura township and is owned by the Luhrs family. The cleared site contained dominant grasses (*Bothriochloa pertusa* and *Cenchrus ciliaris*) which required control by cultivation and spraying before establishing the site. As recommended for central Queensland, a fallow ahead of sowing was required to accumulate soil moisture. There is good road access to the property, but only paddock access to the site.

Sites for individual plot assessments
Both of the sites were located on 'Junction Creek'.The property is located within a large triangle of basalt country between Charters Towers, the Lynd Junction and Hughenden and lies on southern side of the Nulla basaltic province north-west of the Great Basalt Wall. Mean annual rainfall is ~ 650 mm and the region experiences an extended dry-season component, with annual rainfall significantly lower than that used for the red basalt site at 'Whitewater'. Two sites were selected based on uniformity of vegetation, accessibility and having relatively intact native vegetation:

Red soil – open *Eucalypt* woodland, rocky with slope <5% and located 50 m off the main 'Junction Creek' Charters Towers road. Key species included *Heteropogon contortus* and *Bothriochloa bladhii*.

Black soil - naturally open grassland, low frequency of basalt rocks and located ~ 2 km from the homestead with all-year access. The plain was dominated by grass (*Dichanthium*).

Site characteristics
The characteristics of each site are presented in Table 2. All sites represent native woodland communities, however the 'Spyglass' and 'Moura' sites were previously cleared of woody vegetation. All of the sites primarily support native grassland species, but most have been invaded to a varying extent by an early-flowering, low biomass type of *Bothriochloa pertusa* (Indian couch). The red earth site at 'Spyglass' contained a large population of *Chamaecrista rotundifolia* (Wynn cassia) which required special management before sowing to reduce soil seedbanks. Experimental areas were selected within each property. Key considerations included uniformity of soil and vegetation types and relative freedom from sown legumes or grasses to be tested. Access by vehicle and the potential to safely introduce and manage livestock were also required. In some cases, a range of potential sites were considered before selecting one.

Soil testing
Soil fertility was assessed before sowing at each property to confirm suitability of the site and to estimate fertiliser application rates. Representative soil samples (a subsample from 4 to 6 combined

soil 0-10 cm soil cores) were collected from each potential site (2-3 per property). Each soil sample was submitted to Incitec Pivot™ and analysed for key indicators of suitable soil chemistry for growth (pH, electronic conductivity, cation exchange capacity, and plant available macro- (nitrogen, phosphorous, sulphur, potassium, calcium and magnesium) and micro- (boron, copper, iron, manganese, zinc) nutrients. The key indices for selected or preferred sites is shown in Table 3. The soils were all of moderate to high fertility and suitable for sown pasture development. All were neutral, or had slightly acidic reaction, except the black clay soil at 'Junction Creek' ($pH_{water +}$=8.5). Plant available phosphorous was highest in the red basalt sites and relatively low (to levels where responses to applied phosphorous would be expected) in all of the others. Phosphorous buffering capacity (the capacity to store and therefore supply phosphorous over time) was low in all but the red and black basalt soils at 'Whitewater' and 'Junction Creek', respectively. Levels of plant available sulphur were low at all sites, but extremely low on the black soil at 'Junction Creek'. Based on these results, sulphur applied pre-plant, either with phosphorous (single superphosphate) or alone (as elemental sulphur or Gran-am) were considered to significantly benefit plant growth. There were no significant signs of potassium deficiency, although plant available levels at 'Huonfels', 'Spyglass' and 'Wonga' were lower than the other basalt soil sites when sampled. Sodium (or chloride) levels were low at all sites and not considered to adversely influence plant growth.

Site potential 'footprint'

Site 'footprint' mapping (extent), intended to act as a starting point for extrapolation research results to similar areas within a region, was completed for each site as for B.NBP.0766 to identify the potential areas of adoption represented by each experimental site. Digital spatial layers of soil type, long-term rainfall and vegetation groups were sourced and overlaid to create 'footprint' maps for each experimental site (GPS coordinates). The maps were compiled by a digital mapping specialist with extensive experience in north Queensland and using freely available digital resources. These were then checked by DAF officers familiar with the regions of each map. The effect of changing rainfall by 10, 20, 30 or 40% was calculated and incorporated into the maps. The maps are presented in Appendix 10.3 and projected areas of best match in Table 3. Estimated best-match (+/- 10% mean annual rainfall) 'footprint' of each site varied considerably: 2100 km^2 for the black clay soil near Charters Towers to ~ 14000 km^2 for the red earth and duplex sites within the same region. The areas doubled for most sites when rainfall values deviated further from long-term mean rainfall. The area (240 000 km^2) represented by B.NBP.0766 and B.NBP.0812 is represented in Fig. 2, but this is clearly an over-estimation of adoption potential due to landscape variability and on-property infrastructure.

Fig. 3 Land-types used for the six plant evaluation experiments.

'Whitewater' – red basalt, Mt. Surprise

DAF 'Spyglass' – red earth, Charters Towers

'Huonfels' – duplex ('Goldfields'), Georgetown

'Wonga' – brown clay, Moura

'Junction creek' – red basalt, Charters Towers

'Junction creek' – black basalt, Charters Towers

Table 1 Characteristics of the B.NBP.0812 evaluation sites.

Property (location)	Soil type	Mean rainfall (mm)[1]	Lat. / Long. (°)	Dominant trees at site	Dominant understorey plants[2]
'Junction Creek' (Charters Towers)	Red basalt	651	-19.76 / 144.94	Box	BP, HC, SH, SS
	Black basalt		-19.76 / 144.94	None (open)	BP, HC, UM
'Spyglass' (Charters Towers)	Red earth	600	-19.49 / 145.69	Cleared	BP, HC, CR, SS, UM
'Whitewater' (Mt Surprise)	Red basalt	785	-18.14 / 144.64	Iron bark, Bloodwood	BP, HC, TT, SH, SS
'Huonfels' (Georgetown)	Red duplex	754	-18.12 / 143.29	Iron bark, Bloodwood	BP, HC, SS
'Wonga' (Moura)	Brown duplex	700	-24.58 / 150.00	Cleared	BP, CC

1 1961-1990 AWAP

2 Bo = *Bothriochloa* spp. BP = *Bothriochloa pertusa,* CC = *Cenchrus ciliaris,* HC = *Heteropogon contortus*, *SH = Stylosanthes hamata*, SS = *Stylosanthes scabra,* TT = *Themeda triandra*, UM = *Urochloa mosambicensis.*

Table 2 Key soil chemistry indices for plant growth for the B.NBP.0812 sites.

Property (location)	Soil type	pH_{water}	$P_{Colwell}$ (mg/kg)	P buffer index	S_{MCP} (mg/kg)	$K_{Amm. acetate}$ (cmol(+)/kg	$Na_{Amm. acetate}$ (cmol(+)/kg
'Junction Creek' (Charters Towers)	Red basalt	6.9	31	25	5	0.98	0.04
	Black basalt	8.5	9	220	<1	0.82	0.02
'Spyglass' (Charters Towers)	Red earth	6.2	<5	19	7	0.43	0.03
'Whitewater' (Mt Surprise)	Red basalt	6.6	240	220	5	1.00	0.04
'Huonfels' (Georgetown)	Red duplex	6.3	6.0	57	3	0.49	0.03
'Wonga' (Moura)	Brown duplex	6.6	<5	37	3	0.14	0.06

Table 3 Estimated experimental soil and climate 'footprint' for each experimental site.

Property (location)	Soil type	Estimated represented area (km^2)	
		+/- 10% MAR[2]	+/- 40% MAR[2]
'Junction Creek' (Charters Towers)	Red basalt	6046	12301
	Black basalt	2164	5360
'Spyglass' (Charters Towers)	Red earth	13860	28949
'Whitewater' (Mt Surprise)	Red basalt	7438	20285
'Huonfels' (Georgetown)	Red duplex	10298	17015
'Wonga'[1] (Moura)	Brown clay loam	6913	13865

1 This site replaces 'Unumgar' from B.NBP.0766 (Moura). The soil type and vegetation are very similar to the nearby B.NBP.0766 site so the same 'footprint' mapping was applied.

2 MAR = Median annual rainfall.

3.1.2 Selection of grasses and legumes for assessment

The initial list of species and cultivars for each site was based on performance during B.NPB.0766 and historical recommendations for use on the land type, albeit often for more extensive production systems. Key resources included FutureBeef Land-type regional recommendations and the Tropical Forages website (www.tropicalforages.info/) (Cook et al. 2005) for selection based on growing environment from a broader context. The availability of commercial seed (where applicable) was a secondary consideration when selecting lines.

Grass x legume combinations (4 experiments)
Here, the aim was to development an experimental regime which enabled the comparison of combinations of growth habits between grasses and legumes i.e. they achieve combinations of twining and shrub legumes with erect (tussock, short stolons or rhizomes) and sprawling (strongly stoloniferous) grasses (Table 4). Land-type standard comparators were included, including combinations of these, to provide reference points for the comparison of performance. For the basalt, red earth and duplex land-types these were *Urochloa mosambicensis* and *Stylosanthes scabra*. The central Queensland site had *Cenchrus ciliaris* as the key grass comparator, but no obvious legume comparator as a clear long-term legume has not been identified (although there is a range of candidates). A range of varieties was considered within each species where a range had previously been tested within B.NBP.0766. Please note, 'Oolloo' *Centrosema brasilianum* was not included at these sites, despite moderate early performance at one site, 'Lanes Creek' (Georgetown duplex), because early attempts to supply seed commercially have stalled and future production seems extremely uncertain.

Individual small-plot assessments (2 experiments)
The two sites (red and black basalt) included a comprehensive suite of legumes and grasses, drawing on the material assessed during B.NBP.0766 and additional grasses and (mostly) legumes being developed by James Cook University (JCU)/Agrimix with prior seed production undertaken at DAF Walkamin (Table 5). There was a weighting towards the taxa which performed best at the similar (same soil type, but drier) 'Whitewater' basalt site near Mt Surprise for the red soil site in particular. There was a total of 34 lines of legumes for the red site, and 32 legumes for the black site (*Centrosema, Clitoria, Desmanthus, Macroptilium* and *Stylosanthes*). The selected grasses (*Bothriochloa, Brachiaria, Cenchrus, Chloris, Dichanthium, Digitaria, Panicum* and *Urochloa*) included 22 lines from the core suite tested in B.NBP.0766 plus one *Cenchrus setiger* under development by JCU. One additional *C. setiger* line was included as a single plot at both and black soil sites. The suite of grasses and legumes selected included some older cultivars broadly considered well-adapted to the soil type but not necessarily in the test regions (relatively low rainfall and basalt soils north west of Charters Towers).

Table 4 Grasses and legumes selected for comparison as mixed swards on basalt, red earth and duplex soils in north Queensland and a brown duplex soil in central Queensland.

Red basalt, Mt Surprise

Grass		Variety / line	Growth habit	Longevity	Flowering time
Bothriochloa insculpta	creeping blue	TGS125652B	Erect, tussock, stoloniferous	Perennial	Early-season
Brachiaria brizantha	brizantha	Mekong	Erect, tussock (tall)	Perennial	Late-season
Brachiaria hybrid	brach hybrid	Mulato2	Erect, tussock	Perennial	Late-season
Digitaria milanjiana	finger	Jarra	Decumbent, stoloniferous	Perennial	Mid-season
Panicum coloratum	coloratum	ATF714	Erect, tussock	Perennial	Early-season
Panicum maximum	panic	Gatton	Erect, tussock (tall)	Perennial	Mid-season
Panicum hybrid	panic	Massai	Erect, tussock (tall)	Perennial	Late-season
Urochloa mosambicensis	sabi	TGS1012	Decumbent, stoloniferous	Perennial	Early-season

Legume		Variety / line	Growth habit	Longevity	Flowering time
Clitoria ternatea	butterfly pea	Milgarra	Erect, twining, herbaceoous	Perennial	Early-mid season
Desmanthus spp.	desmanthus	Progardes	Erect shrub, variable height	Perennial	Mid-season
Macroptilium atropurpureum	atro	TGS84989	Climing, herbaceous	Perennial	(very) Late-season
Macroptilium gracile	gracile	TGS849	Trailing, herbaceous	Annual	Early season
Stylosanthes hamata	Caribbean stylo	Amiga	Erect (short), herbaceous	Perennial	Early season
Stylosanthes guianensis	common stylo	ATF3308*	Erect sub-shrub, moderate height	Perennial	Late-season
Stylosanthes seabrana	caatinga stylo	Unica	Erect shrub, moderate height	Perennial	Mid-season
Stylosanthes scabra	shrubby stylo	Seca	Erect shrub, moderate height	Perennial	Mid-season

* marketed as Beefmaker, Nina or Hughes stylo

Red earth, Charters Towers

Grass		Variety / line	Growth habit	Longevity	Flowering time
Bothriochloa insculpta	creeping blue	TGS125652B	Erect, tussock, stoloniferous	Perennial	Early-season
Brachiaria brizantha	brizantha	Mekong	Erect, tussock (tall)	Perennial	Late-season
Digitaria milanjiana	finger	Jarra	Decumbent, stoloniferous	Perennial	Mid-season
Panicum coloratum	coloratum	ATF714	Erect, tussock	Perennial	Early-season
Panicum maximum	panic	Gatton	Erect, tussock (tall)	Perennial	Mid-season
Panicum hybrid	panic	Massai	Erect, tussock (tall)	Perennial	Late-season
Urochloa mosambicensis	sabi	TGS1012	Decumbent, stoloniferous	Perennial	Early-season

Legume		Variety / line	Growth habit	Longevity	Flowering time
Clitoria ternatea	butterfly pea	Milgarra	Erect, twining, herbaceoous	Perennial	Early-mid season
Desmanthus spp.	desmanthus	Progardes	Erect shrub, variable height	Perennial	Mid-season
Desmanthus virgatus	desmanthus	Marc	Erect shrub, short	Perennial	Early-mid season
Desmanthus leptophyllus	desmanthus	TQ90 or JCU7	Erect shrub, moderate height	Perennial	Mid-season
Macroptilium atropurpureum	atro	TGS84989	Climing, herbaceous	Perennial	(very) Late-season
Macroptilium gracile	gracile	TGS849	Trailing, herbaceous	Annual	Early season
Stylosanthes hamata	Caribbean stylo	Amiga	Erect (short), herbaceous	Perennial	Early season
Stylosanthes seabrana	caatinga stylo	Unica	Erect shrub, moderate height	Perennial	Mid-season
Stylosanthes scabra	shrubby stylo	Seca	Erect shrub, moderate height	Perennial	Mid-season

Red duplex, Georgetown

Grass		Variety / line	Growth habit	Longevity	Flowering time
Bothriochloa insculpta	creeping blue	TGS125652B	Erect, tussock, stoloniferous	Perennial	Early-season
Brachiaria brizantha	brizantha	Mekong	Erect, tussock (tall)	Perennial	Late-season
Digitaria milanjiana	finger	Jarra	Decumbent, stoloniferous	Perennial	Mid-season
Panicum coloratum	coloratum	ATF714	Erect, tussock	Perennial	Early-season
Panicum hybrid	panic	Massai	Erect, tussock (tall)	Perennial	Late-season
Panicum maximum	panic	Gatton	Erect, tussock (tall)	Perennial	Mid-season
Urochloa mosambicensis	sabi	TGS1012	Decumbent, stoloniferous	Perennial	Early-season
No sown grass					

Legume		Variety / line	Growth habit	Longevity	Flowering time
Clitoria ternatea	butterfly pea	Milgarra	Erect, twining, herbaceoous	Perennial	Early-mid season
Desmanthus leptophyllus	desmanthus	JCU7	Erect shrub, moderate height	Perennial	Mid-season
Desmanthus spp.	desmanthus	Progardes	Erect shrub, variable height	Perennial	Mid-season
Desmanthus virgatus	desmanthus	Marc	Erect shrub, short	Perennial	Early-mid season
Macroptilium atropurpureum	atro	TGS84989	Climing, herbaceous	Perennial	(very) Late-season
Macroptilium gracile	gracile	TGS849	Trailing, herbaceous	Annual	Early season
Stylosanthes hamata	Caribbean stylo	Amiga	Erect (short), herbaceous	Perennial	Early season
Stylosanthes scabra	Shrubby stylo	Seca	Erect shrub, moderate height	Perennial	Mid-season
Stylosanthes seabrana	Caatinga stylo	Unica	Erect shrub, moderate height	Perennial	Mid-season

Sandy duplex, Moura

Grass species		Variety / line	Growth habit	Longevity	Flowering time
Bothriochloa insculpta	creeping blue	Bisset	Erect, tussock, stoloniferous	Perennial	Late-season
Bothriochloa pertusa	Indian couch	Keppel	Prostrate, stoloniferous	Perennial	Mid-season
Brachiaria decumbens	signal	Basilisk	Erect, tussock	Perennial	Mid-season
Cenchrus ciliaris	buffel	Gayndah	Erect, tussock	Perennial	Mid-season
Chloris gayana	Rhodes	Sabre	Erect (tall), stoloniferous	Perennial	Late-season
Digitaria milanjiana	finger	Strickland	Decumbent, stoloniferous	Perennial	Mid-season
Panicum coloratum	coloratum	ATF714	Erect, tussock	Perennial	Early-season
Panicum hybrid	panic	NuCal+Massai	Erect tussock	Perennial	Late-season
Panicum maximum	panic	Gatton+G2	Erect, tussock (tall)	Perennial	Mid-season

Legume species		Variety / line	Growth habit	Longevity	Flowering time
Clitoria ternatea	butterfly pea	Milgarra	Erect, twining, herbaceoous	Perennial	Early-mid season
Desmanthus spp.	desmanthus	Progardes	Erect shrub, variable height	Perennial	Mid-season
Desmanthus virgatus	desmanthus	Marc	Erect shrub, short	Perennial	Early-mid season
Desmanthus leptophyllus	desmanthus	TQ90 + JCU7	Erect shrub, moderate height	Perennial	Mid-season
Macroptilium atropurpureum	atro	TGS84989	Climbing, herbaceous	Perennial	(very) Late season
Macroptilium atropurpureum	atro	Aztec	Climbing, herbaceous	Perennial	Late season
Stylosanthes hamata	Caribbean	Amiga	Erect (short), herbaceous	Perennial	Early season
Stylosanthes seabrana	caatinga	Unica	Erect shrub, moderate height	Perennial	Mid-season
Stylosanthes scabra	shrubby	Siran	Erect shrub, moderate height	Perennial	Mid-season

Table 5 Grasses and legumes for comparison as individual lines on red and black basalt-derived soils at 'Junction Creek', north-west of Charters Towers in north Queensland.

Legume species	Variety	Red basalt	Black basalt
Centrosema brasilianum	CPI 55698*	Y	
	Gilbert River Centro	Y	Y
	Davies*	Y	
Centrosema molle	Cardillo	Y	Y
Clitoria ternatea	Double		Y
	Milgarra	Y	Y
Desmanthus bicornutus	Fletcherview basalt 2	Y	Y
Desmanthus hybrid	P1*	Y	
	P2*	Y	
	P3*	Y	
Desmanthus leptophyllus	JCU7	Y	Y
	TQ90		Y
Desmanthus sp.	Breen*	Y	Y
	Fletcherview basalt 1	Y	Y
	Hillgrove 170	Y	Y
	Hillgrove 2007	Y	Y
	Hillgrove 79	Y	Y
	JCU6	Y	Y
	JCU8	Y	Y
	JCU9	Y	Y
	Powerline	Y	Y
Desmanthus virgatus	ES203		Y
	Marc		Y
	Progardes (composite)	Y	Y
	Q9153		Y
Macroptilium atropurpureum	Aztec	Y	Y
	CPI84989	Y	Y
Macroptilium bracteatum	Cardarga		Y
	Juanita	Y	Y
Macroptilium gracile	TGS849	Y	Y
Macroptilium martii	JCU*	Y	
Stylosanthes guianensis var *guianensis*	Nina 3308	Y	Y
Stylosanthes guianensis var. *intermedia*	Oxley	Y	Y
Stylosanthes hamata	Amiga	Y	Y
	Verano	Y	Y
Stylosanthes scabra	Seca	Y	Y
	Siran	Y	
Stylosanthes seabrana	Primar	Y	Y
	Unica		Y
Stylosanthes sp.	Breen	Y	
Stylosanthes viscosa	JCU	Y	

Grass species	**Variety**	**Red basalt**	**Black basalt**
Bothriochloa bladhii	Swann	Y	
Bothriochloa insculpta	Bisset	Y	Y
	CPI125265B (Cedo)	Y	
Bothriochloa pertusa	Keppel	Y	Y
	Medway	Y	Y
Brachiaria brizantha	Mekong	Y	
Brachiaria decumbens	Basilisk (Signal)	Y	
Brachiaria hybrid	Mulato 2	Y	
Cenchrus ciliaris	Gayndah		Y
Cenchrus setiger	Capsize	Y	
	Kununurra type*	Y	
Chloris gayana	Katambora	Y	Y
	Reclaimer	Y	
	Sabre	Y	Y
	Tolgar	Y	
	Toro	Y	
Dichanthium aristatum	Floren	Y	Y
Dichanthium sericeum	Scatta		Y
Digitaria eriantha	Premier		Y
Digitaria milanjiana	Jarra		Y
Heteropogon contortus	S06	Y	
Panicum coloratum	ATF714	Y	Y
	Bambatsi		Y
Panicum maximum	G2	Y	
	Gatton	Y	Y
Panicum maximum x *P. infestum*	Nucal (C1)	Y	Y
Urochloa mosambicensis	Nixon (Sabi)	Y	
	Saraji	Y	Y
	TGS1012	Y	

* only one replicate sown due to limited seed stocks

3.2 Seed preparation and sowing of the experimental sites

3.2.1 Preparation of seeds for sowing

Seeds for the experiments were sourced from commercial companies (where available) with preference for uncoated seeds as these could be tested for viability and purity more readily and *Rhizobium* inoculum could be applied more reliably. Seeds were mostly purchased within six months of sowing, and stored in an air-conditioned store until ~one month before sowing when they were exposed to ambient conditions (to reduce embryo dormancy). In some cases older seed was used, but this was stored in a controlled environment store (50% RH, 10°C) over the summer (wet) period prior to management as for the other lots. Commercially unavailable seed lots of older cultivars were sourced from the DAF seed store with particular care for managing dormancy. Newer lines were sourced from the DAF seed production program, often in collaboration with seed companies who donated seeds to the program (Agrimix, PPG Wrightson, Australian Premium Seeds (absorbed), Heritage Seeds (absorbed, now Barenbrug) and Selected Seeds).

The testing of grass and legume seed for normal germination was conducted between July and November, depending on the age of seed and the perceived need to manage dormancy. Conventional methods were used for the testing of tropical pasture seeds (Vennell, 1980) (Fig. 4).

The key purpose of the seed testing was to estimate seed germination by either seed number (legumes) or weight (grasses) to enable the adjustment of sowing rates for reliable establishment. A representative sub-sample of each lot was drawn using a 'riffle box' sub-sampler: the weight of the subsamples varied by species, but were within the specified guidelines for each. These were managed differently for legumes and grasses.

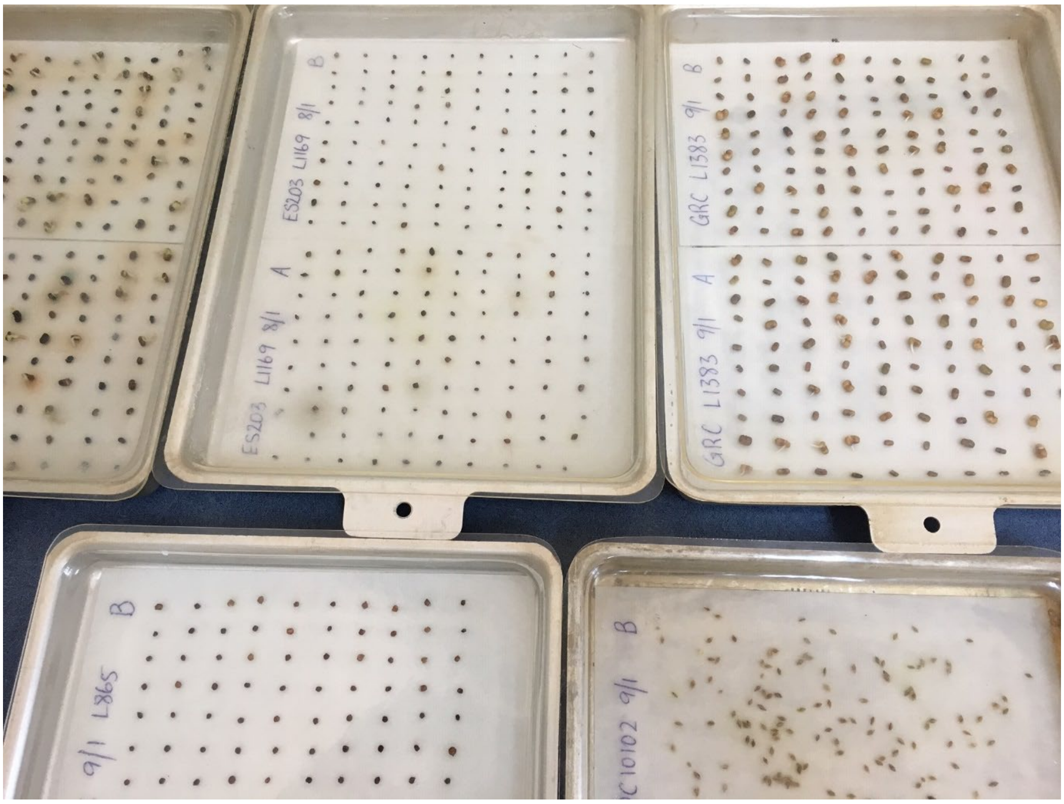
Legumes - for previously untested lots of legume seeds, two 100 seed representative subsamples were drawn by hand from the subsample and assessed for normal germination by number using standard seed test procedures (top of paper, 20/35°C and incubated). Each subsample was weighed prior to testing. Most tests were concluded 10 to 14 days after 'wet down'; for the legume seeds, any seeds remaining on the blotters at the end of the test were assessed for hardseed dormancy, fresh (swollen, but not germinated) or dead (clearly non-viable) seeds. Repeat tests of lots which had been previously tested (e.g. the previous year) were conducted in case there had been a significant decline in viability during storage; only one replicate was used in these cases. The results were expressed as percentage germination by number, which can be converted to germination to an estimate of the number of germination by weight using the 100 seed weight.

Grasses – the grass samples were further divided using the riffle-box into two small (~0.2 to 0.5 g) replicates and these were placed directly onto blotters and incubated as for the legumes. The number of normal seedlings over 10 to 14 days were counted, removing seedlings as they were counted. The results were expressed as germination per gram for simple adjustment of sowing rates. Recently harvested lots with low germination were assessed by carefully dissecting the caryopses (kernals) from two sub-samples of 50 seeds, inspecting them for form and recording the percentage of fully formed and healthy caryopses. It should be noted, the seed lots of the legumes were very clean seed lines (pure seed proportions > 95%), so it was deemed not necessary to conduct physical purity tests in the first instance.

Legumes with a high hardseed content were mechanically scarified; small lots with sandpaper on a rubbing board and larger lots using either a clover dehuller (stylos) or a spinning-disc scarifier (others). Large stylo lots were scarified using a tractor-mounted hammermill and re-cleaned (air-screen cleaner). Seed viability testing was then repeated. An example of seed test results can be found in Appendix 10.4.

All legume seeds were inoculated with an appropriate *Bradyrhyzobium* or *Rhizobium* strain sourced commercially (Newedge Microbials) each year and stored in a refrigerator until application. A methyl cellulose sticker was used to apply the inoculum within 36 hours of sowing (but usually within a few hours) and treated seeds were dried in the shade and kept cool until sowing.

Fig. 4 Germination tests for grasses. Two replicates of 100 seeds are incubated (20/35°C, light/dark cycles) on moistened blotters for 10-14 days**.**



3.2.2 Calculating sowing rates

The choice of sowing rates depended on the level of experimentation and recognised that all plantings were conducted without supplementary irrigation. Relatively high sowing rates were used for the small-plot experiments at 'Junction Creek' to ensure there were sufficient plant populations of grasses and legumes for comparing lines over time. Sowing rates for the larger grass x legume plots at 'Whitewater', 'Spyglass', 'Huonfels' and 'Wonga' were based on commercially recommended rates using the *Tropical Forages* pasture selection and information tool (www.tropicalforages.info Cook et al., 2005) and tended to be lower than for the small plot assessments.

The target sowing rates were calculated by nominating a desired number of normal seedlings (in tests) per gram by combining recommended sowing rates with normal seed test expectation for good quality commercial seed (Table 6). Actual sowing rates used (in paddock) were then adjusted based on seed viability test results compared to expected results combined with measures of mean seed weight. When coated seeds were used, sowing rates were tripled to allow for the reduction in seeds per unit weight. In a few cases, minor adjustments had to be made due to limited amounts of seed for sowing (to achieve the replication desired). In one instance ('Mulato 2 *Brachiaria* hybrid at 'Whitewater') only poor-quality commercial seed was available for sowing. Very high sowing rates were used, but these still provided a low number of viable caryopses per unit area.

Table 6 Target sowing rates and viability expectation.

Plant group		Sowing rate (kg/ha)				Viability target (%)
		Separate plots	Grass x legume	Grass x legume mix		
		Junction Creek	W. water Spyglass	Huonfels	Wonga	
Grasses	panicoid grasses (*Brachiaria, Panicum, Urochloa*)	5	3-4	4[1]	4	80
	Chaffy grasses (*Bothriochloa, Cenchrus, Chloris, Dichanthium*)	5	3	4	4	50
	Digit grasses (*Digitaria*)	5	3	4	4	70
Legumes	Large seed (*Clitoria*)	12	8	3	8	80
	Medium seed (*Macroptilium*)	8	6	2	6	80
	Small seeded (*Desmanthus, Stylosanthes*)	5	3	1	4	70

1 Mekong *Brachiaria brizantha* sown at 10 kg/ha: very large seed and poor vigour

Table 7 Experimental designs.

Property (location)	Type of experiment	Entire fenced area (ha)	Experimental design	Replicates	Plot size (m^2)
'Junction Creek' (Charters Towers)	Individual plots	Red: 1 Black: 1	RCB[1]	3	15
'Spyglass' (Charters Towers)	Grass x legume	4	RCB	3	152
'Whitewater' (Mt Surprise)	Grass x legume	6	RCB	3	63
'Huonfels' (Georgetown)	Grass x legume mix	4	RCB	3	270
'Wonga' (Moura)	Grass x legume mix	4	RCB	3	180

1 replicated completed blocks

Table 8 Methods used to prepare the sites for sowing and fertiliser application rates.

Property (location)	Preparation in year before sowing	Initial control of weeds in plant year	Pre-sow control of weeds	Fertiliser applied (kg/ha)
'Junction Creek' red (Charters Towers)	Grazed as normal over dry season	Glyphosate to control older plants. Cultivation (discs)	Cultivated (tines and crumble roller).	GranAm 120
'Junction Creek' black (Charters Towers)	Cultivated (discs) for sowing but heavy rain postponed for a year. Not grazed.	Not required	Cultivation (discs), rolled	SSP 120
'Spyglass' (Charters Towers)	Cultivated 1 year before sowing. Repeat cultivation to control seedlings.	Cultivated (tines and crumble roller) to control seedlings.	Cultivated (tines and crumble roller). Glyphosate to control seedlings after storm.	SSP 120
'Whitewater' (Mt Surprise)	Grazed as normal over dry season	Cultivated (tines)	Cultivated (tines).	GranAm 120
'Huonfels' (Georgetown)	Grazed as normal over dry season	Glyphosate (boom) to control seedlings after first storms	Single cultivation (tines).	SSP 150
'Wonga' (Moura)	Drought. Stock withheld.	Cultivation (x2) (discs)	Glyphosate (boom) to control surviving weeds, rolled	SSP 150

3.2.3 Experimental design and timetable of establishing the experimental sites

Replicated experimental designs were used at all sites (Table 7). The individual plot experiments at 'Junction Creek' were two randomised complete block experiments (grass or legume lines) at each site. Factorial designs were used for the grass x legume combination experiments. In all cases, randomly allocated (within blocks) strips of the various grasses were sown and legume treatments (sub-plots) randomly assigned within each strip. There were two broad design types:

1. A split-plot factorial design (3 replicates) with grasses established in long strips as main plots, and legumes randomly assigned to sub-plots ('Whitewater' and 'Spyglass'). This approach enables detailed comparison of grass/legume interactions.
2. A simplified design using randomised strips of grasses (2 replicates) sown to a mixture of legumes ('Huonfels' and 'Wonga'). This design targets an understanding of legume succession when using mixtures, a practice likely to be used commercially.

The small-plot experiments at 'Junction Creek' were sown in the 2017-18 (red) and 2018-19 (black) wet seasons. The legume x grass combination experiments were sown during 2018-19 ('Whitewater') and 2019-20 ('Spyglass' and 'Huonfels') wet seasons. The site at 'Wonga' was sown in February 2021.

3.2.4 Site preparation and sowing

All experiments were located within mesh-fenced areas to prevent access by kangaroos (mostly successful). The choice of land preparation method varied between sites based on soil type (particularly presence of rocks), whether the site had previously been cleared and the perceived need to deplete soil seed banks of species considered to be potential contaminants of the experiments (Table 8). At 'Spyglass' it was necessary to begin eroding soil seed banks a full year before sowing. In all cases, final site preparation before sowing was completed after the first storms of the summer growing period. Supplementary phosphorous and sulphur (single superphosphate) or sulphur along (GranAm) was applied as basal fertiliser (only) based on soil tests completed within six months of sowing and this was incorporated in the final cultivation. Glyphosate applied at label rates was used in some instances to control seedlings which had emerged between the final cultivations and sowing. Examples of cultivation methods are presented in Fig. 5.

The individual small-plots at 'Junction Creek' were all sown into 3 rows 0.3 m apart which had been formed by a flanged (Cambridge) roller and the plots were rolled afterwards to cover seeds. The seeds for the grass x legume combination experiments were all broadcast by hand onto prepared ground and rolled immediately after sowing. All legume seeds were inoculated with recently purchased *Bradyrhzobium / Rhyzobium* inoculant before sowing as described above. There was no supplementary irrigation or selective weed control (by boom application) after sowing, although volunteer *Urochloa mosambicensis* was controlled at 'Spyglass' by spraying with glyphosate at label rates after sowing where it is considered a blocked nozzle on the boom sprayer provided poor control of emerging seedlings before sowing of the plots.

Establishment was broadly successful. However, at 'Whitewater' extremely low rainfall after sowing (48 mm in the 6 months after sowing) and damage by grasshoppers caused poor survival of some grasses (Jarra *Digitaria milanjiana* and ATF714 *Panicum coloratum*). These were resown the following summer by distributing seeds by hand after first storms and 'mulch striking' them by mowing to cover seed with debris. This was mostly successful.

Fig. 5 Examples of methods used to prepare the experimental sites.

A fully cultivated site being sown at 'Junction Creek' (red). Seeds are placed in furrows and covered.

Using a flanged roller to prepare small plots for sowing at 'Junction Creek' (black).

Applying mesh fencing to a fully prepared site at 'Spyglass'.

Weeds emerged vigorously after rain at 'Spyglass' and were controlled by cultivation and glyphosate

Using tines to work up a rough seed bed in the rocky soils at 'Whitewater' (second cultivation).

Seeds broadcast by hand at 'Whitewater before rolling with a flanged (Cambridge) roller

3.3 Site management and field data collection

3.3.1 General management

The research sites were managed as simple paddocks. There was no supplementary fertiliser applied and weed control was limited to the hand-pulling of weeds (e.g. *Desmodium incanum*) which came with some commercial stylo seed. Woody suckers were controlled. The borders of the plots areas were mowed two or three times a year to allow easy access to plots for ease of measurements and sampling and for field days. Key interventions are presented in Table 9.

3.3.2 Livestock management and cutting

The experiments were all managed as 'weaner' type production paddocks, being spelled in the wet season and grazed during the early-mid- dry season. Supplements (urea) were only applied in one instance (to reduce *Dichanthium* growth at the black soil site on 'Junction Creek') to reduce volumes of unpalatable grasses after ratings were complete for the year. Grazing was not conducted in the year of sowing to ensure good establishment and seed set. A brief grazing was conducted in the first wet season after establishment when herbage yields were particularly high. In most cases, however, the first grazing was at the end of the second wet season when plants were 14-16 months old (Table 10).

The plots were mostly grazed by weaners, although occasionally cows were used when weaners were not available. The plots were grazed until there was approximately 1500 kg DM/ha remaining at the site and then removed for the remainder of the dry season. The plots were usually cut using a slasher (or mower for small plots) after the green day (defined as more than 50 mm over a 4-week period) and if there were signs of plant regrowth (early cutting had been shown to damage plants even when dormant). This was usually in December or January. The plots were cut to 10-15 cm and allowed to re-grow. Grazing was generally introduced shortly after plant biomass measurements and plant sampling for nutrient analysis had been collected.

3.3.3 Data collection

Plant establishment and growth

Field measures and sampling procedures are outlined in Table 9. Plant population was measured once it was considered there was sufficient rainfall for establishment and green cover estimated periodically thereafter (usually 4-6 weeks after sowing). Thereafter, changes in green cover were assessed regularly over each growing season and prior to the onset of the following year. Plant reproductive growth stage and ratings of 'haying-off' were recorded periodically to estimate the capacity for seed set and assist in the interpretation of yield and quality results. Rainfall was recorded at each site (most) or nearby Bureau of Meteorology station (< 5 km, 'Wonga').

Herbage yield and feed quality

Sampling for herbage yield was primarily intended to coincide with first or second rounds of weaning in northern Queensland when the quality of native pastures had begun to decline. Plant biomass was measured once it was considered the wet season was completed (May or June with limited prognosis for follow up rainfall) or (in one instance) when grazing was considered necessary to reduce very high grass biomass following an early start to the wet season ('Spyglass' March 2021). In 2022, 'Spyglass' was grazed twice during the wet season to reduce grass dominance and encourage legume growth and biomass was not measured.

Feed quality was measured when completing the biomass measurements. Measures of herbage yield and quality were linked through using the same samples and ground cover within sampling areas (quadrats) was used as a covariate for analysis of herbage yield. The dried legume samples were separated into leaf and stem components, whereas grasses were measured whole. Additional samples were collected during the wet season to estimate feed quality under optimal growing conditions to compare with feed sampled during the early-mid dry season.

Over 280 samples were collected between May 2020 and late June 2021, processed and submitted to Dairy One™ (Appendix 10.5). The samples were analysed using wet chemistry analysis of key feed quality indices (as calibrations are not available for NIR analysis). Key measures included: % crude protein, % adjusted crude protein, % acid detergent fibre, % neutral detergent fibre, % lignin, % crude fat, % ash, % total digestible nutrients, metabolisable energy and % mineral content (Ca, P, Mg, K, Na, Fe, Zn, Cu, Mn, Mo and S) (Appendix 10.6). The data were transferred to a master data set linked to previous feed analyses (B.NBP.0766) and summary tables of key feed quality indices and mineral contents compiled.

Grazing preference
A simple rating system was devised to confirm the acceptance of the various grasses and legumes to grazing livestock and estimate any differences in grazing intensity (preference) between the grass and legume lines. Visual ratings of grazing intensity were conducted two to six weeks after cattle were introduced to the plots. Urea based supplements were only used when there was residual stemmy material remaining after the grazing assessments.

3.3.4 Statistical analysis of field data

All statistical analyses (tests of significance, correlations and fitting of curves to continuous data) were completed by a senior DAF biometrician using Genstat software (VSN International, 2014). Descriptive statistics (to identify trends) and simple analyses of variance (balanced, normally-distributed data sets) were conducted by the Project Leader. The methods used for each analysis are described with the corresponding statistics and figures in the Appendices. In most cases, the results for each variable are compared with an 'industry' standard species for the particular land type e.g. black spear, sabi of buffel grass for the grasses or shrubby stylo for the legumes. Selections of the analyses are presented in the body of this report. Simple descriptive statistics (means and standard errors) and figures were prepared by the research team.

3.4 Seed production to support research and commercial adoption

3.4.1 Selection of grasses and legumes for seed increase

Some of the grasses and legumes which performed well in B.NBP.0766 were yet to be commercially adopted by seed companies and there were limited amounts of seeds for scaled-up plant evaluation activities. Seed production was undertaken within the DAF pasture seed production program to produce seed for developing the plant evaluation sites and provide seeds for establishing first commercial crops.

Two legumes, *Macroptilium gracile* TGS849 and *M. atropurpureum* TGS84989, and four grasses, *Panicum coloratum* ATF714, *P. maximum* x *infestum* NuCal and Massai and *Urochloa mosambicensis* TGS1012. One other promising variety, *Bothriochloa insculpta* CPI126552B, was under multiplication for a private company as part of the DAF seed increase program (crop area of 800 m^2) at the on-set of B.NBP.0812. Seed increase of these lines began in 2016 in anticipation of research needs and continued until 2022 for two grasses (*P. maximum* x *infestum* NuCal and Massai) to provide a reserve of foundation seed.

3.4.2 Management of seed crops

The seed crops were all grown at DAF's Walkamin Research Facility (17.14°S, 145.43°E; 630 m asl) on the Atherton Tablelands in north Queensland. The area has an upland tropical environment with mean annual summer-dominant rainfall of 1020 mm. The soils used were deep, free-draining krasnozems ('Mapee') with site slopes of less than 5°. Each crop was located in mesh-fenced (for wallabies and rabbits) and irrigated (solid set) areas used routinely for the seed production. Previous soil tests conducted on these soils revealed a near-neutral reaction and P, S, K, Mg levels generally optimum for legume production (Cox et al., 2012).

The crop areas were prepared using cycles of cultivation, rolling and controlling emerging weeds with glyphosate. Choice of site for each was based previous management, with legumes being sown where grass seed crops had recently been grown and grasses sown where legumes had recently been produced. Single superphosphate (200 kg/ha) and muriate of potash (100 kg/ha) were incorporated into soil during the final cultivation for all seed crops as is normal practice at DAF Walkamin. Thereafter the grasses and legumes were managed differently:

Grasses
Because of low amounts of planting seed, the *Panicum* hybrids (Massai and NuCal) and *Panicum coloratum* ATF714 were initially sown using seedlings raised in a shade-house. The first ATF714 seed crop was sown in a grid to provide rapid cover, whereas the Massai and NuCal were sown in rows 1 m apart and with ~25 cm between plants. All crops were watered every 2-3 days after sowing to supplement rainfall over the first two weeks and thereafter irrigated to supplement rainfall at ~30 mm per week. Thereafter, seeds of *Panicum coloratum* ATF714 and *Urochloa mosambiecensis* TGS1012 were sown by broadcasting during the wet season using rates of 6-10 kg/ha of clean seed and each site rolled (Cambridge roller). No additional fertiliser was applied for the first crop. After the first seed crop, each crop was 'started' by cutting to 10-20 cm (higher cuts for the *Panicum* hybrids) using a slasher or industrial lawn mower and applying 100 to 120 kg N/ha as urea and irrigating immediately afterwards to incorporate. The 2018 seed crops also had an additional 20 kg S/ha applied as GranAm. Broadleaved weeds were controlled by applying 2,4-D at label rates and weed grasses removed manually by chipping or careful spot-spraying with glyphosate. The grasses were all harvested using a MF8 Massey Ferguson combine harvester adapted for pasture seed harvesting (reduced aspiration and high bulk capacity). The harvested seeds were dried on a platform drier using unheated air for the first 2 days and 35°C for a further 1 to 2 days depending on drying conditions. The seed lines were then cleaned using small-scale air-screen seed cleaners and winnowers.

Legumes
The legumes were grown on weed mats (2.4 or 3.0 m wide) laid after applying the basal fertilisers as above. *Rhizobium* inoculated seeds were sown directly into holes in the weed mats (2-3 seeds per hole, 1-2 cm deep) and the crops irrigated as for the grasses. Insects were controlled using a rotation of methomyl and dimethoate once flowering and monitoring for pests had begun. The seed crops were allowed to continue to flower and produce seed for as long as practicable. The early-flowering *M. gracile* was harvested during winter after ceasing irrigation, whereas the late-flowering *M. atropurpureum* required irrigation throughout the dry season prior to harvesting in November or December. The crops were harvested by cutting plants at ~5 cm, removing (rolling

Fig. 6 Examples of methods used to produce grass and legume seed crops at DAF Walkamin.

Massai and NuCal (C1) seed crops are row planted and nitrogen fertilised for vigorous growth

Once harvested, grass seed crops (here, ATF714) are slashed, trash removed and fertilised

The seed crops were harvested with a scaled-down combine harvester. Timing of harvest is critical to maximise the number of mature seeds harvested before they are shed from panicles.

Legume (here TGS84989) seed crops were grown on weed mats, sometimes with steel picket / wire trellises to encourage flowering and to maximise seed yields. First year crop,flowering was late.

The same seed crop the following year. Flowering was earlier in the second year enabling harvesting under more settled conditions.

back) the mat of crop and vacuum harvesting the fallen seed. The harvested seed lots were dried and cleaned as for the grasses. Perchlorethylene, an industrial solvent which can separate seed from soil based on differences in physical density, was used to separate soil and seeds in some instances.

3.5 Data management for extension messaging

3.5.1 Consolidation of data

Field data were analysed and summarised each year as they collected and were consolidated within annual technical milestone reports. These included summary tables and graphs which related to key extension messaging. Continuous data (green cover) were accumulated and re-analysed each year. Detailed statistical analyses were kept as a series of internal DAF memos and simple tables of means and standard errors were maintained for future reference. As key measures were the same as those used in the pre-cursor project (NBP.0766) the new data could be combined with the older data sets. All data were backed up.

3.5.2 Industry engagement

Results for the projects (and program overall) were presented at a series of field days/information days, regional BeefUp forums and at Beef Australia (2021). Key messaging directly related to this projectaddressed:

- Grass and legume selection for different land-types including persistence and recruitment
- Yield expectations using ‘production paddock’ systems using legume only or grass+legume systems on soils of high and low fertility
- Feed quality expectations for different pasture plants and stages of maturity
- The role of competition between grasses and legumes when fertilised, including grazing preferences.

This information was used in combination with historical research results and complementary DAF research (particularly leucaena and fertilised pasture research in north Queensland) to promote the use of legumes for improving animal liveweight gain and stocking capacity, but also reinforce messaging on careful grazing land management.

3.5.3 Bio-economic analysis

A key aim of the project team was to estimate the financial benefit of ‘production paddocks’ in north Queensland using data from the current research program in combination with historical and complementary research. To achieve this, two master data sets were compiled for herbage yield and feed quality using data from B.NBP.0766 and B.NBP.0812 (grown individually or in grass x legume combinations). Key ‘drivers’ of herbage yield (land-type, age of pasture, period of growth since ‘green day’, accumulated rainfall) were included in the yield database to interpret yields.

A series of economic analyses were initially completed to estimate the marginal value of developing ‘production paddocks’ using strips of (1) either legumes + grasses or (2) legumes only in north Queensland. The analysis drew on data generated in this project (B.NBP.0812) and the pre-cursor project (B.NBP.0766) and used the approach developed by DAF and collaborating agencies to identify the best options for improving business profitability and resilience in seasonally dry areas on Queensland through the Drought and Climate Adaptation Program (DCAP). To enable comparisons, the analysis used the same approach as that used to assess the profitability of over-sowing legumes (stylos) or fertilising stylos on infertile soils in the Gulf of Carpentaria region (Bowen et al., 2019).

Two land-types were assessed, drawing on the 'Whitewater' and 'Spyglass' sites:

1. Infertile soils requiring P and S fertiliser (red earths in the broader Charters Towers region)
2. Fertile soils requiring S fertiliser only (red basalt in the same region).

Two pricing scenarios were used to test the response of the economic statistics to sale price.

Once completed at a paddock level, the analysis was extended to a whole-property level using two 'base property' scenarios, each representing different areas of the Burdekin catchment, and comparing the development of 'production paddocks' with the status quo.

1. Property near Charters Towers with a mixture of fertility and marginal average soil phosphorous: this drew on data collected at DAF Spyglass
2. Property near on the volcanic basalt plateau near Mt Surprise with high average soil phosphorous: this drew on data collected at 'Whitewater'

The analyses are to be included in a DCAP options analysis publication for the Burdekin catchment, adding to the DAF series of bio-economic analyses and draft versions are attached to this report. Key findings from the analyses are to be used to communicate the costs and benefits of developing 'production paddocks' on soils of low or high (P) fertility in the seasonally dry tropics of north Queensland. Analysis parameters and results are described in Section 5 to allow more convenient cross-referencing. The two analyses are Attachments 1 and 2 for this report.

Table 9 The timing of key field interventions and measurements, 2018-2021.

Property	**Sowing date / *re-set date***	**Plant population[1]**	**Cover[2]**	**Wet season biomass[3]**	**Growth stage and hay-off[4]**	**Level of grazing[5]**
Junction Ck red	14 Feb. 18	15 Mar. 18	06 Jun. 18		06 Jun. 18	Estab. year
		27 Jun. 18	13 Mar. 19		13 Mar. 19	
			06 Jun. 19		06 Jun. 19	
			07 Aug. 19	07 Aug. 19	07 Aug. 19	None year 2
			13 Nov. 19		13 Nov. 19	
	17. Jan. 20		17 Jan. 20		17 Jan. 20	
	(mower cut)		18 Mar. 20		18 Mar. 20	
			20 May 20	20 May 20^	20 May 20	
	03 Aug. 20		05 Aug. 20		05 Aug. 20	07 Aug. 20
	(grazed)		23 Feb. 21		23 Feb. 21	
			23 Jun. 21	23 Jun. 21^	23 Jun. 21	19 Sep. 21
	13 Aug 21		08 Apr. 22		08 Apr. 22	
	(grazed)					
Junction Ck black	24 Jan. 19	13 Mar. 19		None year 1	13 Mar. 19	Estab. year
			06 Jun. 19		06 Jun. 19	
			07 Aug. 19		07 Aug. 19	
			13 Nov. 19		13 Nov. 19	
	17. Jan. 20		17 Jan. 20		17 Jan. 20	
	(mower cut)		18 Mar. 20		18 Mar. 20	
			20 May 20	20 May 20^	20 May 20	06 Aug. 20
	20 Sep. 20		06 Aug. 20		06 Aug. 20	10 Sep. 20
	(grazed+		23 Feb. 21		23 Feb. 21	
	mower cut)		24 Jun. 21	24 Jun. 21^	24 Jun. 21	19 Sep. 21
	13 Aug 21		08 Apr. 22		08 Apr. 22	
	(grazed)					
Whitewater	27 Feb. 19	23 Apr. 19	23 Apr. 19	None year 1	23 Apr. 19	Estab. Year
		28 May 19	28 May 19		28 May 19	
		23 Jul. 19	23 Jul. 19		23 Jul. 19	
		23 Oct. 19	23 Oct. 19		23 Oct. 19	
	23 Jan. 20		26 Mar. 20		26 Mar. 20	
	23 Jan. 20		06 May 20	06 May 20^	06 May 20	
	(mower cut)				25 Jun. 20	10 Jul. 20
	3 Nov. 20					20 Jul. 20
	(mower cut)				03 Nov. 20	
			3 Dec. 20		3 Dec. 20	
			8 Apr. 21		8 Apr. 21	
	20 Jul. 21		13 May 21	13 May 21^	29 May 21	
	(grazed)				17 Jun. 21	17 Jun. 21
					17 Jul. 21	17 Jul. 21
	08 Dec. 21		7 Dec. 22			
	(slashed)		16 Feb. 22	2 Mar. 22	16 Feb. 22	
					15 May 22	15 May 22
Huonfels	4 Mar. 2020	25 Mar. 20		None year 1	25 Mar. 20	Estab. Year
			25 Jun. 20		24 Jun. 20	
			27 Aug. 20		27 Aug. 20	
	Not required				03 Nov. 20	
			22 Feb. 21		22 Feb. 21	
			3 Jun. 21		3 Jun. 21	
	20 Nov. 21		7 Jul. 21		12 Aug.21	12 Aug. 21
	(grazed)		16 May 22		16 May 22	

Property	**Sowing date / *re-set date***	**Plant population[1]**	**Cover[2]**	**Wet season biomass[3]**	**Growth stage and hay-off[4]**	**Level of grazing[5]**
Spyglass	5 Feb. 2020	17 Mar. 20		None year 1	17 Mar. 20	Estab. Year
			03 Aug. 20		03 Aug. 20	
	Oct. 20				10 Nov. 20	
	(mower cut)		16 Mar. 21	16 Mar. 21^	16 Mar. 21	
					5 Jun. 21	5 Jun. 21
	11 May 21 (grazing)		3 Aug. 21 4 Apr. 22	Grazed to increase legumes	3 Aug. 21	
	14 Dec. 21 (slashed)					
Wonga	24 Feb. 2021	16+24 Apr. 21				Estab. Year
	** 21 (grazed)		** Jun 22		** Jun 22	

1 Junction Creek: Legumes: number of plants/m row, 2 measurements/plot Grasses: % of row occupied by grass at ~2cm above ground (absence/presence along 1 m ruler), 2 measurements/plot (central row)
Other sites: number of plants per 0.25 m^2 quadrat; 'Whitewater' 2 quadrats per plot, 'Spyglass' 3, 'Huonfels' 5, 'Wonga' 6.

2 Cover: visual estimate of area above ground occupied by the grass or legume (0-10 scale) taken within randomly placed quadrats; 'Junction Creek' sites 2 quadrats/plot (when linked to other measures, otherwise whole plot), 'Whitewater' 3, 'Spyglass' 5, 'Huonfels' 5.

3 Dried biomass (70ºC until constant weight) from 2 samples per plot collected within 0.3 ('Junction Creek' sites) or 0.25 ('Whitewater') m^2 quadrats cut to 2-5 cm. Legumes were separated into leaf and stem fractions and weighed separately. The number of culms were counted for each grass sample and expressed per m^2. ^ herbage samples used for nutrient analysis: leaf/stem at 'Whitewater', 'Spyglass' and 'Huonfels' and whole at 'Junction Creek'

4 Visual scores per plot ('Junction Creek') or replicate (other sites):
- *growth stage*: V = vegetative; EF = early flowering; F = mid flowering; S = seeding (mature)(legumes only); X= shattered/dehisced (legumes only)
- *haying off status*: Legumes and grasses: 1 = plants growing/green; 2 = <60% plants haying off; 3 = 60-80%; 4 = 80-99%; 5 = 100% or dead

5 A single rating per plot conducted after livestock had been removed: 0 = untouched; 1 = occasional plants grazed (<20% of plants); 2 = moderate amount of plants grazed (20-80% plants); 3 = most plants grazed (>80% of plants) but limited to leaves and ends of branches (tips); 4 = most plants grazed (>80% of plants) including leaves and stems; 5 = most plants grazed back to crowns (<5 cm above ground).

Table 10 Grazing management at the experimental sites, 2021.

Property	Year[1]	Date in	Date out	Stock number and class	Estimated liveweight (kg/hd)[2]	Est. intake (kg DM) [/ha][3]	Assessment of grazing
Junction Ck red	2	30 Jul. 20	3 Aug. 20	15 weaners	125	131 [131]	07 Aug. 20
	3	10 Aug. 21	14 Aug. 21	24 weaners	210	353	19 Sep. 21
Junction Ck black	1	30 Jul. 20	3 Aug. 20	17 weaners	125	149 [149]	06 Aug. 20
		2 Sep. 20	7 Sep. 20	10 weaners	140	123 [123]	10 Sep. 20
	2	6 Aug. 21	13 Aug.21	10 cows	420	875	19 Sep. 21
Whitewater	1	17 Jun 20	27 Jul. 20	10 weaners	280	1960 [327]	10 Jul. 20 20 Jul. 20
	2	10 Jun. 21	20 Jul. 21	18 weaners	340	712	17 Jun. 21 17 Jul. 21
	3	02 May 22	24 May 22	16 heifers	320	329	25 May 22
Huonfels	Not grazed – establishment year					-	
	2	10 Jul. 21	20 Nov. 21	6 steers	300	3190	12 Aug. 21
Spyglass	1	27 Apr. 21	11 May 21	28 heifers	300	515	5 Jun. 21
	2	09 Jan. 22	24 Jan. 22	12 cull cows	420	331	NA[4]
	2	16 Feb. 22	04 Mar. 22	18 steers	300	378	NA[4]
Wonga	1	TBA	TBA				NA

1 Full season after establishment
2 Based on owner records, based on recent weights.
3 Based on 1 AE = 400 kg and animal intake of 1.8% liveweight/day (DM basis). Per hectare values are based on the entire fenced area.
4 Grazing to suppress grass growth (wet season grazing) to encourage legume growth through cattle selecting for young grass leaf.

4. Field results

4.1 Growing conditions during the experiment

4.1.1 Historical trends in rainfall and temperature in the study regions

The six experimental sites, five in north Queensland and one in central Queensland, all have significant historical dry season components for rainfall, with most rainfall occurring during the warmer summer months of December to March (Table 11). The dry period is particularly marked in north Queensland, with mean monthly totals of less than 20 mm typically occurring May to October providing little opportunity for pasture growth. The northern environments are also typically hot with mean monthly daily range of ~20-30°C during summer and 10-25°C during winter with no or only a few light frosts during winter. Growing conditions are particularly challenging at the sites in the Gulf of Carpentaria due to the combination of elevated temperatures and the marked dry season. Growing conditions in central Queensland sites can be considered more 'benign' than most northern sites with a greater component or rainfall between April and September and slightly cooler minimum and maximum temperatures. There is, however, a substantially greater probability of frosts (minimum temperature <2°) in winter months, occurring most years in inland areas.

The growing environments are highly variable season to season, particularly for rainfall. Long-term mean monthly rainfall recorded at Bureau of Meteorology weather stations is consistently higher than median values (Table 11). Median values for monthly rainfall are frequently zero for winter months in north Queensland, particularly away from the coast. Values are also significantly lower in central Queensland, but 'in a median year' useful rain can be expected (even if growth can be compromised by frost).

4.1.2 Rainfall at the experimental sites

The field assessments were conducted between February 2018 and May 2022 depending on time of sowing. Monthly rainfall totals are presented in Table 12 compared to long term mean and median values. Growing seasons were defined as November to October to cover a typical season of growth and the 're-setting' of growth by cutting after first storms which usually occur between November and January in north Queensland.

The study period coincided with the emergence of *La Nina* (negative Southern Oscillation Index (SOI) values) conditions during 2021 and 2022 which are characterised by higher probabilities of above average rainfall in north-eastern Australia than during *El Nino* (sustained negative SOI) or neutral (no clear trend) environments. The SOI was predominately in a neutral phase 2017-2021 (http://www.bom.gov.au/climate/enso/soi/).

Rainfall at the north Queensland sites was higher than long-term mean (and median) values during *La Nina* conditions but substantially lower in central Queensland where higher probabilities of above average rainfall were not realised. Low rainfall (and the opportunity to accumulate sub-soil moisture) delayed the sowing at the Moura site ('Wonga') by a year. Rainfall differed considerably by region in the 'neutral phase' years, coinciding with the establishment of the north Queensland sites. Whereas rainfall was relatively high in the Charters Towers region ('Junction Creek' and 'Spyglass'), seasonal totals for 2018-19 and 2019-20 were substantially lower than long-term values near Georgetown ('Huonfels') and Mt. Surprise ('Whitewater'). There was an extended dry season (April-December) in 2019 after 'Whitewater' was sown, but otherwise dry season length was similar to long term records in north Queensland. The winter rainfall component after sowing at Moura was typical of long-term values with more than 10 mm recorded in most months.

A number of extreme rainfall events occurred over the study period. The first of these, in February 2018, delayed the sowing of the black soil site at 'Junction Creek' by a year, but the red soils site became trafficable more quickly. High daily rainfall events (>160 mm) were recorded during the wet season in north Queensland, but this is not particularly unusual. Of more significance were occasional high rainfall events during the dry season, particularly during May 2022 at the end of the project.

Overall, the period of the experiment can be considered to represent typical challenging environments for establishing pastures experienced in northern Australia with more favourable growing conditions for growth once established.

Table 11 Long-term monthly temperature and rainfall data for locations close to the plant evaluation sites. Bureau of Meteorology records www.bom.gov.au/climate/data. Sowing month in box.

Rainfall

Location recording station	**Site(s)**	**Mean and *median* monthly rainfall**												**Ann**
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Mt Surprise 1873-2022[1]	Whitewater	209 *195*	205 *195*	112 *90*	27 *13*	14 *3*	14 *2*	7 *0*	5 *0*	5 *0*	18 *6*	53 *41*	114 *93*	791 *806*
Georgetown 1872-2009[2]	Huonfels	225 *191*	213 *188*	123 *100*	29 *11*	9 *0.5*	10 *1*	7 *0*	4 *0*	6 *0*	17 *7*	50 *36*	128 *105*	820 *792*
Charters Towers 1993-2018[3]	Junction Creek DAF Spyglass	141 *112*	116 *102*	82 *64*	30 *18*	18 *7*	18 *7*	12 *3*	9 *0*	6 *0*	19 *8*	39 *24*	71 *60*	556 *509*
Moura 1941-2022[4]	Wonga	93 *73*	95 *71*	65 *49*	37 *23*	36 *26*	27 *18*	24 *11*	22 *12*	28 *14*	57 *47*	74 *61*	98 *83*	665 *635*

Temperature

Location	**Site(s)**	**Mean monthly maximum and *minimum* temperatures**												**Ann**
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Mt Surprise 1913-78[1]	Whitewater	33.1 *20.9*	32.3 *20.9*	31.7 *19.4*	30.7 *16.7*	28.5 *13.4*	26.6 *10.5*	26.5 *9.6*	28.5 *10.6*	31.2 *13.9*	34.2 *17.2*	35.1 *19.7*	34.7 *20.6*	31.0 *16.1*
Georgetown 1909-2007[2]	Huonfels	34.4 *22.9*	33.5 *22.7*	33.4 *21.5*	32.5 *19.4*	30.4 *16.1*	28.2 *13.1*	28.2 *12.0*	30.0 *13.1*	33.0 *16.2*	35.8 *19.7*	36.6 *21.7*	36.1 *22.8*	21.7 *18.4*
Charters Towers 1940-2022[5]	Junction Creek DAF Spyglass	31.5 *24.3*	31.2 *24.2*	30.8 *23.1*	29.7 *20.8*	27.7 *17.8*	25.7 *15.0*	25.2 *13.8*	26.1 *14.9*	27.8 *17.3*	29.5 *20.8*	30.8 *23.0*	31.6 *24.2*	29.0 *19.9*
Moura 1952-2022[6]	Wonga	33.9 *20.8*	33.0 *20.4*	31.8 *18.4*	28.9 *14.1*	24.7 *9.7*	21.6 *6.5*	21.2 *5.3*	23.3 *6.5*	27.0 *10.5*	30.1 *14.7*	32.1 *17.6*	33.6 *19.7*	28.5 *13.7*

[1] 30036, [2] 30018, [3] 30137, [4] ,39071 [5] 032040, [6] 35070

Table 12 Total monthly rainfall at the experiment sites compared to long-term mean values.

'Whitewater' (Mt. Surprise), sown 27 February 2019

Year	Mean and *median* monthly rainfall												Growing season total (mm)[1]
	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	
Long term mean	53	114	209	205	112	27	14	14	7	5	5	18	791
and *median*	*41*	*93*	*195*	*195*	*90*	*13*	*3*	*2*	*0*	*0*	*0*	*6*	*806*
2018-19	13	99	149	255	47	0	0	0	0	0	0	6	**569**
2019-20	5	23	163	238	91	17	45	0	0	2	0	18	**602**
2020-21	10	259	367	217	4	65	0	0	0	0	10	18	**950**
2021-22	111	196	119	123	36	45	95						**725** incomplete

'DAF Spyglass' (Charters Towers), sown 5 February 2020

Year	Mean and *median* monthly rainfall												Growing season total (mm)[1]
	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	
Long term mean	39	71	141	116	82	30	18	18	12	9	6	19	556
and *median*	*24*	*60*	*112*	*102*	*64*	*18*	*7*	*7*	*3*	*0*	*0*	*8*	*509*
2018-19	20	119	99	314	92	18	18	18	31	0	2	0	**729**
2019-20	0	5	224	201	21	0	93	9	31	0	0	38	**621**
2020-21	0	156	185	138	20	90	0	2	8	3	0	36	**637**
2021-22	123	93	196	92	0	144	210						**857** incomplete

'Junction Creek' (), red sown 14 February 2018, black sown 23 January 2019

Year	Mean and *median* monthly rainfall												Growing season total (mm)[1]
	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	
Long term mean	39	71	141	116	82	30	18	18	12	9	6	19	556
and *median*	*24*	*60*	*112*	*102*	*64*	*18*	*7*	*7*	*3*	*0*	*0*	*8*	*509*
2017-18	71	30	90	277 red	153	0	0	0	0	0	0	31	**652**
2018-19	9	112	113 black	554	103	15	0	21	26	0	0	8	**961**
2019-20	23	0	204	222	54	14	59	0	13	0	0	47	**636**
2020-21	13	232	206	199	10	105	0	10	18	4	6	5	**808**
2021-22	120	79	141	47	6	47	217						**657** incomplete

'Huonfels' (Georgetown), sown 4 March 2020

Year	**Mean and *median* monthly rainfall**												**Growing season total (mm)**[1]
	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	
Long term mean and *median*	50 *36*	128 *105*	225 *191*	213 *188*	123 *100*	29 *11*	9 *0.5*	10 *1*	7 *0*	4 *0*	6 *0*	17 *7*	820 *792*
2018-19	12	136	156	196	144	0	0	7	0	0	0	0	**651**
2019-20	3	13	265	202	97	18	30	0	0	0	0	25	**652**
2020-21	55	280	285	210	21	84	0	0	0	1	29	2	**967**
2021-22	103	162	147	109									

'Wonga' (Moura), sown 24 February 2021

Year	**Mean and *median* monthly rainfall**												**Growing season total (mm)**[1]
	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	
Long term mean and *median*	74 *61*	98 *83*	33.9 *20.8*	33.0 *20.4*	31.8 *18.4*	28.9 *14.1*	24.7 *9.7*	21.6 *6.5*	21.2 *5.3*	23.3 *6.5*	27.0 *10.5*	30.1 *14.7*	665 *635*
2019-20*	4	29	151	233	29	6	5	39	10	3	13	29	**551**
2020-21	0	65	59	13	167	16	16	25	27	0	7	62	**457**
2021-22	224	97	19	55	33	29	127						**585** incomplete

* no local measurement, BOM records 22 km away

[1] November to October

Table 13 Rainfall following establishment.

Locality	**Property**	**Sowing date**	**Rainfall (mm) after sowing**			**Need to re-sow following year?**
			1 week	**4 weeks**	**6 months**	
Charters Towers	Junction Creek (red)	14 Feb. 18	27	230	363	No
	Junction Creek (black)	23 Jan. 19	25	645	810	No
Mt. Surprise	Whitewater	27 Feb. 19	0	28	48	Some grasses
Charters Towers	DAF Spyglass	5 Feb. 20	24	201	384	No
Georgetown	Huonfels	4 Mar. 20	54	97	140	Some grasses
Moura	Wonga	24 Feb. 21	16	174	258	No

4.1.3 Rainfall for establishment

Sowing was initially planned for December to early February for the north Queensland, and February-March for the central Queensland sites as per normal practice for these regions based on anticipated rainfall after sowing given historical trends for rainfall. The small plot assessments at 'Junction Creek' were sown into shallow furrows in fully cultivated land, covered and compressed. The other sites were sown by broadcasting seeds onto seedbeds of varying levels of preparation (cultivation with discs/tines, glyphosate application) and covering with a flanged roller after sowing. Sowing was only undertaken once it was considered there was sufficient moisture in the profile to support seedling growth given a reasonable expectation of rainfall after sowing.

Sowing dates and follow-up rainfall over different periods are presented in Table 13. At least 24 mm of rainfall fell in the week after sowing at all sites except 'Whitewater', sown late in February because it was too wet previously to sow. Only 48 mm was recorded at 'Whitewater' in the six months after sowing. This was sufficient for seedling establishment of all grasses and legumes, but first season growth was seriously limited: most plants were little more than seedlings by October and many grass seedlings died. Re-sowing to supplement plant populations was required for some grasses (Jarra *Digitaria milanjiana* and ATF714 *Panicum coloratum*) which seemed to compete poorly with legumes. TGS1012 *Urochloa mosambicensis* was the most competitive grass under these dry conditions. Similar results were observed at 'Hunofels' where rainfall after sowing was also considered to be limiting. Rainfall after sowing at the other sites was considered to be excellent for plant establishment and first year growth, although establishment was delayed by a few weeks at 'Wonga' due to limited rainfall in the weeks after sowing.

4.2 Plant establishment and seedling survival

4.2.1 Establishment under optimal conditions – small plots at 'Junction Creek'

Red basalt site

The red soil site was sown on 14 February 2018 in anticipation of forecast rainfall using the methods used to successfully establish replicated small plots during B.NBP.0766. Over 60 mm rainfall fell in the week following sowing resulting in excellent establishment (Fig. 7). Plant populations were assessed on 15 March 2018: summarised and analyses of data are presented in Appendix 10.7.

Most grasses had > 30 plants/m row four weeks after sowing with *Bothriochloa, Brachiaria* and *Urochloa* having the highest populations along with *Heteropogon contortus* (black speargrass, the standard comparator). Capsize *Cencrus setiger* and *Mulato 2 Brachiria* hybrid had low populations (12-20) because of limited amounts of available seeds. Most lines had green cover values over 60% by August, the lowest being Capsize (30%). The legume plant populations exceeded those considered to be useful for persistence and biomass assessments; more than 20 per m for larger seed legumes (*Clitoria* and *Centrosema*) and 40 (up to 160) for the smaller seeded legumes (*Desmanthus*, *Macroptilium* and *Stylosanthes*). Only one legume, Davies *Centrosema brasilianum* had low seed numbers due to limited amount and poor quality of seed. Grass establishment was excellent overall, with many plots having greater than 40% cover four weeks after sowing; many were in excess of 80%. Wash, and subsequent deep burying of seeds appeared to have reduced establishment in some plots, but, overall, the lines were considered to have sufficient plant populations for assessment. The survival of plants over the growing season was initially a concern given low rainfall after establishment (251 mm February and March and no further rain until

October). The plants proved remarkably resilient, however, with high cover ratings (most 70-100%) by the end of August in most plots.

Black (clay) basalt site

Sowing of the black clay site in January 2019 was followed by exceptionally heavy rainfall (over 600 mm) in the two weeks after planting, which contributed to flooding in the district (Fig. 8). The experimental site was located on the edge of a floodway (~50 m from the tree margin) but was not flooded. There was, however, some evidence of wash within plots which resulted in poor establishment in some plots. There was also a proliferation of weeds in the grass and legume plots, not observed at the red soil site the previous year.

Plant establishment was measured on 13 March 2019 and summary statistics and analyses of data are presented in Appendix 10.8. Plant populations were satisfactory overall and there were no lines failed. The grasses established exceptionally well, with all approaching or exceeding the 40% target cover: the range was 32 to 93 % cover per metre row. Legume establishment was less successful, but satisfactory overall. The *Macroptilium* lines had the best establishment overall, with most exceeding the 40 plants/m establishment target. Establishment of the larger seeded legumes (*Centrosema* and *Clitoria*) had low plant population below the target 20 plants/m row, except for Milgarra *C. ternatea*. Establishment of the small-seeded legumes, *Desmanthus* and *Stylosanthes,* was highly variable between lines with mean populations ranging from 9 to 89 plants/m row, but mostly in the range of 15 to 60 plants/m row.

Fig. 7 First year growth of grasses and legumes sown at 'Junction Creek' (red soil) on 14 February 2018.

Grass plots on 15th March 2018

Legume plots on 15th March 2018

Grass plots in late August 2018. Most had hayed off and become dormant.

Legume plots in late August 2018. Growth had slowed but most legumes retained green leaf.

The grasses following wet season rainfall, March 2019. Many had begun to flower.

The legumes maintained vegetative growth for longer than most grasses (March 2019).

Fig. 8 First year growth of grasses and legumes sown at 'Junction Creek' (black soil) on 23 January 2019.

The legume plots mid-March 2019. Establishment followed a high rainfall (flooding) event.

Most grasses established well, but there was a higher proportion of weeds than at the red soil site.

Legume growth was extremely vigorous.

Table 14 Seedling plant population (plants/m^2) and first year green cover (0 = none, 10 = 100% cover) of grasses and legumes sown at 'Junction Creek' (red soil) on 14 February 2018.

Grasses

Species	Line	Population (15/3/18)		Cover (0-10)				
		Mean	Rank	6/9/18	13/3/19	7/8/19	Mean	Rank
Botbla	Swann	30.3	21	5.00	4.77	4.00	4.28	20
Botins	Bisset	73.8	7	9.33	9.83	10.00	9.79	1
Botins	CPI12562B	89.5	2	9.00	9.17	9.33	9.29	6
Botper	Keppel	74.7	6	7.00	7.67	8.00	7.75	11
Botper	Medway	59.7	14	6.67	8.33	7.00	7.58	12
Brabri	Mekong	85.8	4	10.00	9.33	9.00	9.42	5
Bradec	Basilisk	93.2	1	10.00	9.50	10.00	9.79	1
Brahyb	Mulato 2	22.5	22	7.33	7.83	8.00	7.88	9
Censet	Capsize	12.8	23	2.10	2.10	3.10	2.47	23
Chlgay	Katambora	61.0	13	6.00	6.33	6.00	6.42	14
Chlgay	Reclaimer	44.3	19	3.67	3.50	4.33	3.79	21
Chlgay	Sabre	55.0	15	6.00	6.33	7.00	6.42	14
Chlgay	Tolgar	39.8	20	4.00	4.67	5.33	5.00	18
Chlgay	Toro	48.3	17	5.33	6.67	7.67	7.00	13
Dicari	Floren	87.2	3	8.67	7.00	7.67	7.83	10
Hetcon	SO6	80.3	5	9.33	9.50	10.00	9.71	3
Pancol	ATF714	65.5	12	8.67	7.67	8.33	8.33	8
Panmax	G2	47.3	18	4.00	3.50	4.00	3.79	21
Panmax	Gatton	49.3	16	4.50	5.00	4.67	4.88	19
Panmaxi	NuCal (C1)	66.2	11	6.67	5.67	6.00	6.00	17
Uromos	Nixon (Sabi)	71.0	9	8.67	9.67	9.67	9.50	4
Uromos	Saraji	70.2	10	7.33	5.33	6.00	6.17	16
Uromos	TGS1012	72.7	8	8.33	8.17	9.00	8.54	7
	p-value			0.161			<0.001	
	Av. SED			1.644			1.677	
	Av. 95% LSD			-			-	
			Mean	6.85	6.85	7.27	7.13	
			p-value	0.010				
			Av. SED	0.152				
			Av. 95% LSD	-				

Legumes

Species	Line	Population (15/3/18)		Cover (0-10)				
		Mean	Rank	6/9/18	13/3/19	7/8/19	Mean	Rank
Cenbra	Davies	2.8	29	4.67	7.67	8.67	7.58	14
Cenbra	Gilbert River	34.0	25	8.00	7.33	9.00	8.25	11
Cenmol	Cardillo	49.8	18	8.33	2.33	3.67	4.50	26
Cliter	Milgarra	28.2	27	7.67	6.67	7.33	7.08	15
Desbi	F.view Basalt2	51.3	14	6.51	3.01	4.51	4.88	23
Deslep	JCU7	38.8	24	5.00	3.67	4.00	4.08	28
Dessp	F.view Basalt1	44.5	21	6.51	3.51	3.51	4.13	27
Dessp	Hillgrove 170	33.5	26	8.01	6.51	5.51	6.51	18
Dessp	Hillgrove 2007	41.0	23	6.51	5.01	4.01	4.76	24
Dessp	Hillgrove 79	55.0	13	6.01	5.51	6.51	6.13	20
Dessp	JCU6	51.3	14	8.01	7.01	7.01	6.88	16
Dessp	JCU8	26.5	28	5.67	4.67	4.67	4.92	22
Dessp	JCU9	82.5	8	7.51	3.01	2.01	4.63	25
Dessp	Powerline	41.8	22	7.67	7.33	6.67	6.83	17
Desvir	Progardes	46.3	20	8.00	5.67	5.00	5.83	21
Macatr	Aztec	75.8	9	9.00	10.00	9.67	9.67	1
Macatr	CPI84989	65.3	12	8.00	10.00	10.00	9.50	3
Macbra	Juanita	90.8	7	9.67	9.33	9.33	9.42	7
Macgra	TGS849	161.7	1	8.33	6.00	8.00	7.75	13
Styguig	Nina 3308	96.7	4	9.33	8.67	10.00	9.50	3
Styguii	Oxley	49.0	19	7.33	0.83	3.00	4.00	29
Styham	Amiga	67.5	11	10.00	8.67	9.33	9.17	9
Styham	Verano	50.3	17	9.00	8.00	8.33	8.42	10
Stysca	Seca	91.7	5	8.67	8.67	10.00	9.33	8
Stysca	Siran	143.3	3	8.67	9.33	10.00	9.50	3
Stysea	Primar	91.7	5	9.00	9.67	9.33	9.50	3
Stysea	Unica	145.0	2	9.00	9.67	10.00	9.67	1
Stysp	Breen	51.2	16	6.33	7.67	9.33	8.25	11
Styvis	JCU	75.8	9	8.33	3.33	8.00	6.25	19
	p-value	<0.001		<0.001			<0.001	
	Av. SED	16.15		1.201			0.830	
	Av. 95% LSD	32.42		2.388			1.670	
			Mean	7.75	6.51	7.17	7.12	
			p-value	<0.001				
			Av. SED	0.183				
			Av. 95% LSD	0.366				

Table 15 Seedling plant population (plants/m^{2}) and first year green cover (0 = none, 10 = 100% cover) of grasses and legumes sown at 'Junction Creek' (black soil) on 23 January 2019.

Grasses

Species	**Line**	**Population (13/3/19)**		**Cover (0-10)**				
		Mean	Rank	6/6/19	7/8/19	13/11/19	Mean	Rank
Botins	Bisset	73.3	4	9.3	9.6	9.0	9.3	4
Botper	Keppel	71.7	5	10.0	10.0	9.3	9.7	1
Botper	Medway	51.7	8	8.3	8.6	7.3	8.1	8
Cencil	Gayndah	68.3	6	9.6	9.6	9.6	9.6	2
Chlgay	Katambora	77.5	3	9.3	8.3	9.0	8.8	5
Chlgay	Sabre	30.0	16	6.3	9.0	7.3	7.5	10
Dicari	Floren	93.3	1	10.0	9.6	9.0	9.5	3
Digeri	Premier	51.7	8	4.6	7.6	6.0	6.1	13
Digmil	Jarra	65.0	7	8.6	9.0	7.6	8.4	7
Digmil	Strickland	44.2	12	6.6	8.6	8.3	7.8	9
Dicser	Scatta	39.2	13	6.6	8.0	6.6	7.1	12
Pancol	ATF714	48.3	11	6.6	8.0	7.0	7.2	11
Pancol	Bambatsi	81.7	2	8.0	9.3	8.6	8.6	6
Panmax	Gatton	32.5	15	4.3	6.0	4.3	4.8	16
Panmaxi	NuCal (C1)	50.0	10	5.3	7.0	4.6	5.6	15
Uromos	Saraji	37.5	14	5.0	6.3	5.6	5.6	14
	p-value	0.042		0.967			<0.001	
	Av. SED	18.67		1.220			0.705	
	Av. 95% LSD	38.03		-			-	
			Mean	7.44	8.44	7.48		
			p-value	0.002				
			Av. SED	0.305				
			Av. 95% LSD	-				

Legumes

Species	Line	Population (13/3/19)			Cover (0-10)				
		Mean	Rank	BTM[1]	6/6/19	7/8/19	13/11/19	Mean	Rank
Cenbra	Gilbert River	2.104	27	4.43	3.17	3.33	1.00	2.50	28
Cenmol	Cardillo	1.606	30	2.58	1.67	1.33	1.33	1.44	29
Cliter	Double	1.993	29	3.97	2.79	3.04	7.54	4.45	24
Cliter	Milgarra	5.488	13	30.11	9.33	9.00	9.33	9.22	3
Desbi	F.view basalt2	3.368	24	11.35	3.54	3.54	4.54	3.87	26
Deslep	JCU7	4.474	16	20.01	6.67	6.33	8.00	7.00	16
Deslep	TQ90	8.085	5	65.36	9.33	9.33	9.67	9.44	1
Dessp	F.view basalt1	3.597	23	12.94	4.54	5.04	4.04	4.54	23
Dessp	Hillgrove 170	3.136	25	9.83	5.79	4.54	7.54	5.95	21
Dessp	Hillgrove 2007	4.988	14	24.88	9.04	7.54	9.04	8.54	6
Dessp	Hillgrove 79	5.617	12	31.55	8.54	6.04	8.54	7.70	13
Dessp	JCU6	2.012	28	4.05	6.04	4.04	6.04	5.37	22
Dessp	JCU8	3.732	22	13.93	6.33	6.00	9.33	7.22	14
Dessp	JCU9	7.239	7	52.4	7.04	6.04	7.54	6.87	18
Dessp	Powerline	4.465	17	19.93	7.67	7.33	8.33	7.78	11
Desvir	ES203	9.305	2	86.58	8.33	8.00	8.67	8.33	7
Desvir	Marc	2.809	26	7.89	6.33	5.67	9.33	7.11	15
Desvir	Progardes (	6.382	9	40.73	8.00	7.33	8.33	7.89	10
Desvir	Q9153	6.169	10	38.06	7.33	7.33	8.67	7.78	11
Macatr	Aztec	7.742	6	59.95	10.00	8.33	5.67	8.00	8
Macatr	CPI84989	6.667	8	44.45	10.00	8.67	9.00	9.22	3
Macbra	Cardarga	9.322	1	86.9	9.33	8.67	3.00	7.00	16
Macbra	Juanita	4.034	19	16.27	8.33	7.67	2.00	6.00	19
Macgra	TGS849	8.415	4	70.82	9.00	9.00	9.33	9.11	5
Styguig	Nina 3308	3.973	20	15.78	3.00	2.67	2.00	2.56	27
Styguii	Oxley	3.735	21	13.95	0.83	1.67	0.00	0.83	30
Styham	Amiga	4.067	18	16.54	8.00	4.00	1.33	4.44	25
Stysca	Seca	4.654	15	21.66	6.67	7.00	4.33	6.00	19
Stysea	Primar	5.872	11	34.48	8.67	8.00	7.33	8.00	8
Stysea	Unica	9.186	3	84.39	9.83	9.33	8.67	9.28	2
	p-value	<0.001			<0.001			<0.001	
	Av. SED	1.050			1.227			0.709	
	Av. 95% LSD	2.110			2.424			1.401	
				Mean	6.84	6.19	6.32		
				p-value	0.004				
				Av. SED	0.225				
				Av. 95% LSD	0.443				

[1] BTM = back transformed mean

4.2.2 Establishment of grass x legume mixes under favourable rainfall

Favourable rainfall for pasture establishment was experience at 'DAF Spyglass' (red earth, Charters Towers) in 2020 and at 'Wonga' (brown clay, Moura) in 2021 (Table 13). Grass and legume seeds were broadcast over fully prepared (discs and glyphosate) seed beds and rolled after sowing.

DAF 'Spyglass'

Plant establishment occurred over two rainfall events after sowing: immediately after sowing following showers in the week after sowing (very moist seed bed), and three weeks after sowing following high rainfall between 24th and 28th February. There was sufficient moisture for plant growth and plants showed no obvious signs of water stress. There was, however, evidence of wash downslope (perpendicular to the direction of the grass strips) due to heavy rainfall (Fig. 9).

Plant populations were measured on 17 March 2020, six weeks after sowing (and fall of first rainfall) when it was considered seeds had sufficient opportunity to establish following the two establishment events (Fig. 9). Most plants were at the two to four true-leaf or later growth stages, although some *Stylosanthes* plants had only recently emerged (first or second true leaf). Three 0.5 x 0.5 m quadrats were placed 5, 10 and 15 m along the centre of each of the 189 plots and the numbers of sown grasses and legumes were counted. Other plants present in each quadrat plot were recorded.

Plant establishment was considered successful for all grasses and legumes (Table 15). Mean plant populations were between 9 and 29 seedlings/m^2 for all legumes with the larger-seeded lines (TGS84989 *Macroptilium atropurpureum* and Milgarra *Clitoria ternatea*) having lower populations reflecting the lower numbers of seeds sown per unit area. The remaining small-seeded lines (*Stylosanthes* spp., *Desmanthus* spp. and *Macroptilium gracile*) were more variable with Amiga *Stylosasnthes hamata* and Unica *S. seabrana* having the highest plant populations. Mean grass populations were less variable and ranged from ~11 to 17 seedlings/m^2. There was a high level of variability (quite normal) for the legume and grass populations with maximum values ranging from 40 to 132 seedlings/m^2 for the legumes and 68 to 132 seedlings/m^2 for the grasses. All had quadrat samples with no plants present.

Preliminary comparisons of legume frequency within different grass plots revealed no significant trends at establishment (Appendix 10.9). This was presumably because the plants were too small and had inadequate plant populations to exert significant competition for growing resources (water, other soil nutrients and light) on neighbouring plants. There was a number of common 'weeds' measured in the plots. These included sabi grass (*Urochloa mosambicensis*) (74% of plots, at least one plant recorded in one of five quadrats) other grasses (29), sida (*Sida* spp.)(61), Wynn cassia (*Chamaecrista rotundifolia*) (55), pigweed (*Portulaca oleracea*) (16). The high proportion of *Urochloa mosambicensis* detected was presumably due to some plants surviving earlier spraying (evident in strips).

There was evidence of differences in grass and legume cover by the end of the first dry season although cover values were low (Table 16). TGS1012 *Urochloa mosambicensis* and Mekong *Brachiaria brizantha* were the most dominant grasses and Amiga *Stylosanthes hamata* and Unica *S. seabrana* the most dominant legumes. Analysis of variance showed limited interactions between the various grasses and legumes although overall legume cover of the small-seeded legumes (*Desmanthus* and *Stylosanthes*) when grown with TGS1012 (Appendix 10.9.2).

Fig. 9 The grass-legume combination experiment at DAF 'Spyglass'.


The site with some down-slope wash (March)

Typical population samples (TGS1012) sabi

TGS125652B creeping bluegrass with stylo

Grasses and legumes established by May.

Excellent growth until September (slashed).

Table 16 Plant populations of sown grasses and legumes pooled across legume treatments seven weeks after sowing on 5 February 2020 and green cover measured the following August at DAF 'Spyglass'.

Grass species	Cultivar/line	Plant population (plants/m²)			Green cover (0-10)	
		Mean	Std err	Max.[1]	Mean	
Bothriochloa insculpta	TGS125652B	15.9	2.06	108	2.1	ab
Brachiaria brizantha	Mekong	16.7	1.83	68	4.4	c
Digitaria milanjiana	Jarra	13.1	2.11	132	2.1	ab
Panicum coloratum	ATF714	13.0	2.34	132	0.89	a
Panicum maximum	Gatton	17.4	1.88	76	1.88	ab
Panicum hybrid	Massai	16.8	2.09	92	2.4	b
Urochloa mosambicensis	TGS1012	10.8	1.71	88	7.4	d
	LSD (0.95)	NS			1.34	

[1] Minimum values were all zero

Legume species	Cultivar/line	Plant population (plants/m²)			Green cover (0-10)	
		Mean	Std err	Max.[1]	Mean	
Clitoria ternatea	Milgarra	9.0	1.14	40	0.45	a
Desmanthus leptophyllus	TQ90	14.0	2.38	88	0.35	a
Desmanthus virgatus	Marc	6.3	0.94	36	0.32	a
Desmanthus virgatus + D. bicornutus	Progardes	9.0	1.47	68	0.31	a
Macroptilium atropurpureum	TGS 84989	12.9	1.58	52	0.40	a
Macroptilium gracile	TGS 849	17.9	1.91	64	0.16	a
Stylosanthes hamata	Amiga	29.2	3.64	132	1.90	c
Stylosanthes scabra	Seca	10.4	1.89	92	0.89	b
Stylosanthes seabrana	Unica	24.6	2.68	108	1.61	c
	LSD (0.95)	NS			1.34	

[1] Minimum values were all zero

Wonga

The site was sown on 24 February 2021 using different mixtures of legumes (within a taxa group) into a range of grasses. High rainfall during March resulted in successful plant (seedling) establishment in a well-prepared seed bed (Fig. 10), but low rainfall over the following months inhibited plant growth (although most plants survived). There were differences in grass establishment. Mean grass populations ranged from 5 to 68 plants/m² and were highest in TGS1012 *Urochloa mosambicensis* and Basilisk *Brachiaria decumbens* (Table 17). Poorest establishment was recorded in the *Panicum maximum*, *Panicum* hybrid and Keppel *Bothriochloa pertusa* lines (<10 plants/m²). The standard comparator, Gayndah buffel, had an intermediate population.

The legume populations varied between taxa group (Table 17, Fig. 11). All legumes established satisfactorily, and populations ranged from 10 to 75 plants/m². The stylos had the highest initial plant populations: 40 to 70 plants/m² for most grasses, but were lower in the TGS1012 (15) and Basilisk plots (25) indicating some level of competition. The other legumes all had populations less than 20 plants/m² and also tended to be lowest in the TGS1012 plots. Weed cover, as indicated by weed score (10 = 100% cover), was very low and not considered to influence plant populations.

There were indications of competition between grasses and legumes but the effects were relatively minor during establishment. For example, grass populations (when pooled across grass treatments) were slightly higher when there was no companion legume (~33 plants/m^2), compared to when sown with a legume (24-27 plants/m^2)(Table 17). Stylo populations also tended to be highest when growing with grasses of lower plant populations, particularly the three *Panicum* spp. (Fig. R5, Appendix 10.10)

Fig. 10 The research site at 'Wonga' (brown duplex, Moura).

A fully cultivated seed bed, hot and dry.

Sowing before rolling.

April 2021 drone image of differential establishment. Each rectangular plot is 180 m^2.

Table 17 Plant populations of grasses and legumes (main plots, pooled) sown in combination with various legumes at 'Wonga'(brown clay loam, Moura) seven weeks after sowing on 24 February 2021.

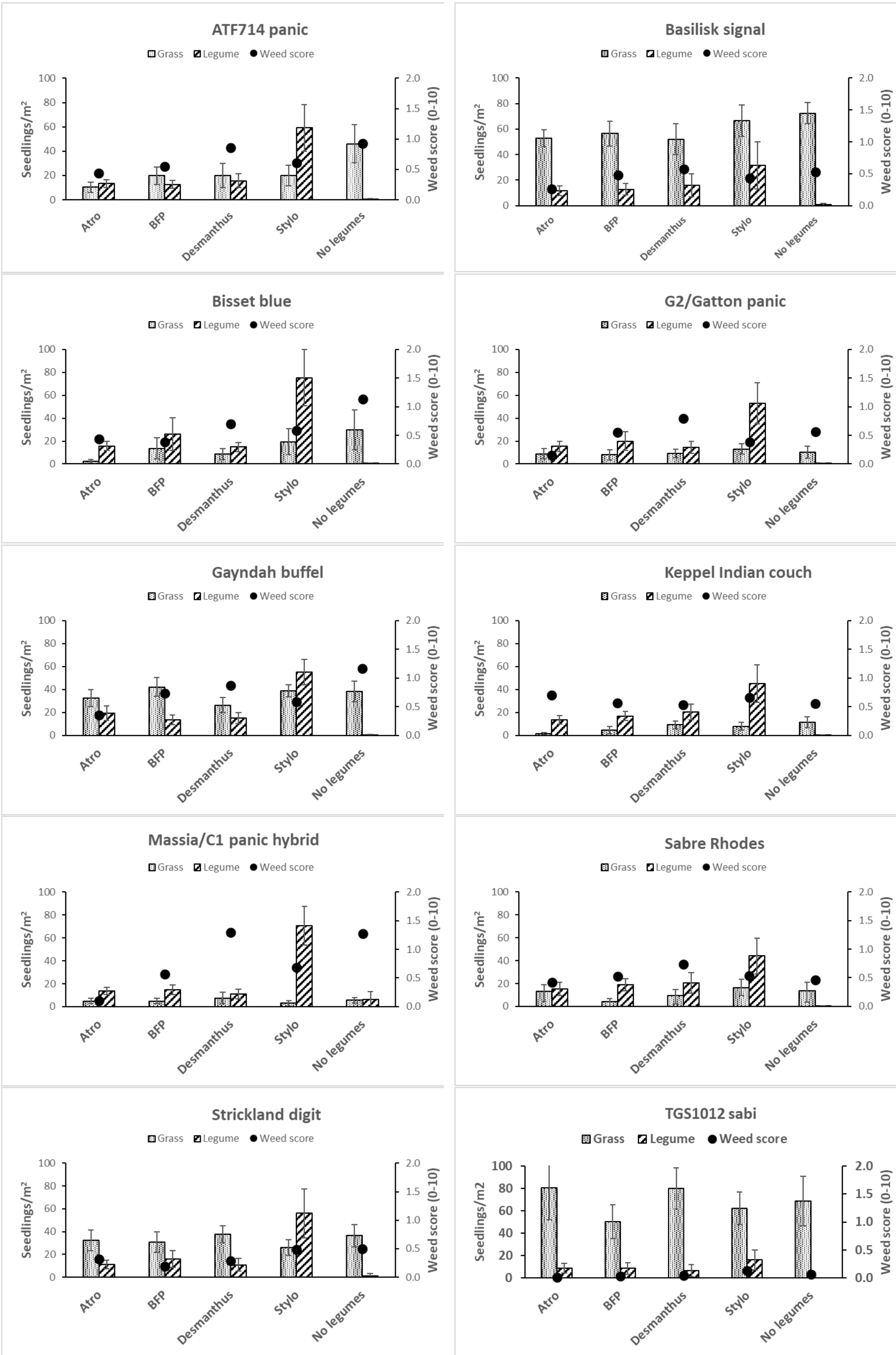
Grass species	**Cultivar/line**	**Grass population (plants/m^2)**			**Pooled legume population (plants/m^2)**	
		Mean	Std err	Max.[1]	Mean	Std. err
Bothriochloa insculpta	TGS125652B	14.7	2.81	160	26.5	4.24
Bothriochloa pertusa	Keppel	6.9	0.92	32	19.3	2.61
Brachiaria decumbens	Basilisk	60.1	2.68	120	14.4	2.63
Cenchrus ciliaris	Gayndah	35.6	1.97	84	20.7	2.52
Chloris gayana	Sabre	11.4	1.55	60	19.9	2.67
Digitaria milanjiana	Strickland	32.6	2.19	100	19.0	3.35
Panicum coloratum	ATF714	23.1	2.81	140	20.2	3.14
Panicum hybrid	Massai	5.2	0.78	32	22.9	3.37
Panicum maximum	Gatton	9.9	1.17	52	20.6	2.99
Urochloa mosambicensis	TGS1012	68.4	5.30	240	8.0	1.46

[1] Minimum values were all zero

Legume species	**Cultivar/line**	**Legume population (plants/m^2)**			**Pooled grass population (plants/m^2)**	
		Mean	Std err	Max.[1]	Mean	Std. err
Clitoria ternatea	Milgarra	16.0	1.27	160	23.8	2.05
Desmanthus spp.	Mixture	14.6	1.14	76	26.0	2.32
Macroptilium atropurpreum	Mixture	13.8	0.80	52	23.9	2.61
Stylosanthes spp.	Mixture	50.6	3.36	240	27.3	2.17
No sown legume	-	1.1	0.46	76	32.8	2.68

[1] Minimum values were all zero

Fig. 11 Plant populations seven weeks after sowing at 'Wonga'(Moura) on 24 February 2021.



4.2.3 Establishment of grass x legume mixes under limited rainfall

Rainfall sufficient for establishment, but highly limiting for dry-season growth, was experienced at 'Whitewater' (red basalt, Mt. Surprise) in 2019 and at 'Huonfels' (duplex, Georgetown) in 2020 (Table 13). These sites were prepared and sown similarly to those at 'DAF Spyglass' and 'Wonga', although cultivation and weed control was completed over a short period between wet season rainfall required for preparation and anticipated rainfall for establishment (monsoon trough).

'Whitewater'

'Whitewater' was prepared during 2018 and sown on 27 February 2019. Sowing of the experiment was delayed following excessively wet conditions during early February which delayed secondary cultivation used to erode soil seed banks and incorporate fertiliser sulphur. Low rainfall (28 mm) in the four weeks after sowing resulted in delayed germination. However, most grasses and legumes had germinated by late March, with the larger-seeded legumes (*Macroptilium, Clitoria*) more advanced than smaller-seeded types (*Desmanthus* and *Stylosanthes*) (Fig. 12). There were a number of common 'weeds' measured in the plots, notably the broadleaved sida (*Sid asp*.), indigo (Indigofera *spp.*) and pigweed (*Portulaca oleracea*) and the grasses Indian couch (*Bothriochloa pertusa*) wiregrass (*Eragrostis* sp.) and crowsfoot (*Eleusine indica*). In general, there were up to 5-30 'weed' plants in each 0.5 m^2 quadrat.

Plant growth was restricted substantially by low rainfall after sowing: only 48 mm was recorded after sowing and a further 6 mm in October. Plant growth and survival was surprisingly high, particularly for the legumes (many were actively growing in May) (Fig. 12). Legumes with particularly vigorous growth included the two *Macroptilium* spp. (although *M. gracile* hayed off after early dominant growth) and the *Stylosanthes* and *Desmanthus* spp. *Clitoria ternatea* plants were more variable. Most legumes produced seed before growth rates slowed after June. Most survived until the end of the year; the exception was *M. gracile* plants which had mostly hayed off early in the dry season. The grasses grew less vigorously, and many plants had poor attachment to soil through a limited number of roots (did not grow much beyond a seedling). The exceptions were Mekong *Brachiaria brizantha*, TGS1215652B *Bothriochloa insculpta* and TGS1012 *Urochloa mosambicensis* which included moderate proportions of well-developed plants along with seedlings: TGS1215652B seeded well.

Detailed studies of changes in grass and legume plant populations were conducted using permanently marked sampling points in each plot. Summary statistics and analyses of variance can be found in Appendix 10.11. Within this analysis, each of the three assessment times were initially analysed separately using standard analysis of variance and the interaction terms assessed for significance. The means were then plotted as a proportion of the total populations against the total population of the unique grass-legume combination. The effect of companion grass on the mean population or cover of each legume and vice versa were also represented graphically and are presented in Figs. 13-16 below.

Initial establishment measured on 23 April was relatively high. Mean plant populations were between 10 and 20 plants/m^2 for all legumes (*Desmanthus, Stylosanthes* and *Macroptilium gracile*) except the larger-seeded lines (TGS84989 *Macroptilium atropurpureum* and Milgarra *Clitoria ternatea*). Mean grass populations were slightly higher for some grasses (up to 59 plants/m^2), but the grass seedlings were showing greater signs of water stress than the legumes. One grass, Mulato 2 *Brachiaria* hybrid, had low plant populations (<1 plant per m^2). A wide range of weeds were reported, with up to 5-30 'weed' plants in each 0.5 m^2 quadrat.

Both grass and legume populations declined significantly over the season (i.e. there was a significant interaction for sampling time), but legume populations were generally between 10 and 75 plants/m^2 by October (Fig. 13). The lowest final populations were for TGS849 *M. gracile*, which initially had high populations but hayed off early in the season, and the larger seeded legumes Milgarra *C. ternatea* and TGS84989 *M. atropurpureum* which initially had low populations. The stylos and Desmanthus all had higher populations by the end of the season, but many plants were small. A similar trend was observed for legume cover (Fig. 15), with legumes declining from high cover ratings in May (40-70% cover) to low values by October (5-25%). Overall, legume populations were considered satisfactory for on-going studies (provided these plants survive until the 2019-20 wet season).

Mean grass populations were initially more variable between species than for the legumes with (10 to over 130 plants/m^2 other than for Mulato 2)(Fig. 14). Populations declined over the season to less than 25 plants/m^2 by October. The exception was TGS1012 *U. mosambicensis* with 25-30 plants/m^2. Poor survival meant some grasses were re-sown in the second year. Green cover also tended to be low and declined over the season as plants did not grow and hayed off (Fig. 16). Note: y-axis values represent predicted means from repeated measures analysis (Appendix 10.11.2).

Despite the small size of the plants in the establishment year there appeared to be some competition effects between the grasses and legumes, perhaps due to competition for soil moisture. Lower legume populations and cover values were associated with TGS1012, and to a lesser effect by TGS1215652B (Figs. 13-16). Any competition effects of legumes on grasses were less obvious with no clear ranking of mean grass population with the type of companion legume at this early stage of the experiment.

Fig. 12 Establishment and first season growth at 'Whitewater'.

Six weeks after sowing.

Vigorous grass and legume establishment

By May the grasses had begun to hay off and but legumes maintained growth

Fig. 13 The effect of grass competition on legume plant populations (plants/m²), 'Whitewater'.

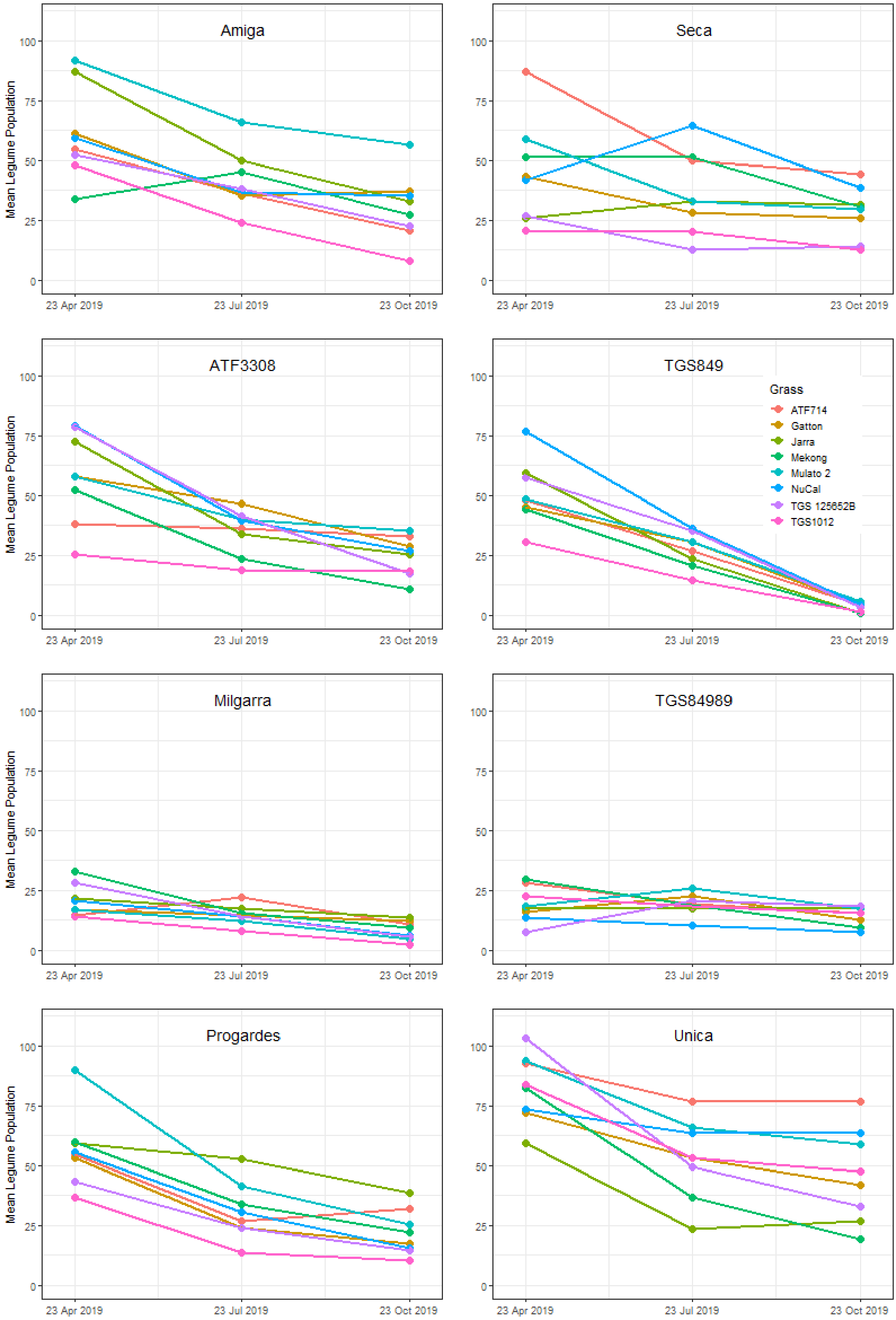


Fig. 14 The effect of legume competition on grass plant populations (plants/m²), 'Whitewater'.

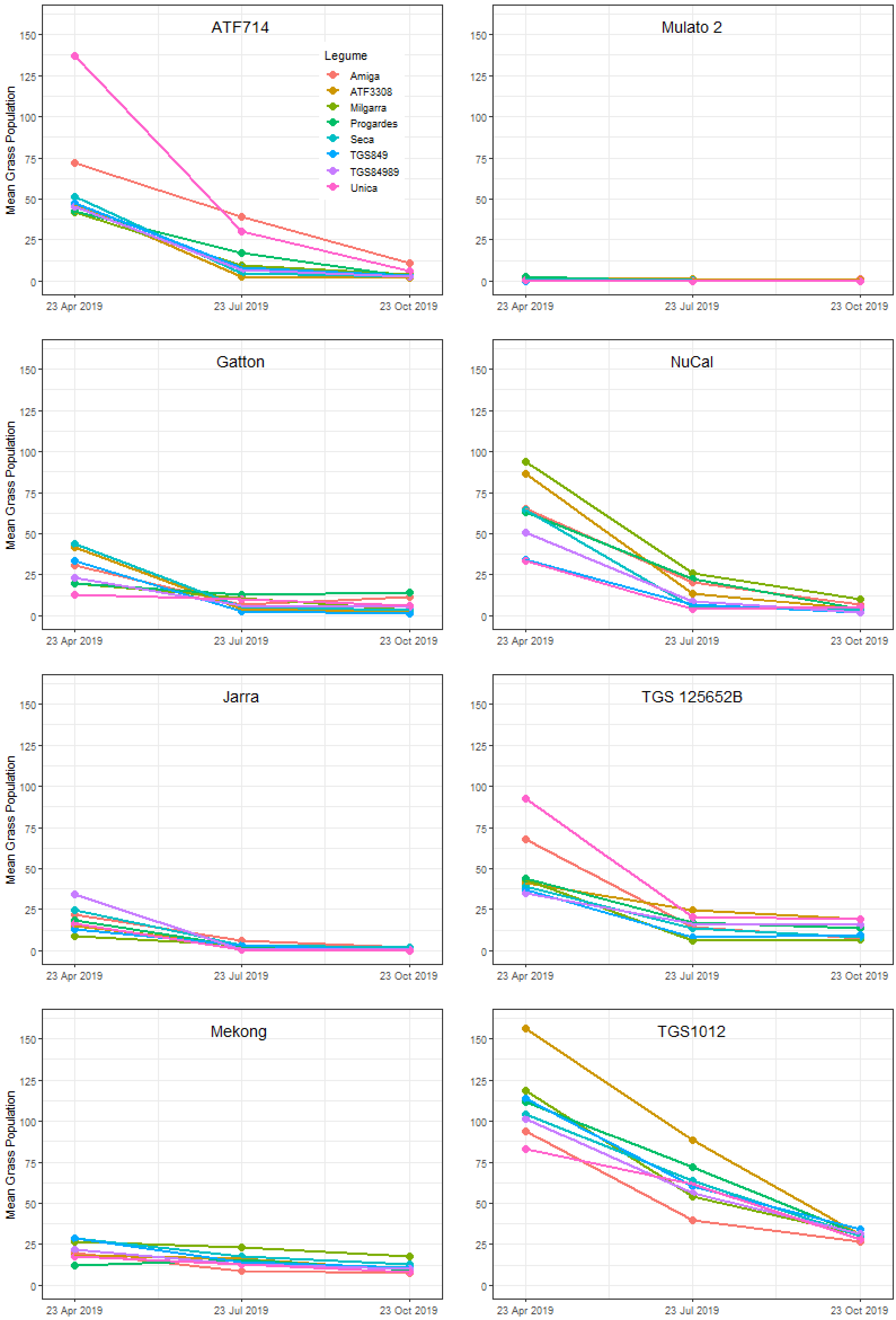


Fig. 15 The effect of grass competition on legume plant cover (0-10), 'Whitewater'.

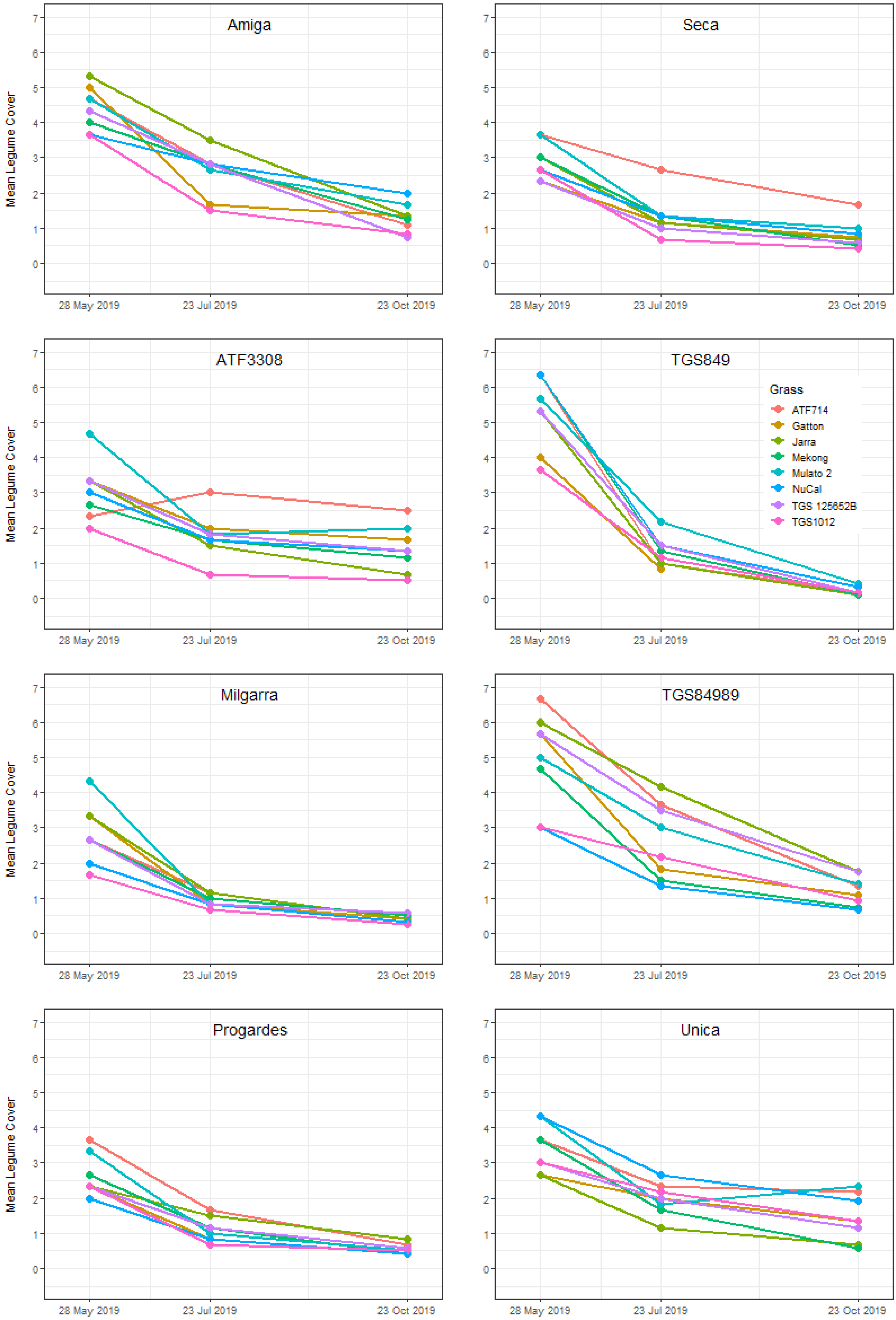
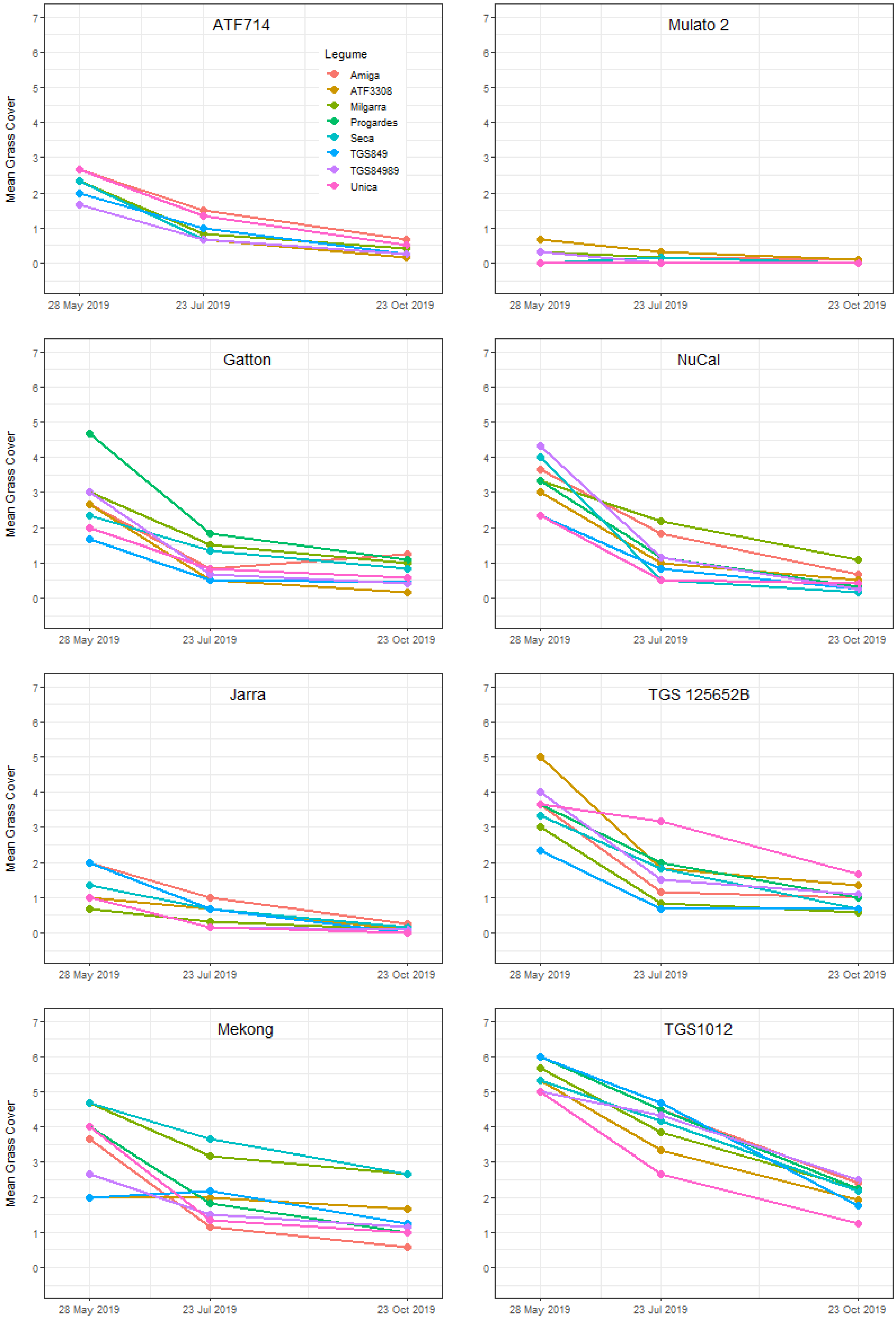


Fig. 16 The effect of legume competition on grass plant cover (0-10), 'Whitewater'.



Huonfels

The experiment at 'Huonfels' near Georgetown, sown on 4 March 2020, comprises replicated strips of grasses (*Bothriochloa, Brachiaria*, *Digitaria, Panicum* and *Urochloa*) sown to a mixture of legumes (*Clitoria, Desmanthus, Macroptilium and Stylosanthes*). It was sown late in the season because of a late start to the wet season and the need to reduce soil seed levels (principally buffalo clover (*Alysicarpus vaginalis*)) by spraying emerging plants (highly successful) (Fig. R17). Excellent rainfall in the two weeks after sowing encouraged rapid germination and small falls (18 mm) in the first two weeks of April maintained seedling growth (totalling 59 mm). There was little rainfall for the remainder of the dry season which limited seedling growth, particularly the grasses. Large populations of grasshoppers during establishment likely reduced seedling numbers, also mostly affecting grasses.

Grass and legume plant populations three weeks after sowing are presented in Fig. R18. Initial grass populations were highest in TGS1012 (102 plants/m^2), followed by Jarra, Massai and Mekong. TGS125652B *Bothriochloa insculpta* (6.4 plants/m^2) had the lowest population. Large-seeded legumes (Milgarra *Clitoria,* TGS84989 *M. atropurpureum*) had lower plant populations (3-5 plants/m^2), whereas the smaller seeded legumes, *Desmanthus* and *Stylosanthes* ranged from 10.7 to 15.3. TGS849 *Macroptilium gracile* (up to 25.9) had particularly large populations. Simple analysis of variance showed no statistical effect of grass type on the mean population of any legume at establishment (as would be expected at this early stage) (Appendix 10.11.1). The establishment methods used resulted in relatively few 'weeds' present. The common weeds included sida (53% of samples), buffalo clover (17%) and American jointvetch (*Aeschynomene americana*) (8%). There were few weed grasses.

Growth during the dry season was best maintained by TGS84989 atro (still growing in November) followed by the stylos and desmanthus. The grasses all showed advanced haying-off by August. All legumes flowered over the year, but suppressed grass (dry conditions) growth resulted in only TGS1012 (sporadically) flowering by the end of the dry season.

Grass and legume cover was measured in June and late August (Appendix 10.12). Cover values were very low (a mean of <10% of cover in each area sampled). The only exceptions were TGS1012 (28% in June and 40% in August) followed by Mekong (10% and 17%). Analysis of variance was completed for the August (end of season) assessment and statistical significance was only detected for TGS1012 cover compared to the other grasses (Appendix 10.12.2). Stylo cover increased most of all of the legumes in the first wet season after sowing, with green covers of 30-50% of ground cover recorded; values were lowest when grown with TGS125652B *Bothriochloa insculpta* and TGS1012 *Urochloa* mosambicensi, grasses which proved very competitive at the other sites.

Fig. 17 Establishment of the grass-legume combination experiment at 'Huonfels' three weeks after sowing on 4 March 2020 and at the end of the dry season.

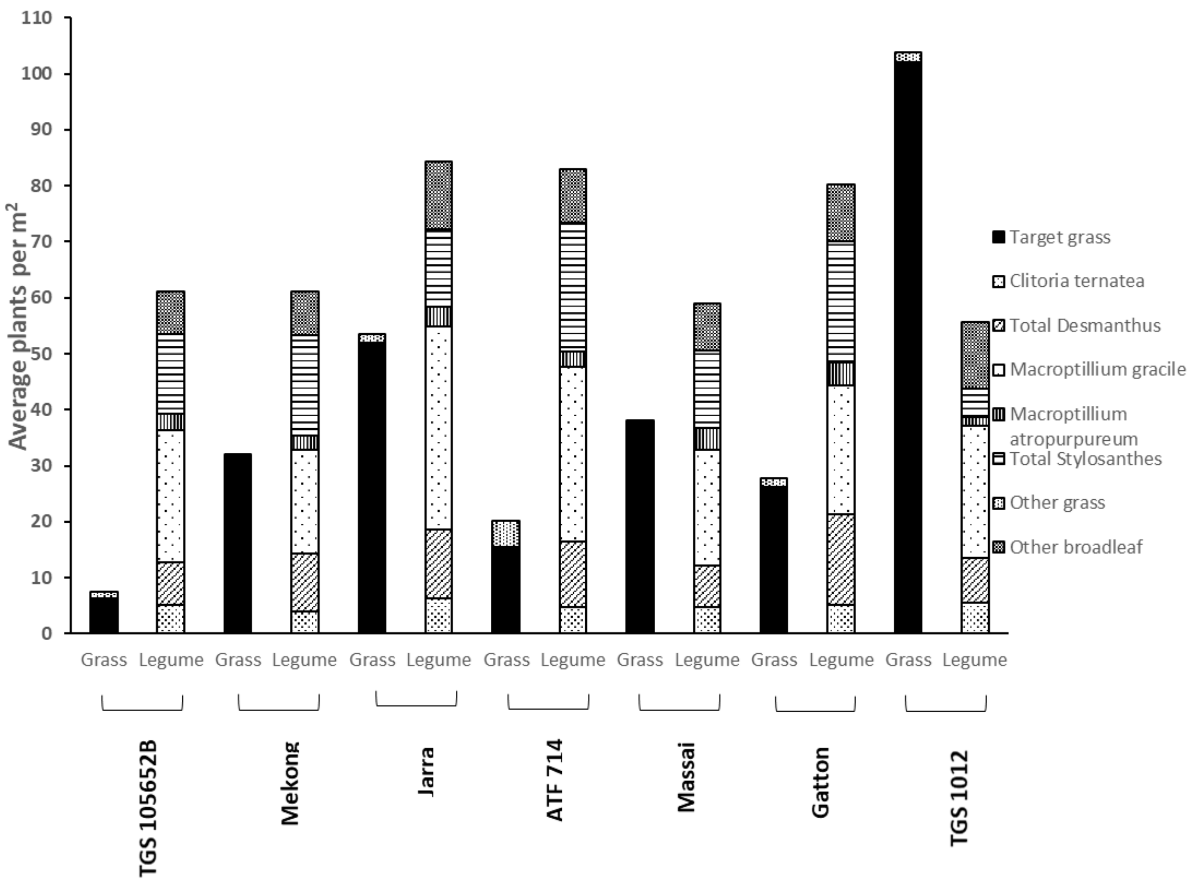
Two replicates of grass strips and legume mixes

Good initial grass and legume establishment

The plots in August

The plots in November (inset TGS1012 and TGS84989).

Fig. R18 Mean number of grass and legume seedlings at 'Huonfels' three weeks after sowing.



4.3 Plant growth: small-plot adaptation studies on red basalt near Charters Towers

The red basalt site was sown on 14 February 2018 with excellent establishment following 60 mm of rainfall in the week following sowing. This was followed by an extended dry season, but subsequent years had considerably higher annual rainfall than for long-term values (Table 12). Plant growth was vigorous during the summer growing period in all years. All grasses and legumes flowered and set seeds over the season, but most had hayed-off by October or November (Fig. 19). Legumes with prolonged stay-green (lower mean hay ratings) included *Centrosema*, *Macroptilium* (but not *M. gracile* which hayed off early) and *Stylosanthes* spp.; *Desmanthus* were more variable, some shedding leaves during the mid-dry season, but responded well to dry-season or early storm rainfall. The grasses tended to have higher hay ratings than the legumes (i.e. hayed off earlier in the dry season). Grasses with the best stay-green on the red basalt soil included some of the *Chloris gayana* and *Brachiaria* spp.

4.3.1 Plant persistence and cover

Splines (fitted curves) of mean cover are presented with mean values for plant population (establishment) for the legumes and grasses in Figs. 20 and 21. These represent changes in live (green) cover over the study period. The full analysis, using Restricted Maximum Likelihood (REML), can be found in Appendix 10.7. Seca stylo was the 'industry standard' for legumes and S06 black speargrass for the grasses.

Most legumes produced high levels of cover in the season after sowing (starting points of the graphs) but many declined thereafter during the second and third dry seasons. Most lines of *Desmanthus* (panels 2 and 3) and the one *Clitoria* (Milgarra) line declined markedly over the four years indicating poor adaptation overall to the red basalt soil: some plants did persist, however, and continued to produce useful leaf during the dry season. All *Centrosema* declined by the final year, despite early promising results for Davies and Gilbert River centro. The *Stylosanthes* spp., including the comparator Seca, maintained high levels of cover overall and *S. seabrana* (Primar and Unica) had high levels of plant recruitment from fallen seeds. The key exceptions were Oxley and Nina *S. guianensis* although Nina (ATF3308) dominated plots in the first few years. The sprawling *Macroptilium* lines (TGS84989, Aztec and Juanita) also maintained very high levels of cover, except for the annual-tending *M. gracile* (TGS849) which died out early in the experiment.

Most grass taxa maintained high levels of live cover over the study period, including the local comparator (SO6 black speargrass). Cover was highly seasonal, declining during the dry season each year. The *Bothriochloa* (panel 1), except for Swann *B. bladhii*, and *Brachiaria* species (panel 2) maintained high levels of cover. The *Dichanthium* lines (panel 3) and Rhodes grasses (*Chloris gayana*) (panel 4), declined towards the end of the study period. Some *Panicum* (ATF714 *P. coloratum*) (panel 5) continue to perform well.

4.3.2 Herbage yield

Herbage yields were sampled between May and September over three years and data are presented here for years 2 and 4 after establishment. The plants were cut to ~5 cm height, dried (70°C) to constant weight and separated into leaf and stem (legumes) before weighing or left as whole samples (grasses). Sample cover was recorded as a covariate. The numbers of grass culms (seedheads) were counted in each sample area to provide a guide of feed quality decline. All years were analysed independently using REML analysis (Appendix 10.14) and summary charts are presented below.

Year 2 (2019)

Plant biomass was sampled in year 2 on 7 August 2019 following an extended 2018-19 growing season. Maximum mean plant biomass values were exceptionally high for the legumes (up to 16 T DM/ha) and grasses (to over 10 T DM/ha) reflecting excellent establishment and growing conditions. Note: these yields represented 19 months growth since sowing. Total mean legume biomass at a species level ranged from < 1 T DM/ha for *Stylosanthes guianensis* var. *intermedia* (Finestem stylo) to 16 T DM/ha for *Stylosanthes guianensis* var. *guianensis* (Nina stylo) (Fig. 22). As a taxonomic group, *Stylosanthes* tended to have the higher herbage yields, but were characterised by low leaf content (i.e. were stemmy) and would therefore likely have moderate nitrogen content and digestibility. The *Desmanthus* lines also had low leaf contents, but also lower total yields. The twining plants, although having low to moderate biomass values, tended to have higher leaf contents indicative of higher feed value.

A range of grass species produced high levels of total biomass (Fig. 23). The highest yielding were *Brachiaria brizantha* (Mekong brizantha) and *B. decumbens* (Basilisk signal). *Chloris gayana* also performed well as a group and 'Sabre' was the highest yielding line overall: 'Katambora' also ranked highly (3rd). Other taxa to perform well included *Panicum maximum, P. coloratum* (ATF714), *Bothriochloa insculpta* (CPI125652B) and the *Brachiaria* hybrid. These higher performing lines comprise most of those identified as having superior performance on similar soil (but higher rainfall environment) in B.NBP.0766. Stem density (mean number of stems/m^2) was highest in the early flowering *B. insculpta* (CPI125652B), black speargrass (S06) and Indian couch (Medway and Keppel) (data not presented). *Brachiaria* and *Chloris* tended to have low to moderate values, but *Panicum* were more variable.

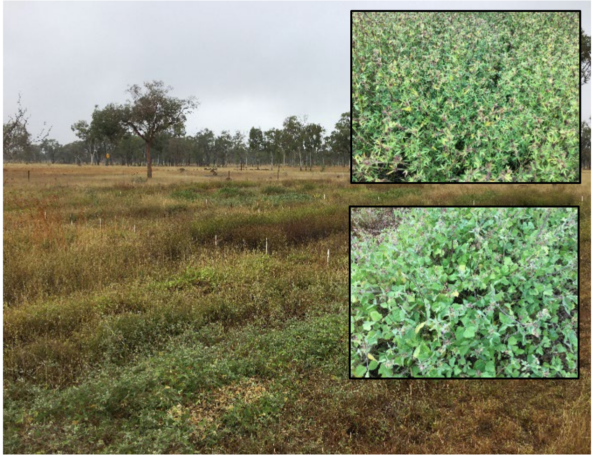
Year 4 (2021)

Year 4 herbage yields were sampled on 23 June 2021, effectively representing 7 months of growth since the onset of the wet season. Mean legume yields ranged from < 1 T DM/ha (<100 kg/ha for many poorly persisting taxa) to 7 T DM/ha for the highest yield line (Unica *Stylosanthes seabrana*) (Fig. 21). The comparator line, Seca shrubby stylo produced ~ 6 T DM/ha. The highest yielding lines were all stylos and the only other line with notable yield was Juanita *Macroptilium bracteatum*. Leaf content varied considerably between the legumes and was again generally low in the *Desmanthus* lines, moderate in *Stylosanthes* and relatively high in the well-adapted twining legumes *Macroptilium* and *Centrosema*: low leaf content in Juanita this year was attributed to leaf fall. Herbage yield was broadly associated with sample cover, which in turn reflected persistence as measured by plot cover. Legumes with higher yields tended to have lower proportions of leaf. Leaf production was in the order of 1-2 T DM/ha in the higher yielding lines (stylos).

Total dried biomass of the grasses ranged from < 1 T DM/ha to over 6T DM/ha and represented a decline from previous years. The comparator (S06 black speargrass) yielded ~4.5 T DM/ha. The best performing grasses were Mekong *Brachiaria brizantha* and the two *Bothriochloa insculpta* lines. *Brachiaria decumbens, Brachiaria* hybrid and Medway *Bothriochloa pertusa* all produced moderate yields. There was a substantial decline in Rhodes grass (*Chloris gayana*) yields compared to the previous years.

Fig. 19 Development of the grasses and legumes at the red basalt site at 'Junction Creek', 2020.

March 2020



Unica stylo and Juanita burgundy bean

May 2020. Vigorous growth after rainfall

August 2020. Poor acceptance of S06 black speargrass compared to other grasses.

Fig. 20 Changes in legume cover at 'Junction Creek', red soil site, 2018-22. The 'dots' represent initial plant populations and curves represent changes in live (green) cover: 0 = no cover, 10 = 100% ground cover). Please refer to Appendix 10.13 for the full analysis**.**

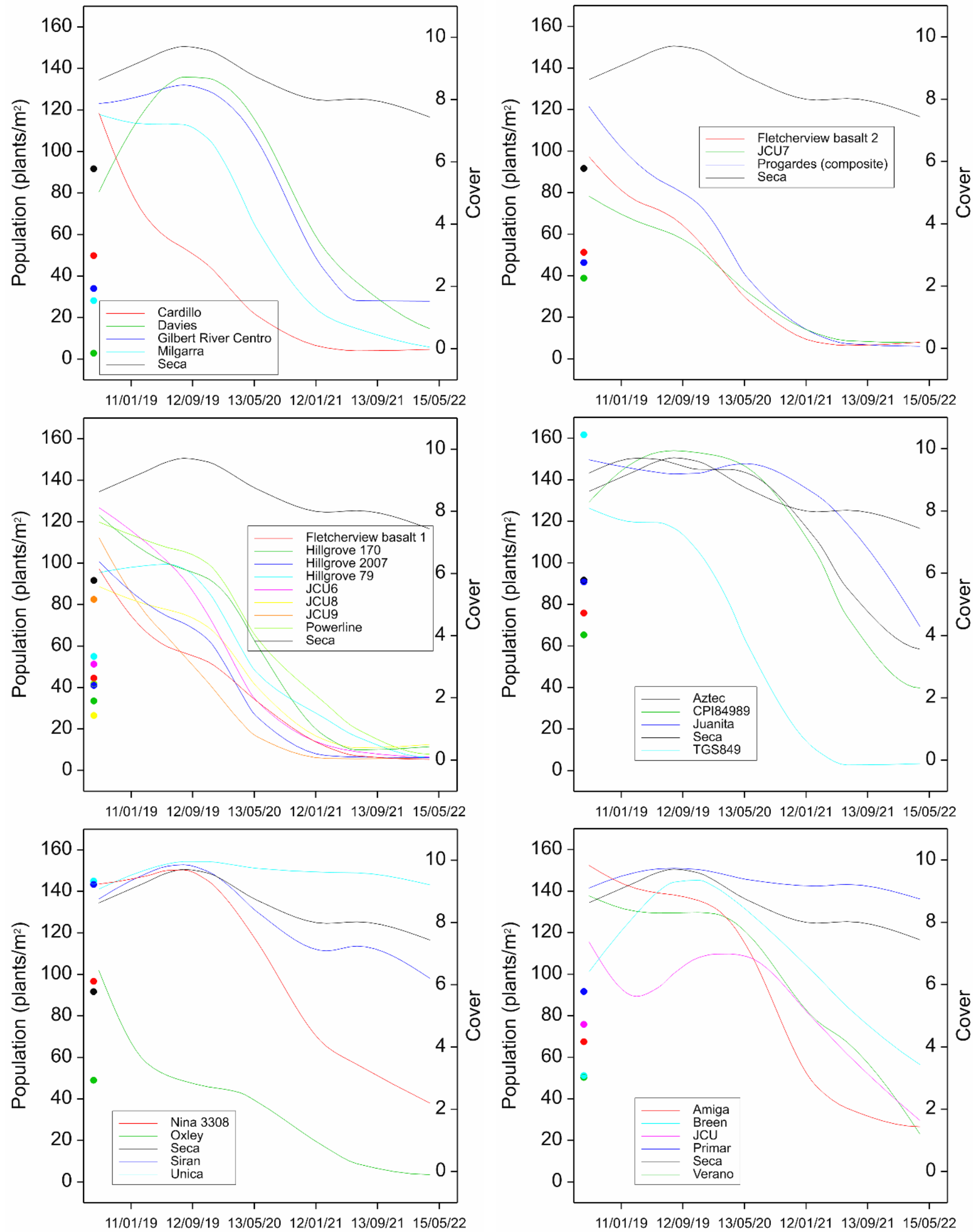


Fig. 21 Changes in grass cover at 'Junction Creek', red soil site, 2018-22. Please refer Fig. R14A for an explanation of symbols and to Appendix 10.13 for the full analysis**.**

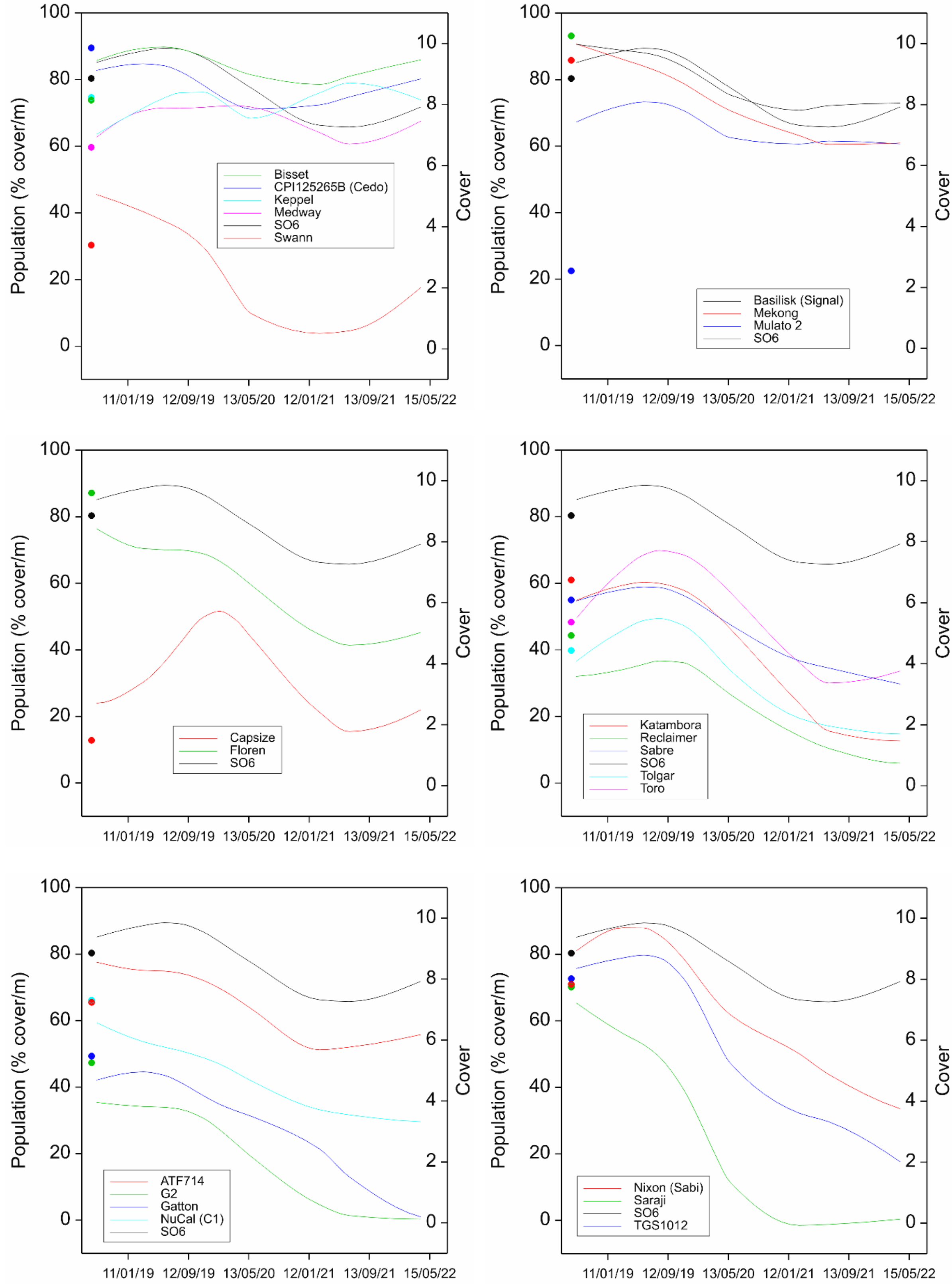
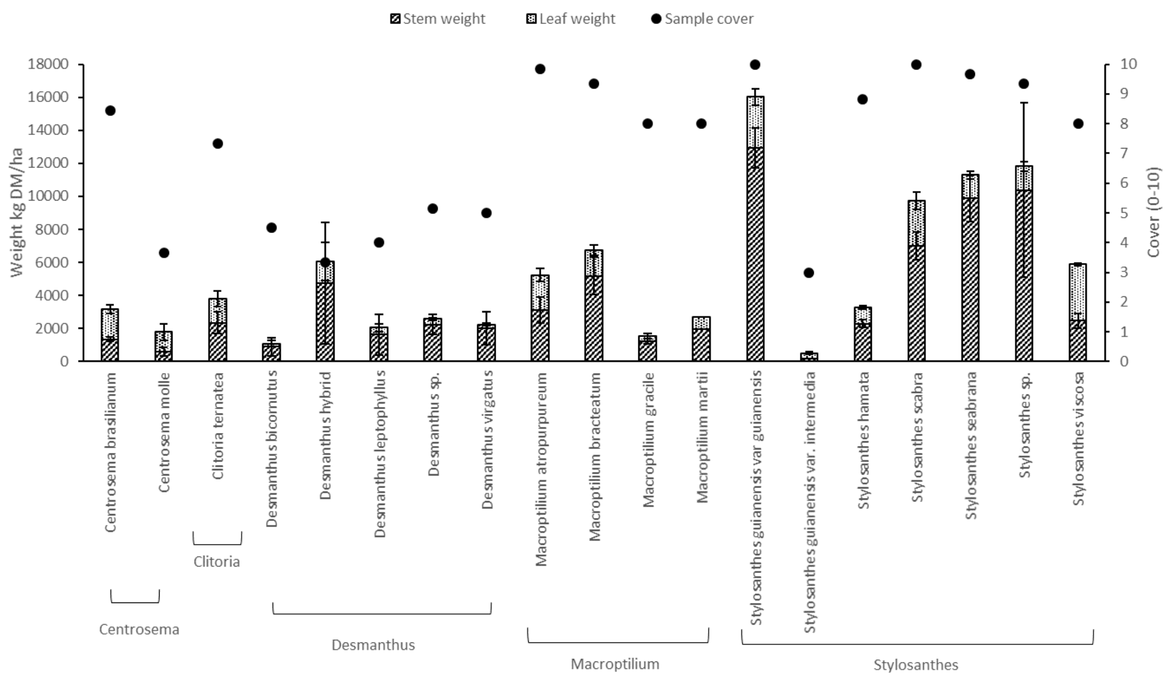
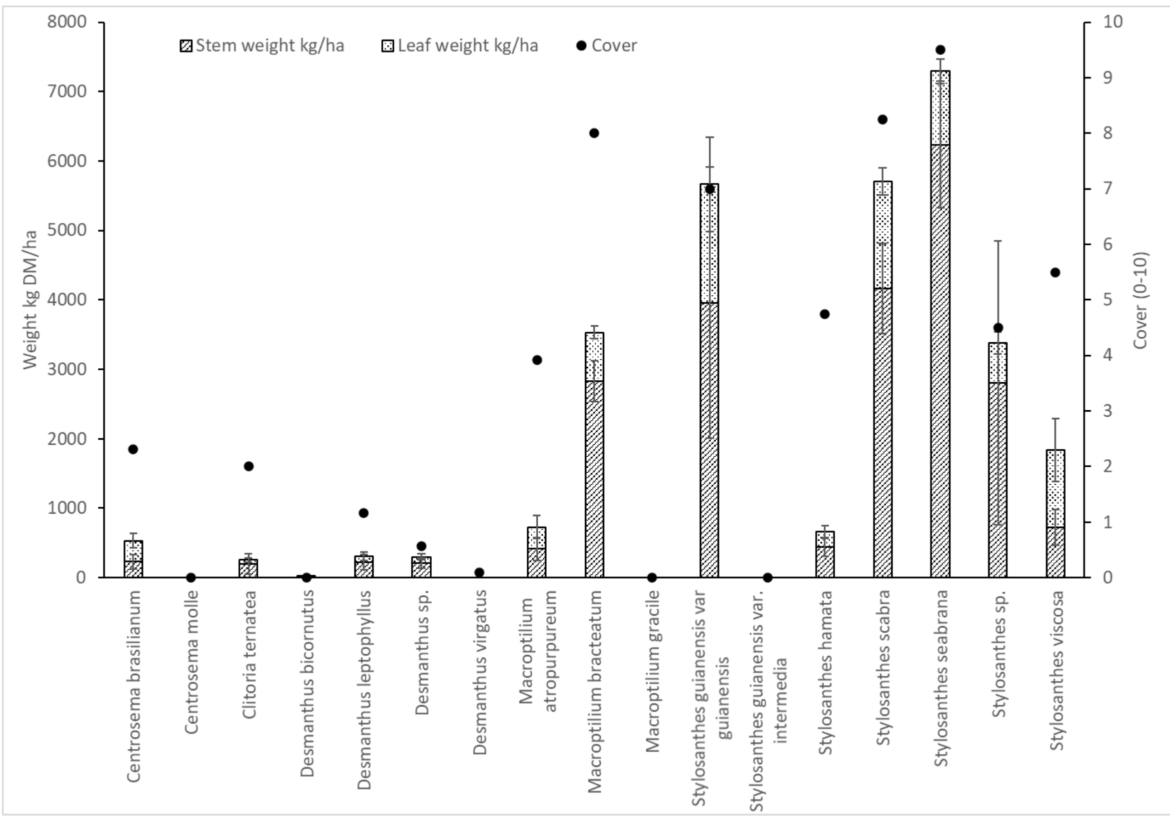


Fig. 22 Dried plant biomass and sample cover of legumes sampled in years 2 and 4 after establishment at 'Junction Creek' (red). Error bars represent two standard errors of the mean. Please refer to Appendix 10.14 for the full analysis**.**

7 August 2019



23 June 2021



23 June 2021

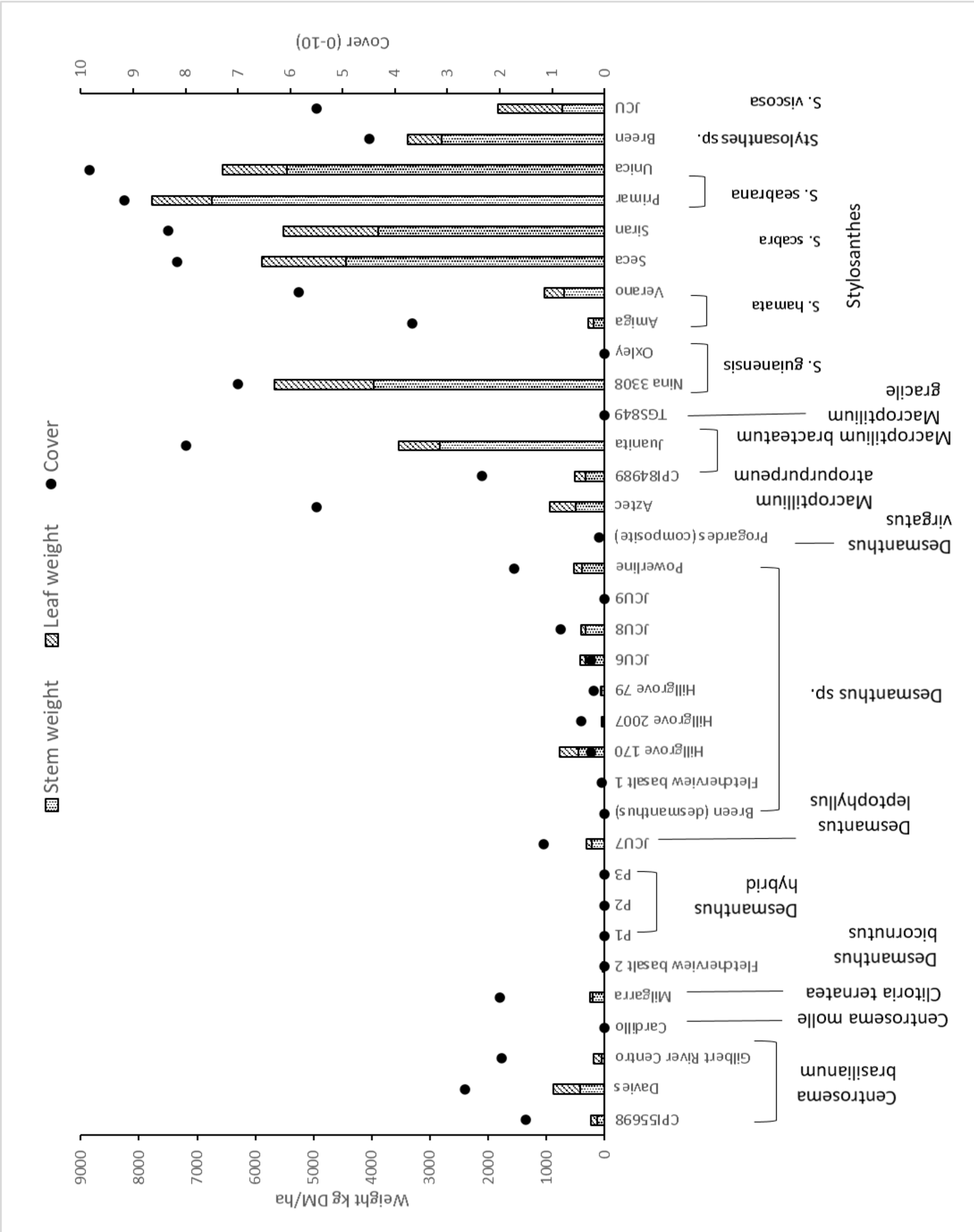
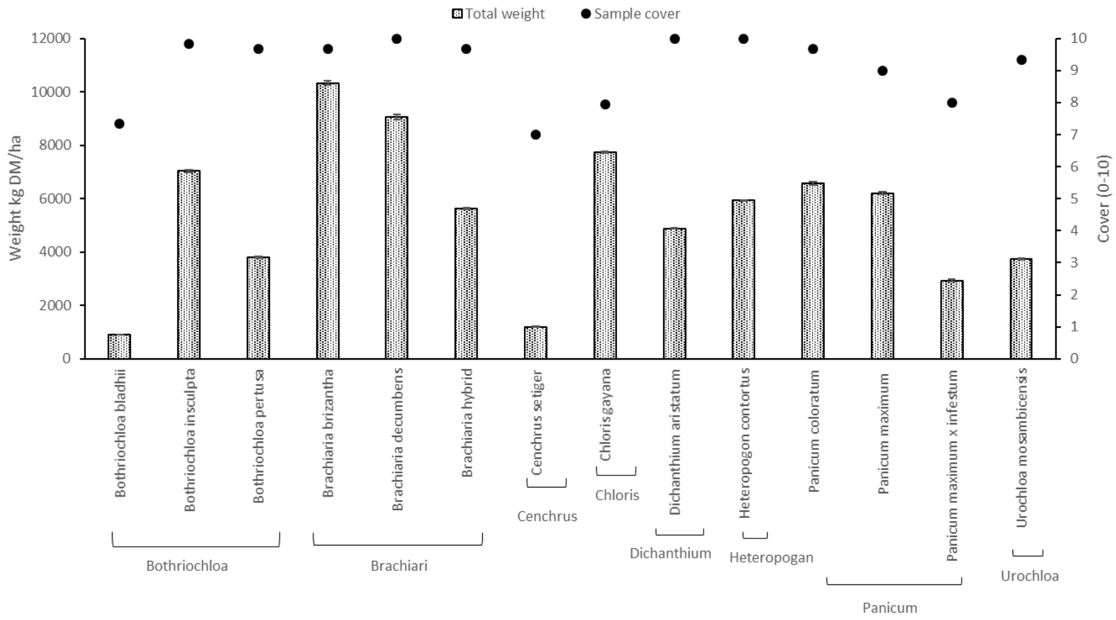
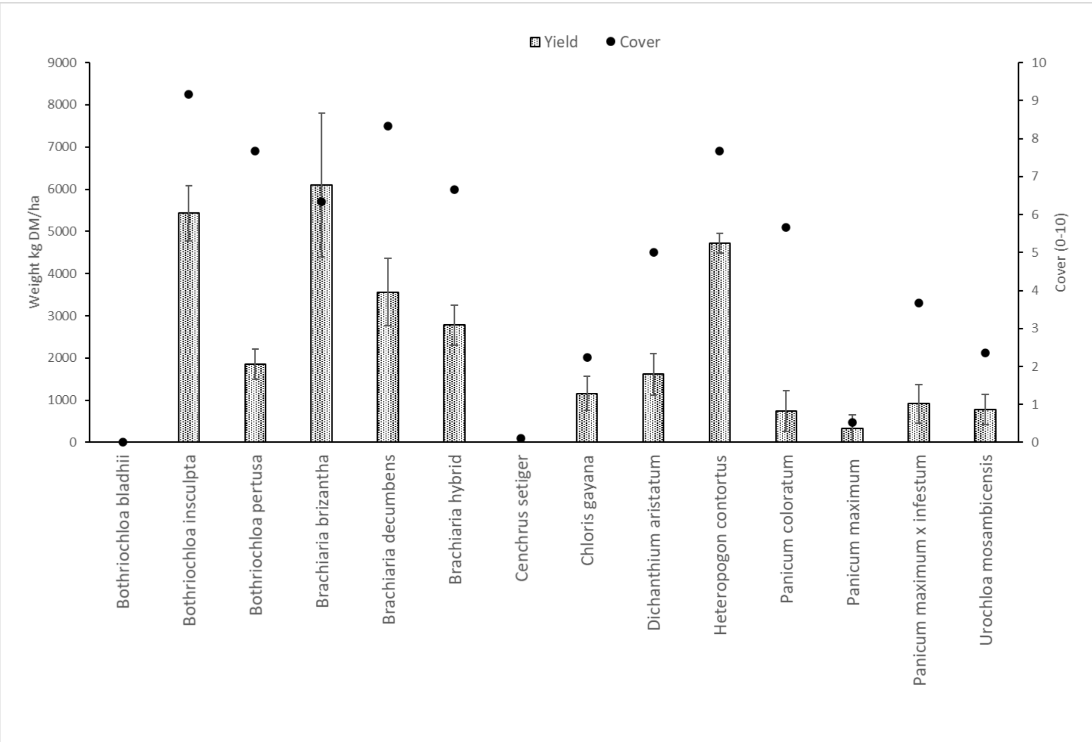

Stem weight
Leaf weight
Cover
Weight kg DM/ha
Cover (0-10)
CPI55698
Davies
Gilbert River Centro
Cardillo
Milgarra
Fletcherview basalt 2
P1
P2
P3
JCU7
Breen (desmanthus)
Fletcherview basalt 1
Hillgrove 170
Hillgrove 2007
Hillgrove 79
JCU6
JCU8
JCU9
Powerline
Progardes (composite)
Aztec
CPI84989
Juanita
TGS849
Nina 3308
Oxley
Amiga
Verano
Seca
Siran
Primar
Unica
Breen
JCU
Centrosema brasilianum
Centrosema molle
Clitoria ternatea
Desmanthus bicornutus
Desmanthus hybrid
Desmanthus leptophyllus
Desmanthus sp.
Desmanthus virgatus
Macroptilium atropurpureum
Macroptilium bracteatum
Macroptilium gracile
S. guianensis
S. hamata
S. scabra
S. seabrana
Stylosanthes sp.
S. viscosa
Stylosanthes

Fig. 23 Dried plant biomass and sample cover of grasses sampled in years 2 and 4 after establishment at 'Junction Creek' (red). Error bars represent two standard errors of the mean. Please refer to Appendix 10.14 for the full analysis.

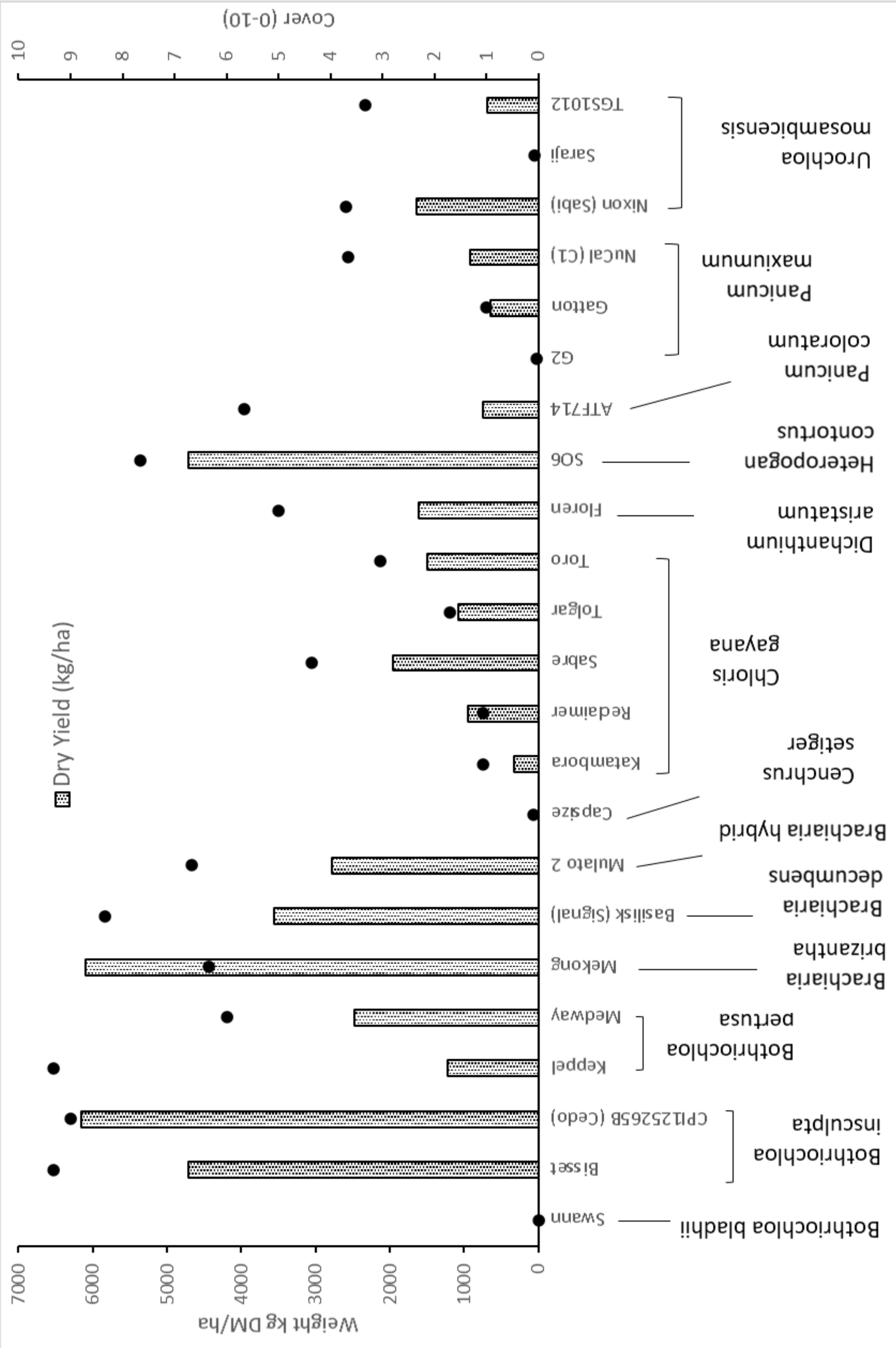
7 August 2019



23 June 2021



23 June 2021


Cover (0-10)
10
9
8
7
6
5
4
3
2
1
0
Dry Yield (kg/ha)
Weight kg DM/ha
7000
6000
5000
4000
3000
2000
1000
0
Urochloa mosambicensis
TGS1012
Saraji
Nixon (Sabi)
Panicum maximum
NuCal (C1)
Gatton
G2
Panicum coloratum
ATF714
Heteropogan contortus
SO6
Dichanthium aristatum
Floren
Chloris gayana
Toro
Tolgar
Sabre
Redaimer
Katambora
Cenchrus setiger
Capsize
Brachiaria hybrid
Mulato 2
Brachiaria decumbens
Basilisk (Signal)
Brachiaria brizantha
Mekong
Bothriochloa pertusa
Medway
Keppel
Bothriochloa insculpta
CPI52526B (Cedo)
Bisset
Bothriochloa bladhii
Swann

4.4 Plant growth: small-plot adaptation studies on black basalt near Charters Towers

The black basalt site at 'Junction Creek' was sown on 23-24 January 2019 with excellent rainfall for establishment and growth in the first season (Table 12). Patterns in seasonal plant growth were similar to those for the nearby red basalt site with vigorous summer growth and haying-off during the mid- to late- wet dry season. Seed set was high and legume growth continued into the late dry season (Fig. R17) when most grasses had hayed off. The site reverted to a native *Dichanthium aristatum* where there was an opportunity for growth and was particularly prevalent in the legume plots. Some legumes which formed a dense mat (e.g. Aztec and TGS84989 *Macroptilium atropurpureum*) prevented invasion by plots. The sown grasses were generally not dominated because of vigorous growth which presumably provided no opportunity for the *Dichanthium* to establish. The *Dichanthium* was unpalatable compared to the sown grasses (Fig. 24) and cows (with nitrogen supplement) were used in the mid- dry season to suppress growth. The plots were 're-set' afterwards by slashing to reduce *Dichanthium* cover.

4.4.1 Plant persistence and cover

Splines of mean cover are presented with mean values for plant population (establishment) for the legumes and grasses in Figs. 25 and R26. The full analyses are provided in Appendix 10.15. Seca stylo was used as the 'industry standard' for legumes (in the absence of no widely used standards on this soil type) and Gayndah buffel for grasses. As for the red basalt site, there were substantial changes in legume cover as poorly adapted lines died out, but most grasses maintained high cover ratings three years after sowing.

Legume cover varied by taxa grouping. The 'standard' (Seca), which is recognised as being poorly adapted to heavy clay soils, declined steadily with only a few plants remaining by the end of the study. Cover generally declined over the study period as grass (*Dichanthium*) cover increased in the legume plots. There were, however, marked differences between the various types of legume. In general, the stylos poorly; the marked exception was the two *S. seabrana* cultivars (Primar and Unica), some of the best performing lines overall. *Desmanthus* (wide range of types) and *Clitoria ternatea* (Milgarra, JCU Double) generally performed well on the heavy clay soil, but green cover of the *Desmanthus* tended to decline due to leaf fall by the middle of the dry season. *Desmanthus* lines JCU6 (tall) and TQ90 (moderate height) performed particularly well. The perennial *Macroptilium* lines (Aztec and TGS84989 *M. atropurpureum* and Juanita and Cardaarga *M. bracteatum*) all showed the capacity to regrow well into the third year, whereas the annual type TGS849 *M. gracile* has disappeared, failing to recruit new plants from seed.

Grass cover was less variable than for the legumes with most grasses maintaining moderate to high cover by the end of the study (Fig. 26). The standard, Gayndah buffel, grew vigorously and appeared well adapted to the heavy clay soils and monsoon environment. Floren *Dichanthium aristatum* and the *Bothriochloa* lines (Bisset, Keppel and Medway) maintained high levels of cover. Bambatsi *Panicum coloratum*, a grass historically recognised as suitable for heavy clay soils, performed well. The Rhodes grasses (Katambora and Sabre) grew well initially but declined in cover over time. Poorly adapted lines included *Panicum* spp. (NuCal, Gatton, ATF714), Saraji *Urochloa mosambicensis* and Scatta *Dichanthium sericeum*.

4.4.2 Herbage yield

Plant biomass was sampled in years 2 and 3 using the same methods for the red soil site. Yields (like cover) was strongly influenced by invasion by a local ecotype of *Dichanthium aristatum* which dominated the site, particularly in years 3 and 4, but appreciable in year 2.

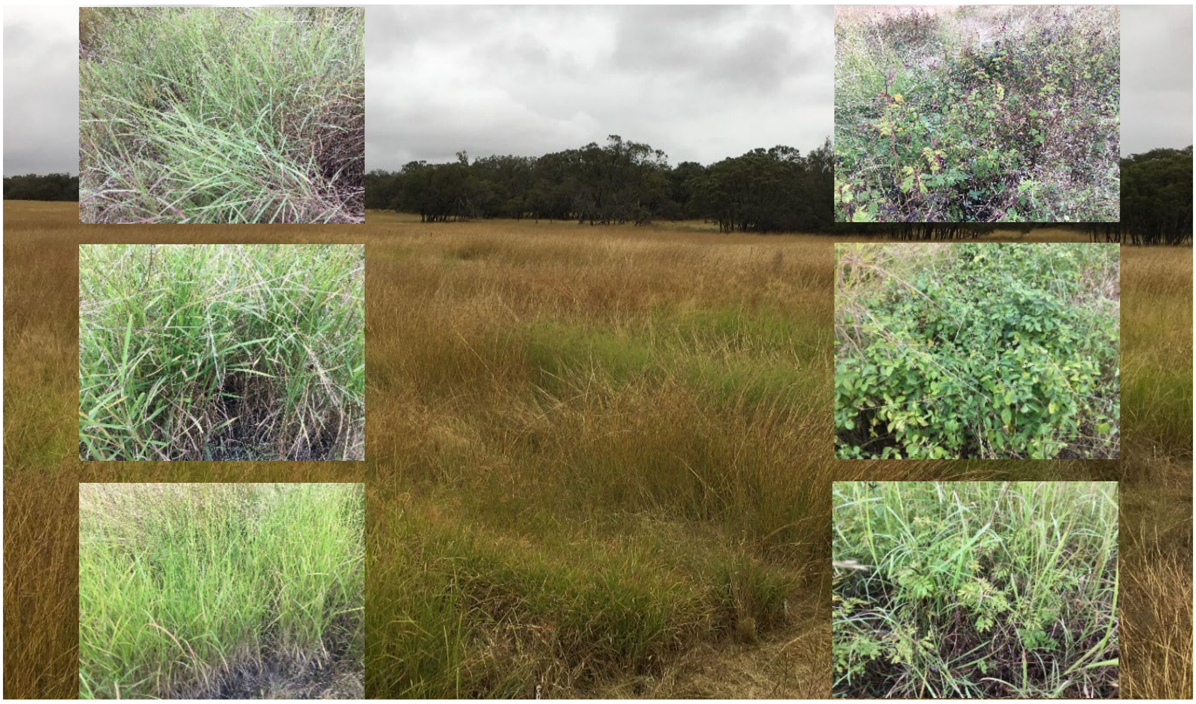
Year 2 (2020)
Plant biomass was sampled in year 2 on 20 May 2020 following a late (January) start to the growing season. Legume herbage yields (at a species level) ranged from < 0.2 T DM/ha for poorly persisting taxa to approximately 4 T DM/ha (Fig. R20), although highest yielding lines yielded over 6 T DM/ha. The highest yielding lines were all *Desmanthus*, including the commercial line Progardes and yet unreleased lines including a line collected within the region (Hillgrove 2007). TQ90, a *Desmanthus virgatus* line previously identified as having potential in north Queensland also yielded well. The next best yielding legumes were *Clitoria ternatea* and some *Macroptilium* lines. The stylos yielded poorly overall. As for the red basalt site percentage leaf content was highest in the twining legumes (40-60%), but these also tended to yield poorly. Most higher yielding legumes (desmanthus) had leaf content in the order of 20-30% total dried biomass. Cardaarga *M. bracteatum* represented a good compromise between yield and leaf content.

Grass herbage yields were very high and ranged from < 1 T DM/ha to 14 T DM/ha: the comparator (Gayndah buffel) yielded only ~3 T DM/ha despite a high cover rating (Fig. R21). The best performing grasses at this early stage were Floren *Dichanthium aristatum* (although there was a high level of variation in between plots), Bisset *Bohriochloa insculpta* and Sabre *Chloris gayana*. Grasses with moderate performance (~6 T DM/ha) included Bambatsi *Panicum coloratum*, Gatton *Panicum maximum*, Jarra *Digitaria milanjiana* and Keppel and Medway *Bothriochloa pertusa.* All of the above are commercially available. The number of reproductive stems generally reflected sample cover (as most grasses flowered prior to sampling) (data not presented). Important exceptions were Gayndah buffel and Bambatsi *Panicum coloratum*, both grasses often recommended for heavy clay soils, which had low numbers of stems despite high cover.

Year 3 (2021)
Plant biomass was sampled as for the red soil site (late June, 7 months growth). *Dichanthium* was dominant in the legume plots despite attempts to suppress it though grazing management. Mean herbage yields ranged from 0 to 10 T DM/ha for the highest yielding line, JCU6 *Desmanthus* (Fig. 27). The highest yielding lines were all *Desmanthus* (notably JCU6, Hillgrove 79, TQ90). The commercial line Progardes continued to perform well. Primar and Unica *Stylosanthes seabrana* increased considerably in herbage yield compared to the previous year (with evidence of many new plants established from seed). TGS84989 *Macroptilium* and an experimental *Clitoria ternatea* line (Double) also performed well. Again, percentage leaf content was highest in the twining legumes (40-60%) moderate in the stylos and low in many desmanthus (had fallen by harvest). TGS84989 was the only legume with high leaf content (50%) and moderate (~ 2 T DM/ha) yield.

Mean grass yields ranged from < 0.5 T DM/ha to over 9 T DM/ha: the comparator (Gayndah buffel) yielded ~2.5 T DM/ha (Fig. 28). The best performing grasses were similar to the previous year and included Floren *Dichanthium aristatum* (still highly variable), Bisset *Bohriochloa insculpta,* Medway *Bothriochloa pertusa* and Sabre *Chloris gayana*. Grasses with moderate performance (~6 T DM/ha) included Bambatsi *Panicum coloratum*, Gatton *Panicum maximum*, Jarra *Digitaria milanjiana* and Keppel and Medway *Bothriochloa pertusa.* All of the above are commercially available. There was a decline in yield for most other grasses, although most performed similarly to Gayndah buffel. Poorly adapted grasses include Gatton and NuCal *Panicum* spp. and Saraji sabi *Urochloa*.

Fig. 24 Development of the grasses and legumes at the black basalt site at 'Junction Creek'.



Grasses and legumes at biomass harvest in May 2020. High performing grasses included creeping blue and Rhodes grasses. The best legumes were a range of desmanthus and butterfly pea.

Grasses in February 2021

Grazing of palatable sown grasses and *Dichanthium*

Desmanthus producing leaf in September 2021

Macroptilium) producing leaf in September 2021

Fig. 25 Changes in legume cover at 'Junction Creek', black soil site, 2018-22. Please refer Fig. R13 for an explanation of symbols and to Appendix 10.15 for the full analysis**.**

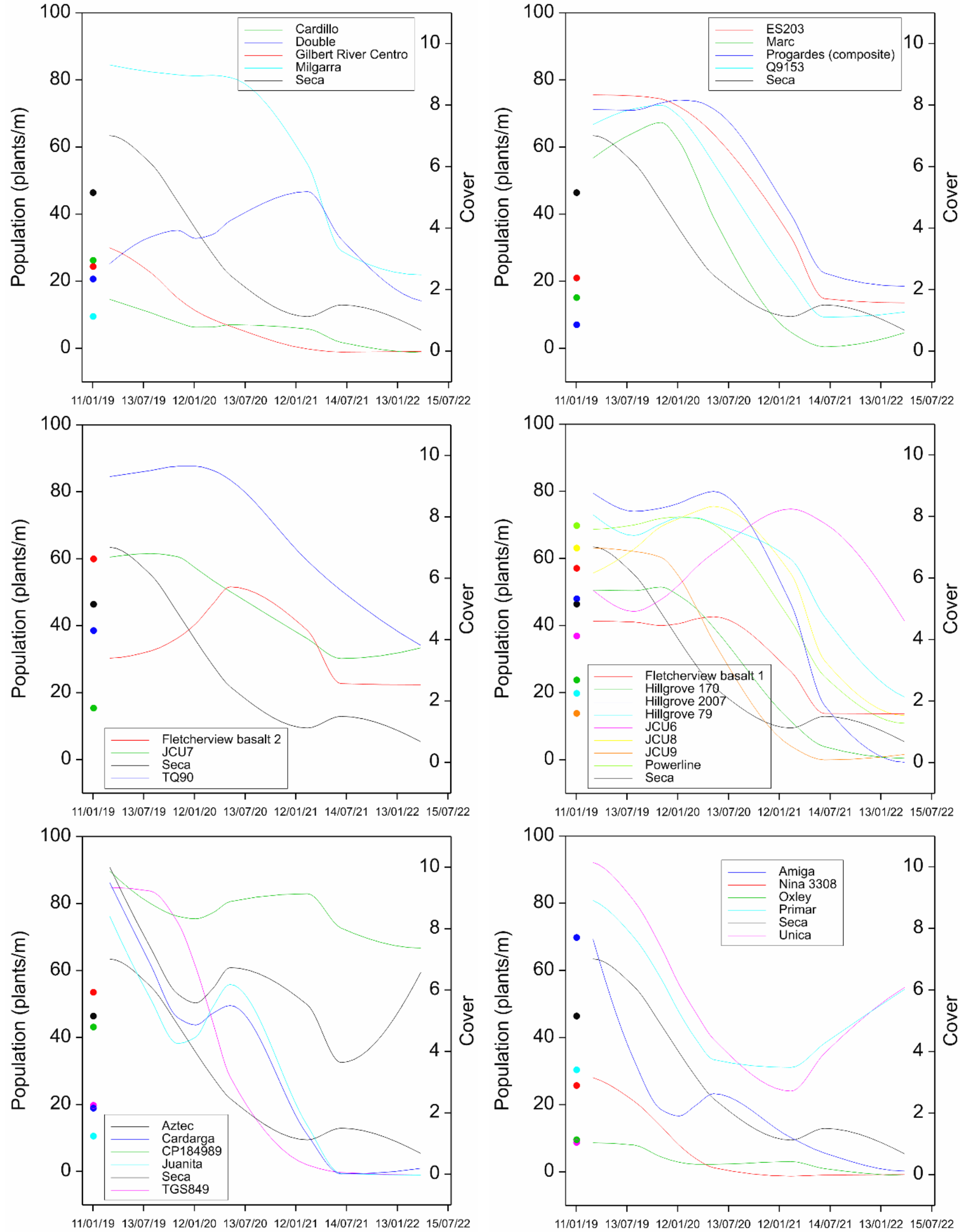


Fig. 26 Changes in grasses cover at 'Junction Creek', black soil site, 2018-21. Please refer Fig. R13 for an explanation of symbols and to Appendix 10.15 for the full analysis.

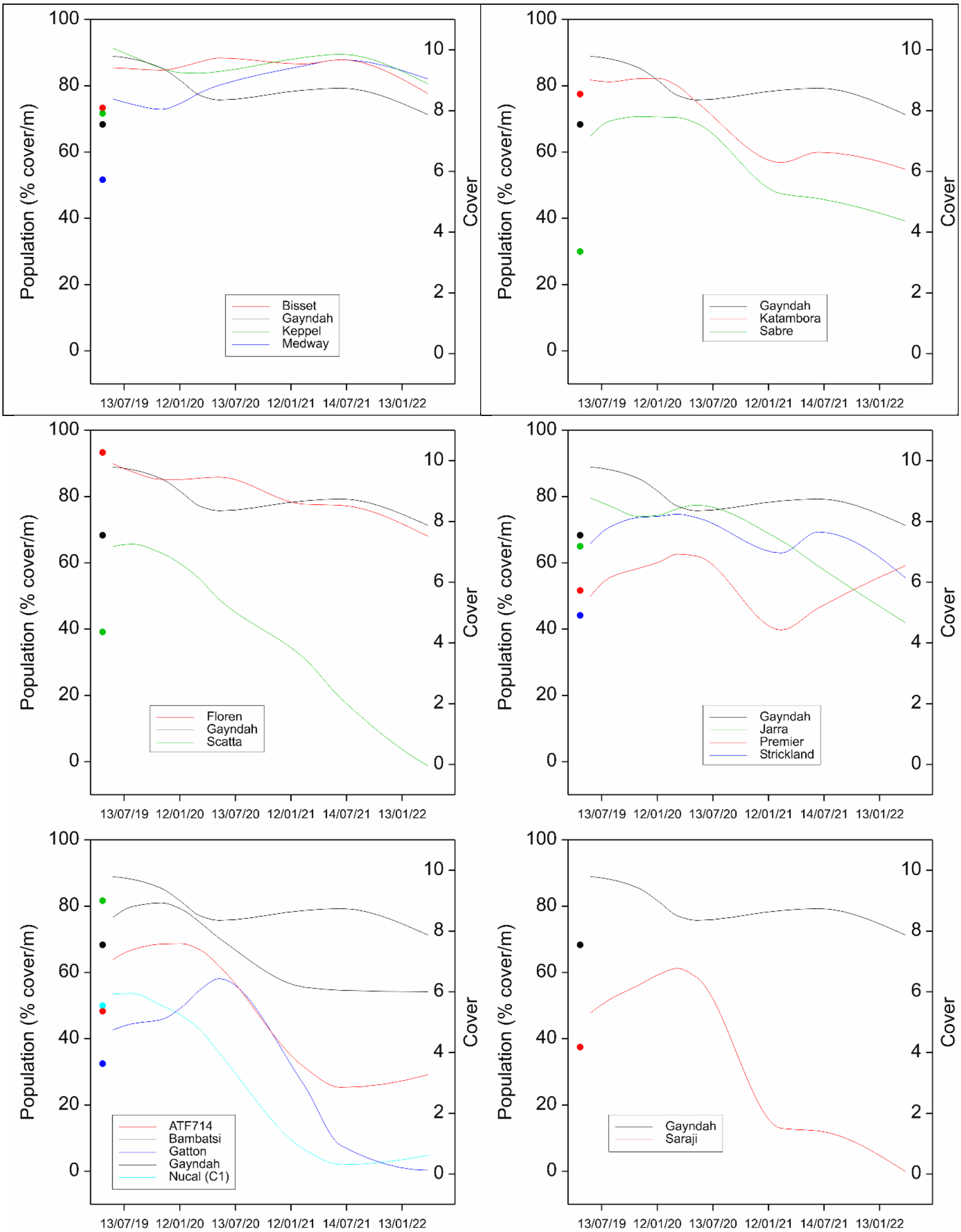
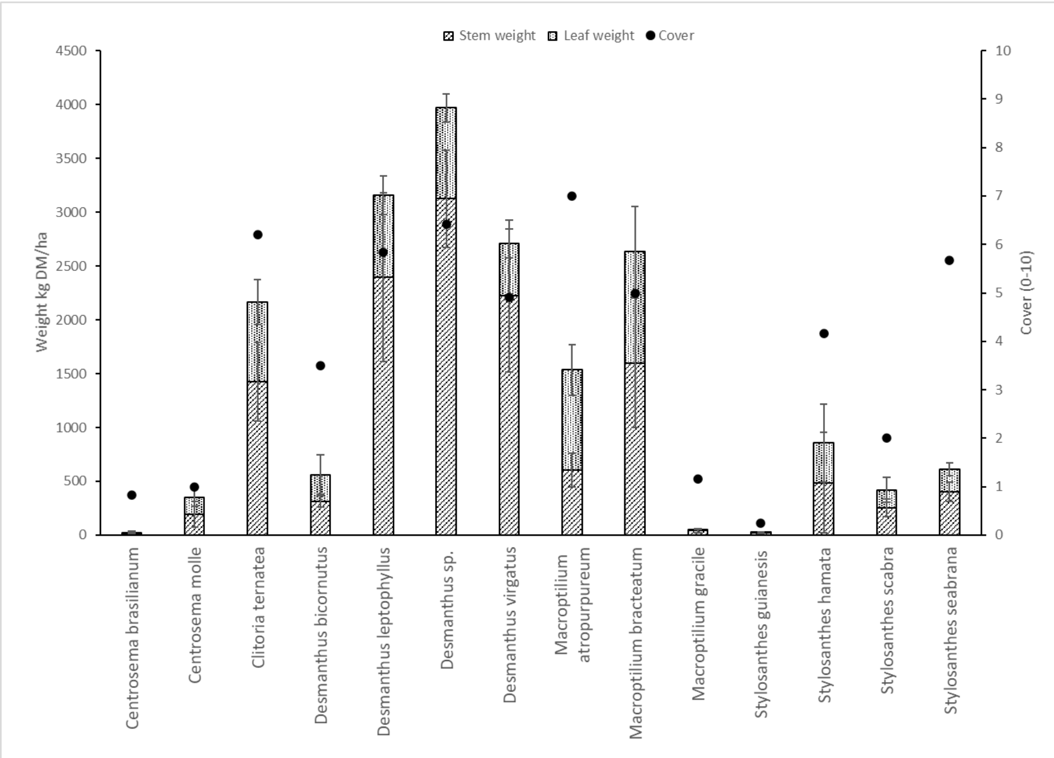
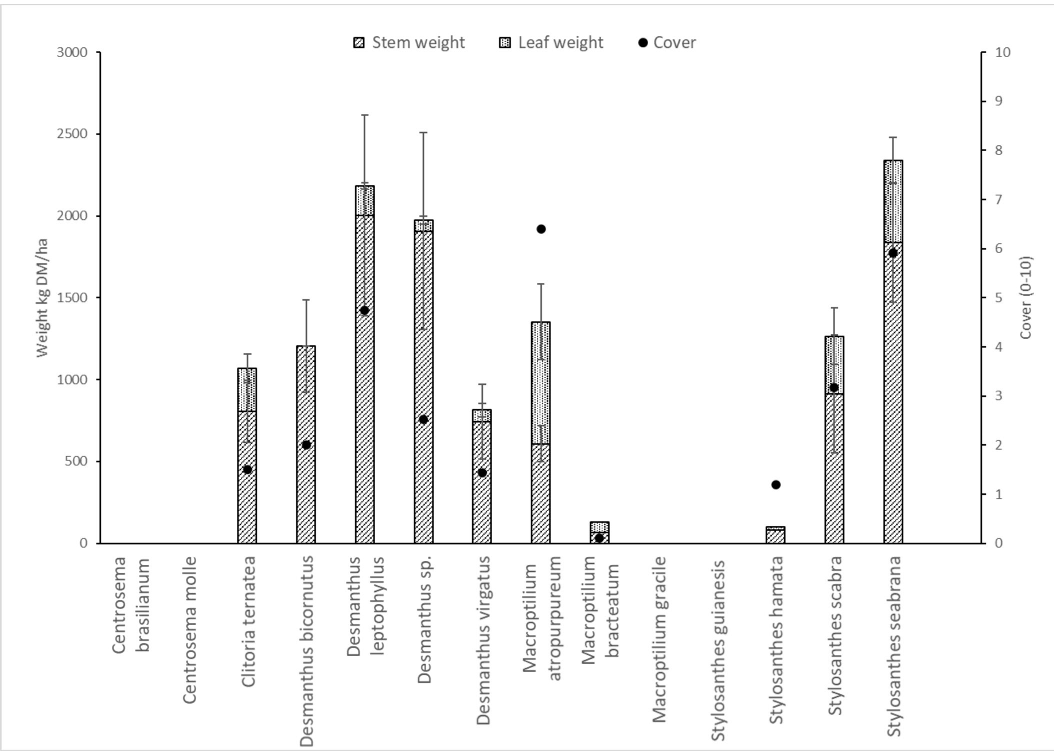


Fig. 27 Dried plant biomass and sample cover of legumes sampled in years 2 and 3 after establishment at 'Junction Creek' (black). Error bars represent two standard errors of the mean. Please refer to Appendix 10.14 for the full analysis**.**

20 May 2020



24 June 2021



24 June 2021

4 T DM/

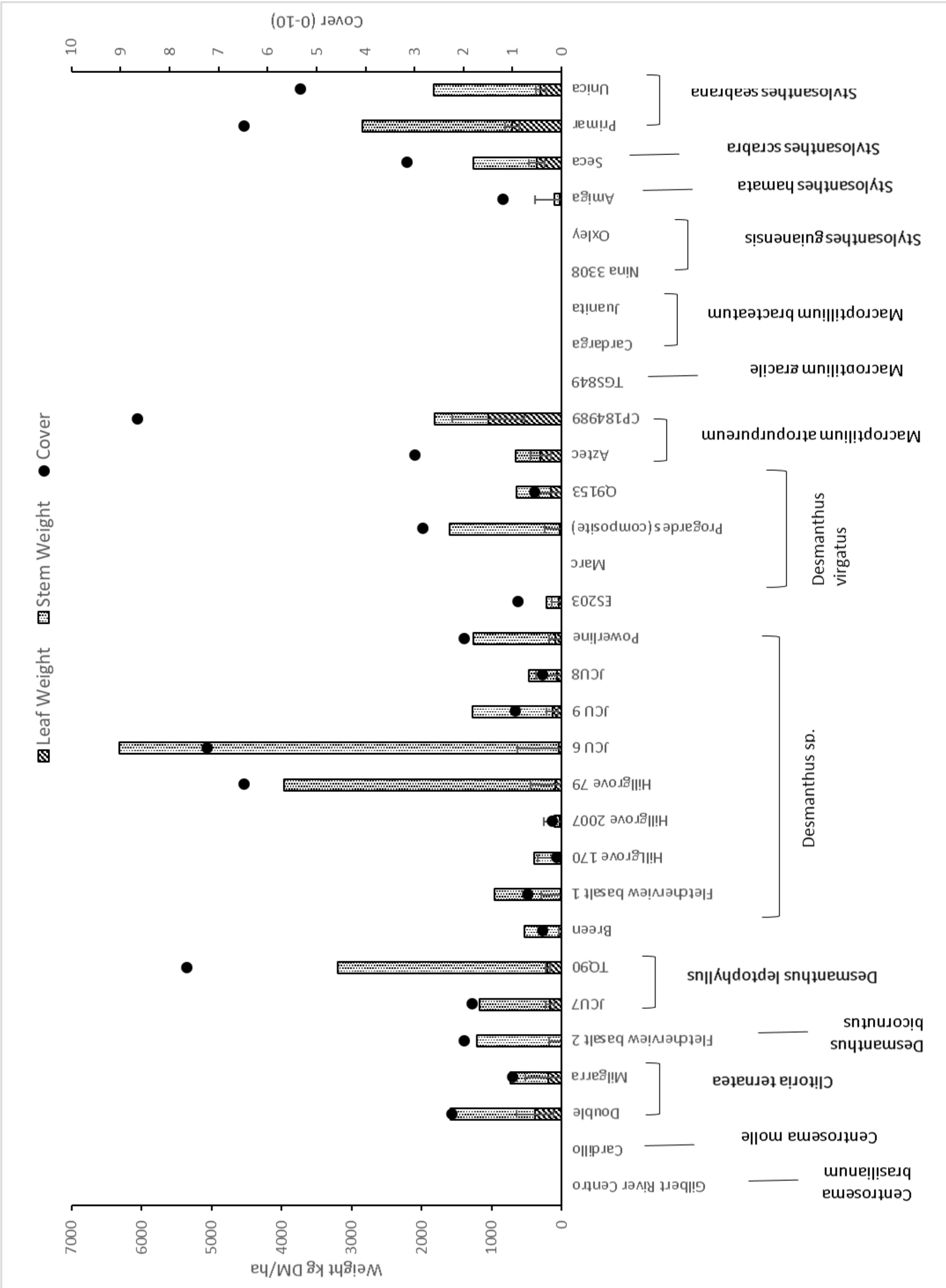
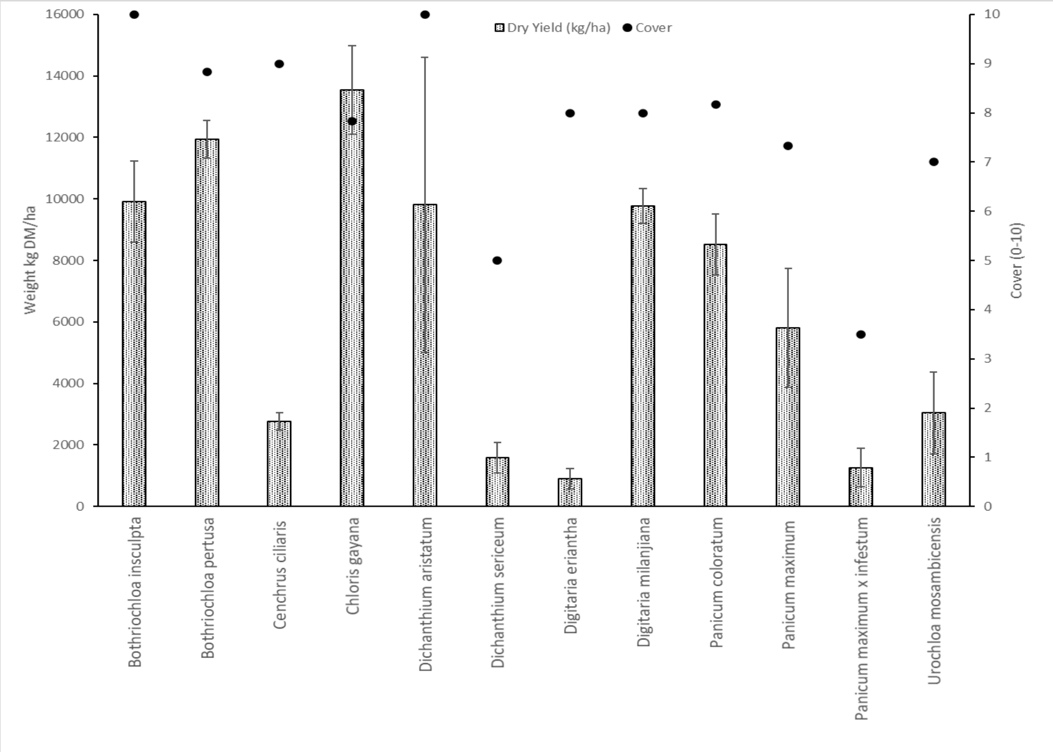
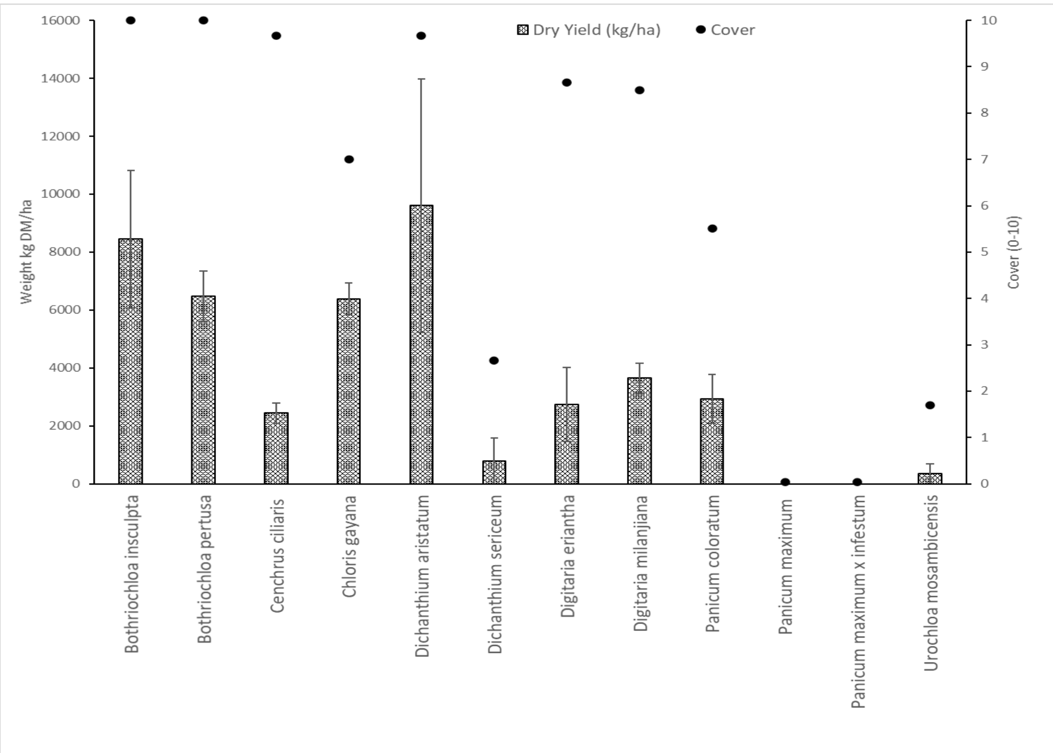


Fig. 28 Dried plant biomass and sample cover of grasses sampled on 20 May 2020 at 'Junction Creek' (black). Error bars represent two standard errors of the mean. Please refer to Appendix 10.13.2 for the full analysis.

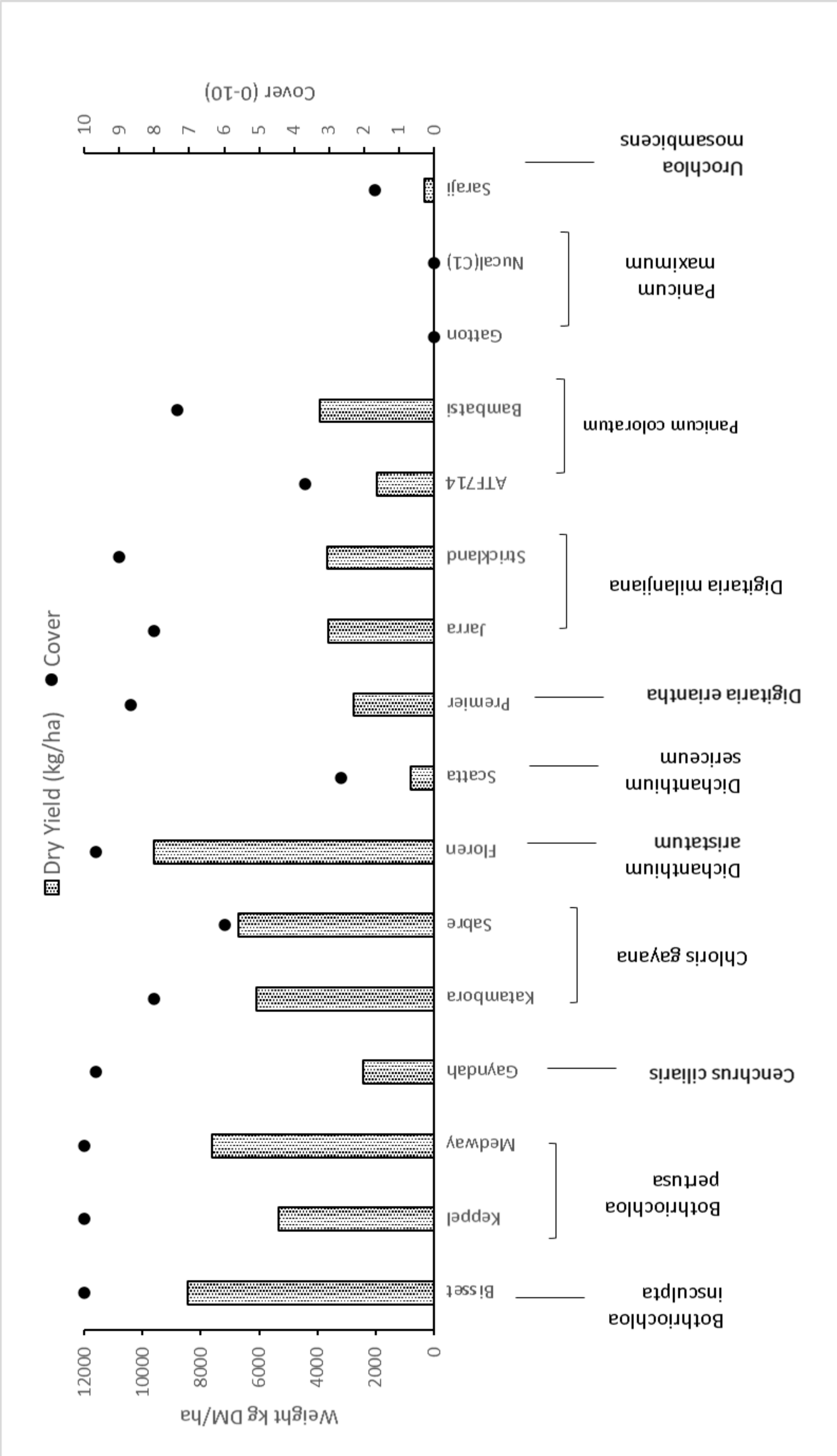
20 May 2020



24 June 2021



24 June 2021


Dry Yield (kg/ha)
Cover
Weight kg DM/ha
Cover (0-10)
Bothriochloa insculpta
Bisset
Bothriochloa pertusa
Keppel
Medway
Cenchrus ciliaris
Gayndah
Chloris gayana
Katambora
Sabre
Dichanthium aristatum
Floren
Dichanthium sericeum
Scatta
Digitaria eriantha
Premier
Digitaria milanjiana
Jarra
Strickland
Panicum coloratum
ATF714
Bambatsi
Panicum maximum
Gatton
Nucal(C1)
Urochloa mosambicens
Saraji
0
2000
4000
6000
8000
10000
12000
0
1
2
3
4
5
6
7
8
9
10

4.5 Plant growth - grass-legume combinations at 'Whitewater' station

The eight grasses and eight legumes selected for evaluation at 'Whitewater' were sown using an 8 grass x 8 legume split-plot (legumes) factorial design comprising 3 replicates (192 plots, each measuring 54 m^2). Live (green) cover was measured to indicate the relative competitive abilities of the grasses and legumes. Measurements of herbage yield, and samples for feed quality, were conducted when the growing season was considered complete, in May both years (Table 19).

4.5.1 Plant persistence and cover

Grass and legume growth was highly seasonal, following annual rainfall patterns (Fig. 29). Exceptionally dry conditions after sowing on 27 February 2019 resulted in a greater survival of legume seedlings compared to grasses. The grasses which showed the strongest capacity to establish and survive the first dry season were Mekong *Brachiaria brizantha*, TGS1215652B *Bothriochloa insculpta* and TGS1012 *Urochloa mosambicensis*. Mulato 2 failed to establish and was effectively treated as a 'no sown grass' treatment thereafter. Most legumes survived, although TGS *Macroptilium gracile* hayed off early and most plants died. Recovery was remarkable after the first wet season and most surviving plants seeded over the following season (although seeding was late in Mekong and Nina (3308) *Stylosanthes guianensis*. Thereafter the surviving plants grew vigorously between December-January and May in all years, with growth rates declining thereafter.

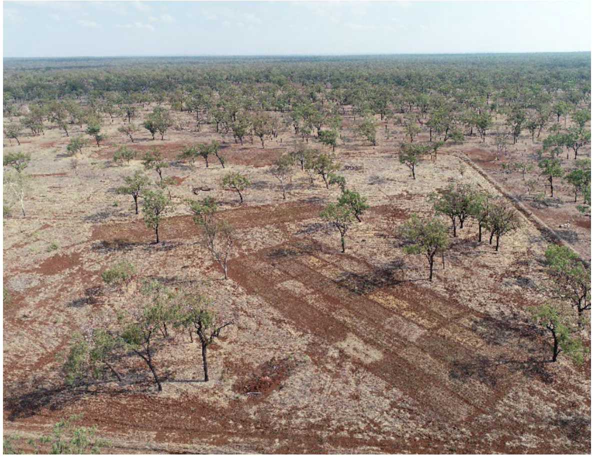
Changes in grass and legume cover are presented in Figs. 30 and 31 and the analysis of variance in Appendix 10.17. Legume cover was relatively high for all legumes in the first year after establishment, the exception being Progardes *Desmanthus* spp. which persisted but did not achieve high cover over the entire growing period (indicating not as well as adapted as the other legumes). Nina (ATF3308) common stylo and TGS849 gracile did not persist in most plots. TGS84989 *Macroptilium atropurpureum,* a sprawling legume dominated plots in the first few years but appeared selectively attached by grasshoppers in the second year and did not recover.
Grader grass (*Themeda quadrivalvis*), an annual low-quality grass, dominated some plots in the first year, particularly plots with low sown grass and legume cover (data not presented). Grader grass declined markedly by 2021 and was absent from most plots in 2022, presumably because seedlings were competing poorly with the sown grasses and legumes.

By 2022 the most dominant legumes were Unica *Stylosanthes seabrana* (erect stylo) and Milgarra *Clitoria ternatea* (twining) followed by the industry standard Seca *S. scabra* (another erect stylo). Nearly 100% cover was achieved by Unica when there was no significant grass competition (Mulato2 (no grass) and ATF714 panic). These dominant legumes all set seed over the growing season and there was good evidence of recruitment each year (highest in Unica).

Grass cover also varied between the lines tested. TGS1012 *Urochloa mosambicensis* and TGS125652B *Bothriochloa insculpta* (stoloniferous), which established well, continued to dominate the plots by the end of the study, but Mekong *Brachiaria brizantha* declined. The erect, clumping Panicum (Gatton, NuCal) and Brachiaria brizantha (Mekong) grasses maintained moderate levels of cover. Jarra Digitaria milanjiana (sprawling and erect habit), which established poorly, substantially increased in cover legume pressure was low.

There was evidence of competition between the various grasses and legumes although the interaction was not always statistically significant (Appendix 10.17). Legume cover was lower overall when growing with Mekong *Brachiaria brizantha*, TGS125652B *Bothriochloa insculpta* and TGS1012 *Urochloa mosamicensis*, the three most competitive grasses in this environment: Unica, and to a

Fig. 29 Development of the grasses and legumes at the black basalt site at 'Whitewater'.



December 2019 after dry establishment period

Mid-March 2020

Mid-March 2020: TGS84989 (left) and TGS1012 (right)

Mekong *Brachiaria brizantha* growing with Milgarra *Clitoria ternatea*

Mekong with Progardes *Desmanthus* spp.

Mekong with TGS84989 *Macroptilium atropurpureum*

Fig. 30 The effect of grass competition on legume plant populations and cover, 'Whitewater'.

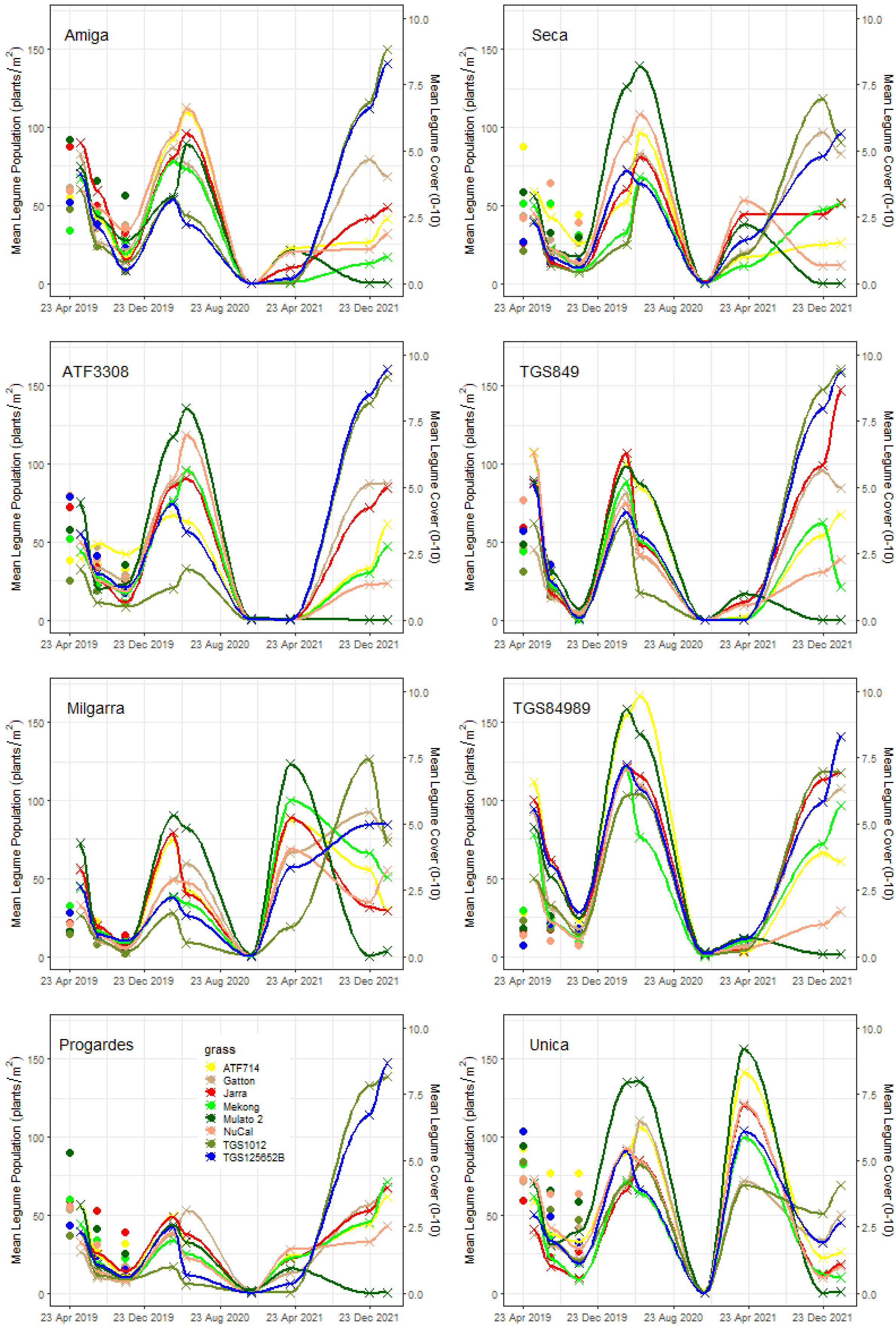
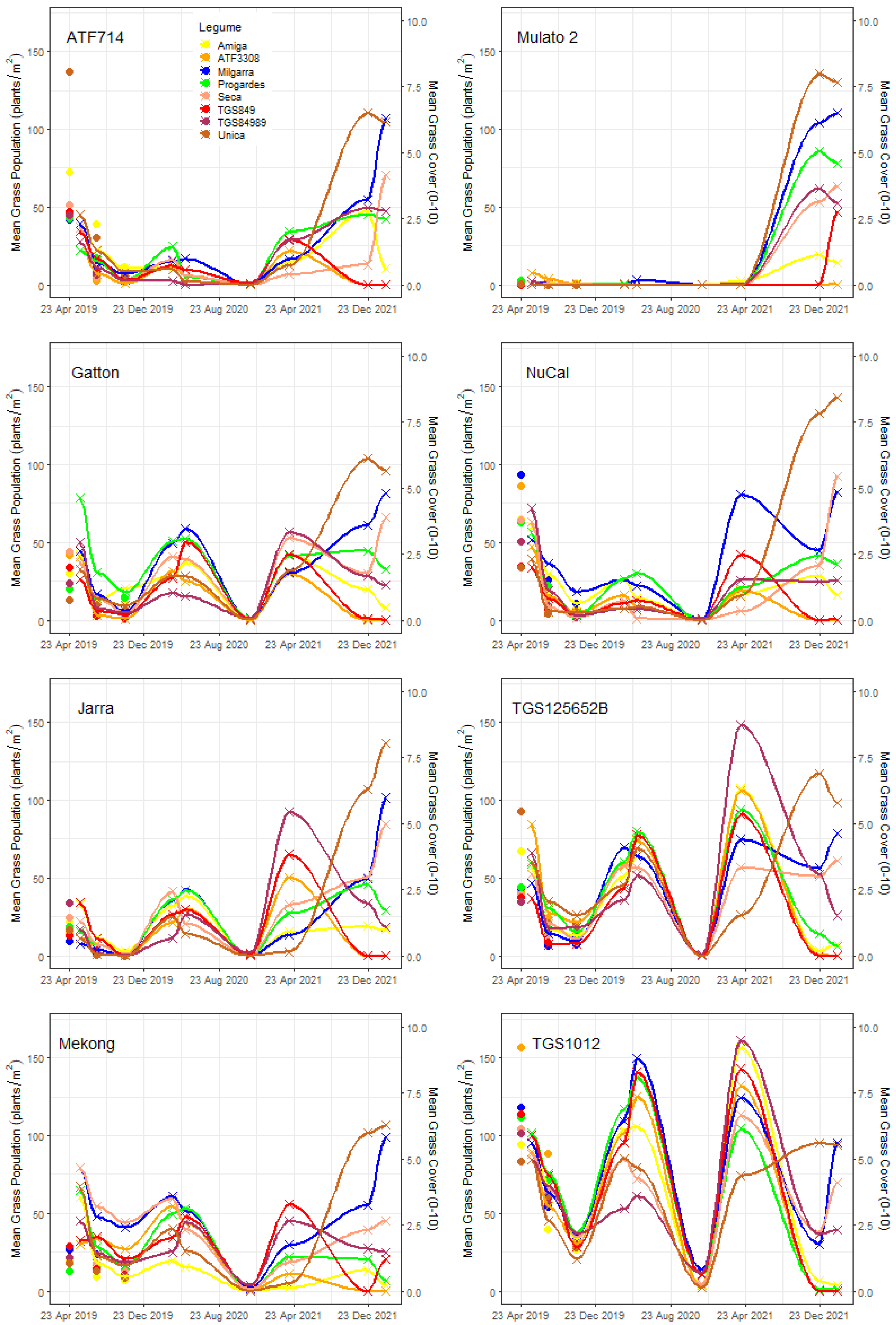


Fig. 31 The effect of legume competition on grass plant populations and cover, 'Whitewater'.



lesser extent, Milgarra and Seca competed best, although Amiga *Stylosanthes* competed well with TGS1012. Conversely, Unica and Seca *Stylosanthes* appear to have the greatest effect on companion grasses and best co-existed with the dominant grasses TGS125652B and TGS1012. Some grasses had very high cover in the TGS84989 plots in the final year when this previously dominant legume was damaged by grasshoppers.

4.5.2 Herbage yield

Herbage yields were measured in May 2020 and 2021, prior to grazing, and are presented in Figs. 32 and 33, with statistical analyses in Appendix 10.18. Only selected plots were sampled in March 2022 (mid-season) to broadly estimate herbage yields before grazing.

Grasses
Grass herbage yields in 2020 ranged from 4-8 T DM/ha for the best performing lines (TGS1012, Mekong and TGS125652B, all newer cultivars), and are considered remarkable given first year production was limited by low rainfall. Herbage yields were most consistent for TGS1012 *Urochloa mosambicensis* and TGS105652B *Bothriochloa insculpta*, which dominated plots. The lowest yields often occurred when TGS84989 was the companion legume, which tended to form a dense mat. Gatton panic and one plot of Jarra (in combination with TGS849) produced moderate yields, but the others were less than 2 T DM/ha.

Herbage yields were slightly higher overall in 2021 (6 – 8 T DM/ha) for the best performing lines (TGS1012 and TGS125652B). Exceptional yields of nearly 14 T DM/ha were measured in the Mekong plots where there was little legume competition (TGS849 and Milgarra), but this was inconsistent with low yields in ATF3308 and Amiga plots. Higher yields were also achieved for Gatton, NuCal and Jarra, mostly when growing in plots with low levels of legume competition (TGS849, ATF3308 and Progardes). The grasses tended to have lower yields when grown with the higher yielding legumes (Unica a followed by Seca and Milgarra).

Grass stem counts were completed in the first year to infer differences in seed set and feed quality at the onset of the dry season. There were significant differences between grasses in the number of reproductive stems per m^2 (Appendix 10.18.2). TGS1012 (116 stems/m^2) and TGS125652B (58), the most dominant grasses, had the highest values along with Gatton panic (42). Despite having high cover, Mekong (a short-day flowering grass) produced relatively few stems (<1). Companion legume had a significant but minor effect on overall grass stem production with the dominant legumes contributing to fewer grass stems: presumably because of suppressing growth.

Legumes

Legume herbage yields in 2020 were generally lower than for the better performing grasses but high in some treatments, reaching 6 to 8 T DM/ha in some Seca (Seca x Mulato 2 'null') and Unica (Unica x Mulato 2 'null') treatments (Fig. 34). Herbage yields of ATF3308 stylo were also initially high. The sprawling and dominating TGS84989 atro (*Macroptilium atropurpureum*) produced moderate yields, but there was a significant amount of leaf fall (turnover) prior to sampling in May. The other legumes had relatively low herbage yields: (< ~ 2 T DM/ha when grown in combination with Mulato 2 or other grasses with low cover. Legume yields were consistently low (usually lowest) when grown in combination with TGS1012; TGS125652B and Mekong had similar limiting effects. The legumes which produced the best yields when growing with these grasses were Unica and Seca stylos and TGS 84989 atro.

Herbage yields of the highest-yielding legumes increased the following year (2021). Production was, however, dependent on the type of companion grass. The highest yielding legume was Unica *Stylosanthes seabrana*, producing over 12 T DM/ha where there was little competition, but < 2 T DM/ha when grown with TGS1012 *Urochloa mosambicensis* (a combined yield of over 7 T DM/ha). Seca *S. scabra* and Milgarra *Clitoria ternatea* yields ranged 1-4 T DM/ha, in comparison, and the yields were lower for the other legumes. Of note was the considerable reduction in yield by Nina (ATF 3308) common stylo (plant death) and TGS 84989 atro (grasshopper damage).

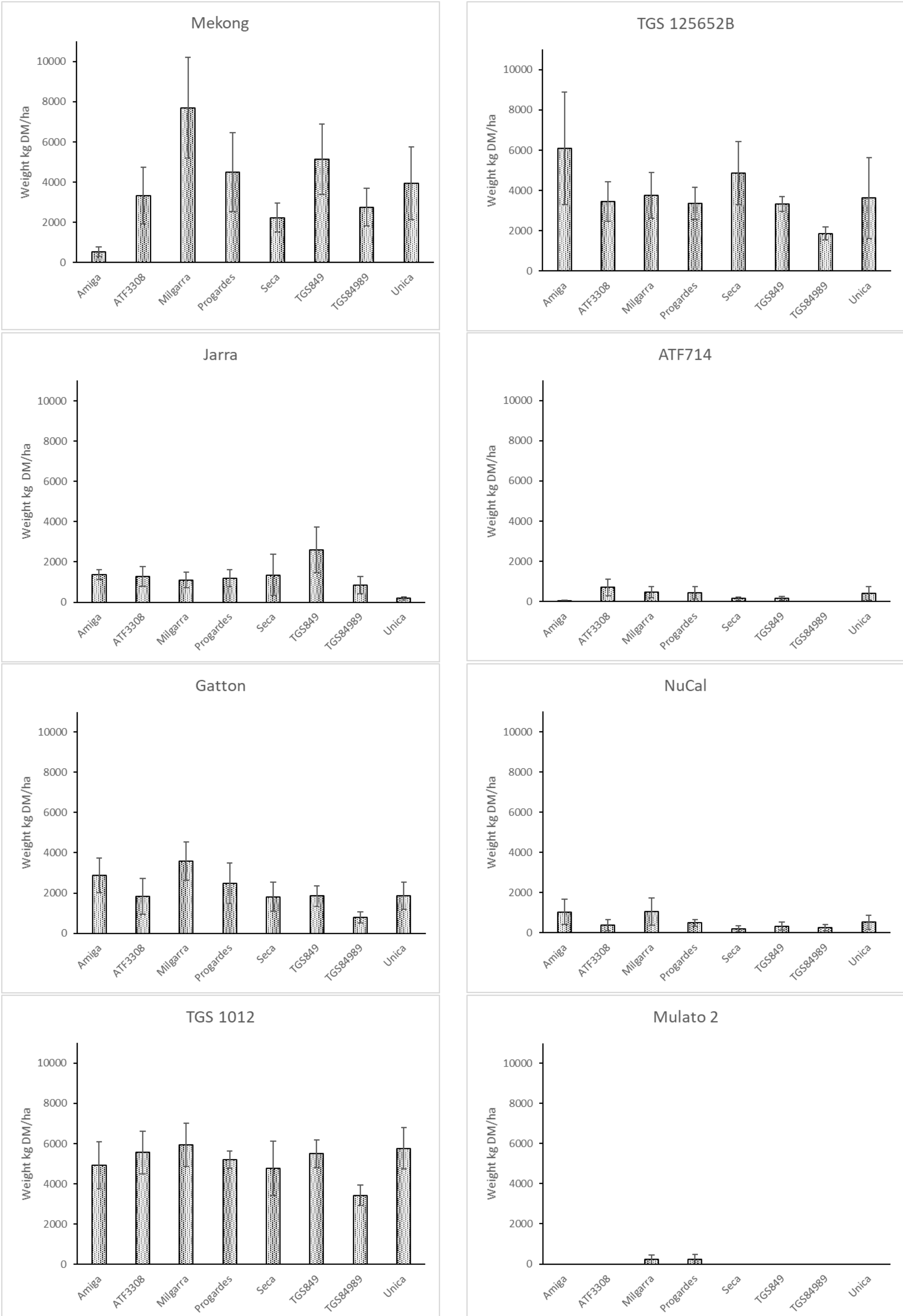
In both years, legume herbage samples were separated into leaf and stem and the proportion of leaf varied significantly between legumes but less so between grass x legume combinations (Fig. 33). Leaf content was highest in the twining legumes (*Clitoria* and *Macroptilium*) in both years (40-60%). The remaining legumes generally contained 30-45% leaf. *Desmanthus* leaf content (25%) was particularly low in the 2020 as drying plants had begun to shed leaves, but was similar to Seca stylo, another shrubby legume, the following year. Unica stylo had a relatively low leaf content (~30%) in 2021 but also produced the highest yields resulting in high leaf yields per hectare. Amiga stylo also had high leaf content (~65%) in the second year, but very low yields and therefore very thin stems which would have been included in the leaf fraction.

Interactions of grass and legume on total herbage yields

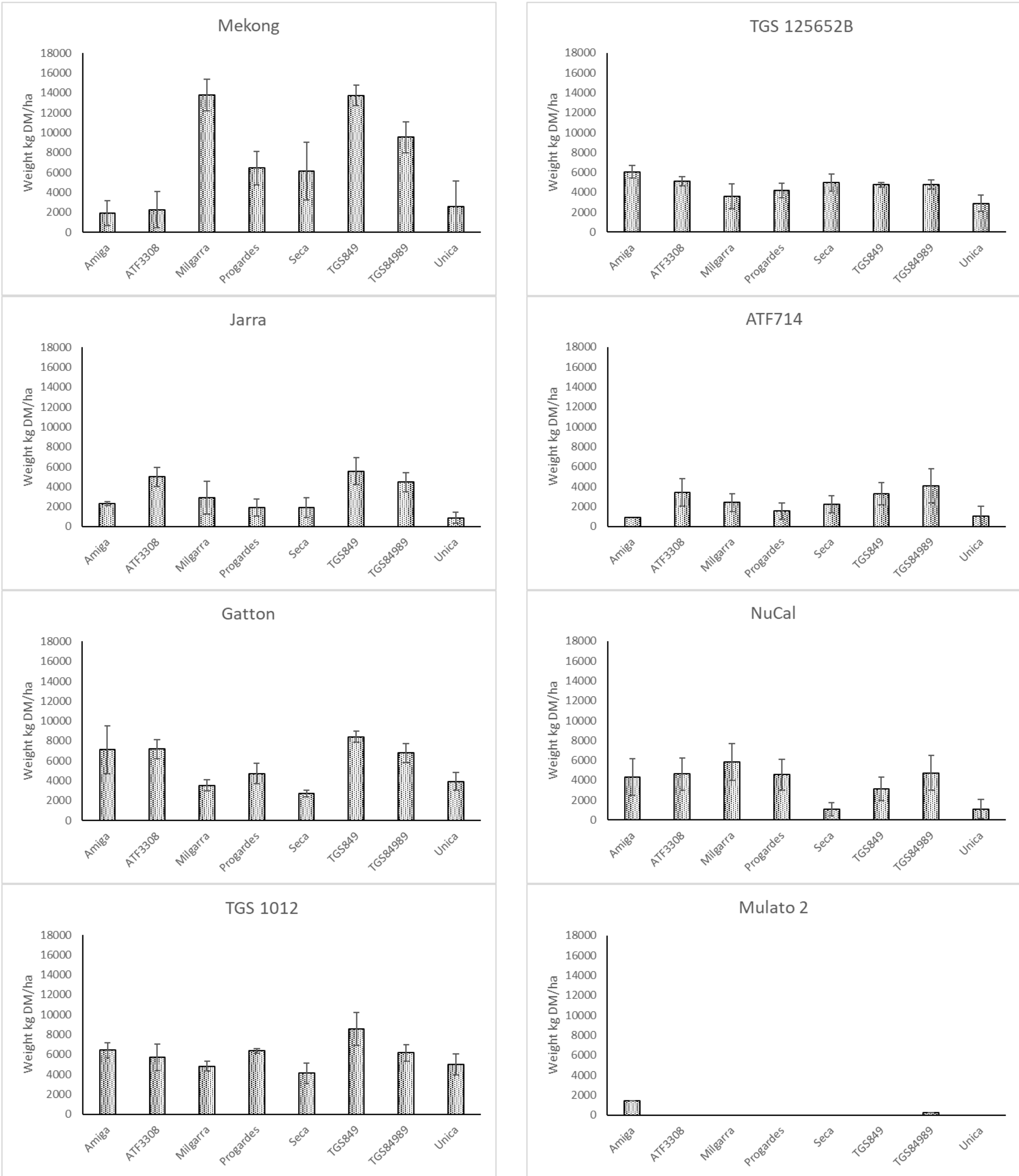
There were significant interactions measured between the grasses and legumes indicating competition between the more dominant grasses or legumes with their companion species. These were weaker and not significant in 2020, perhaps influenced by the presence of other competing plants (notably grader grass). There were stronger relationships, however, for legume, grass (and total) biomass in 2021 (Appendix 10.18.3). Overall, total biomass was highest when combinations included the grasses Mekong, Gatton, TGS1012 or TGS125652B or when they included the legumes Unica or Milgarra (Table 18). An example of a high-yielding combination is Unica + TGS125652B (9.8 T DM/ha). There were also poor yielding combinations (ATF3308 and Mulato2) where both failed (and the plots became dominated by low-value grasses). Unica stylo produced over 13 T DM/ha in the absence of sown grass competition and equalled Mekong also in the absence of competition (TGS849, which had died out).

There were also high level effects of legume on (pooled) grass biomass: grass herbage yields were lowest overall in combination with Unica and Seca and highest where legumes performed poorly (TGS849) (Appendix 10.18.3). Interestingly, there were no significant effects of grass on (pooled) legume yield measured (too much variability), although there were substantial differences across pooled means (TGS1012 resulting in 300% lower legume biomass than when grown with TGS849).

Fig. 32 Mean herbage yields of grasses grown with eight different legumes in small swards at 'Whitewater'. Error bars represent two standard errors of the mean.
6 May 2020



13 May 2021

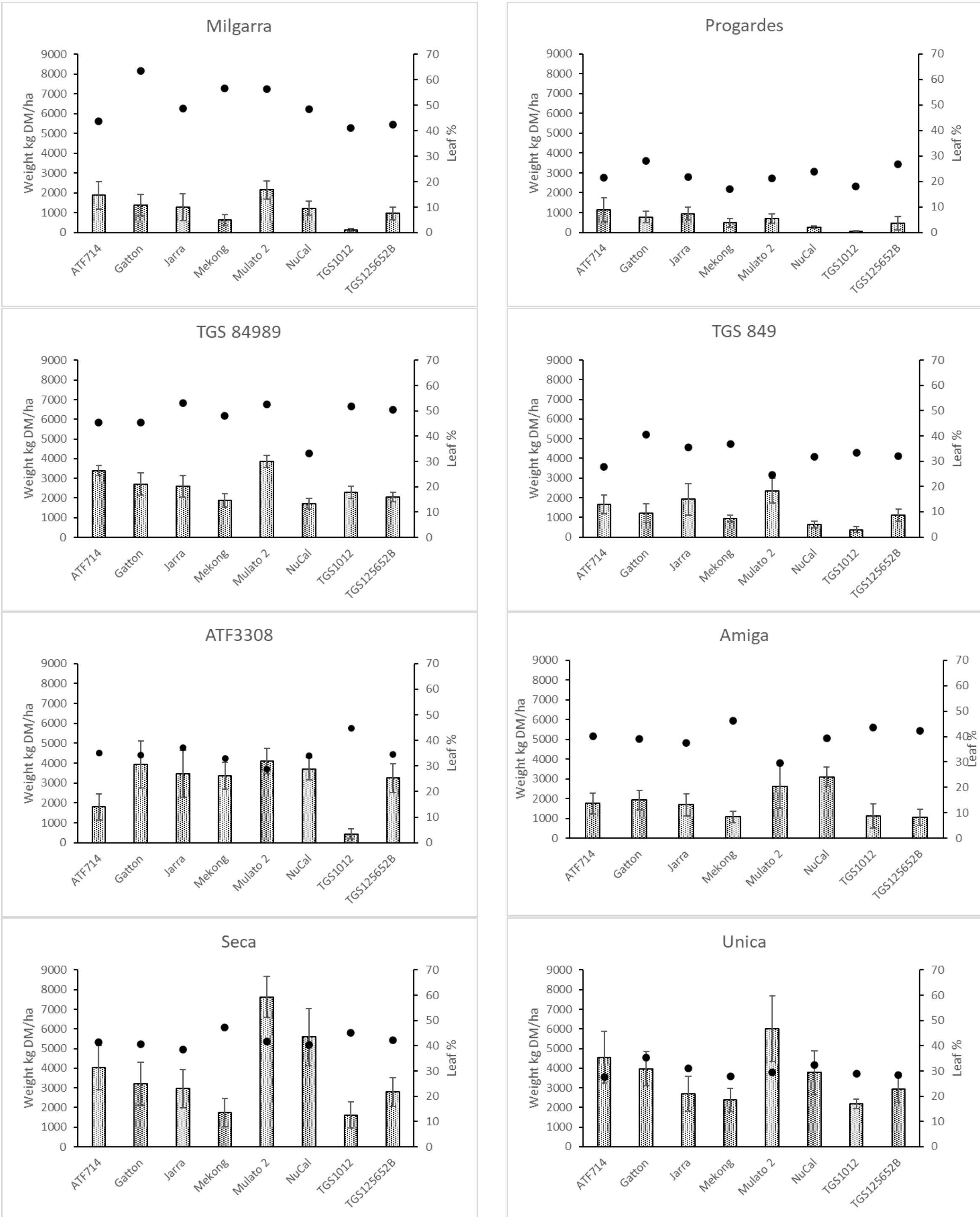


Grasses:
Brachiaria brizantha Mekong
Bothriochloa insculpta TGS125652B
Digitaria milanjiana Jarra
Panicum coloratum ATF714
Panicum maximum Gatton
Panicum hybrid Massai
Urochloa mosambicensis TGS1012
No grass (Mulato 2) *Brachiaria* hybrid

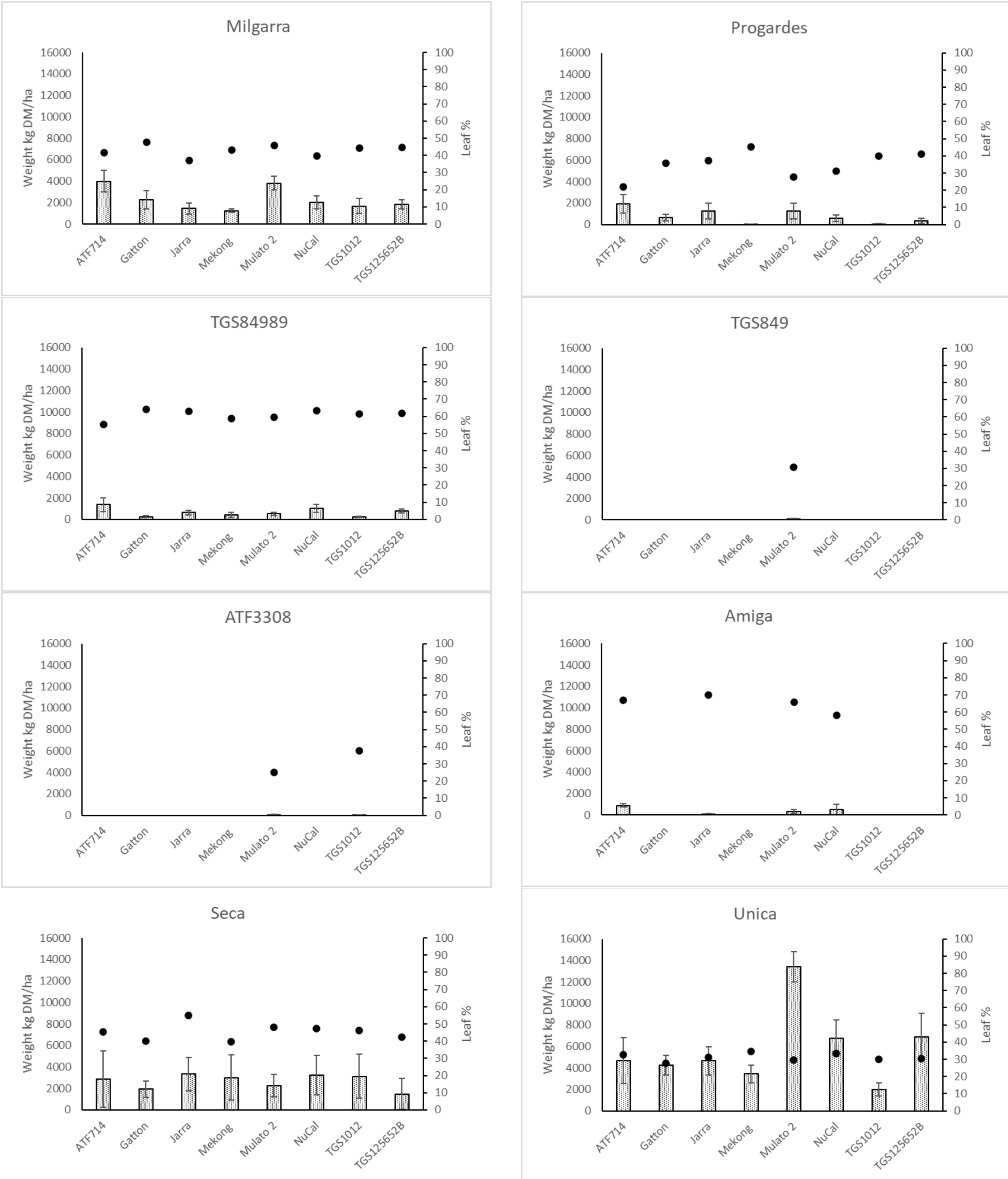
Legumes:
Clitoria ternatea Milgarra
Desmanthus composite Progardes
Mactroptilium atropurpureum TGS84989
Macroptilium gracile TGS849
Stylosanthes guianensis ATF3308
Stylosanthes hamata Amiga
Stylosanthes scabra Seca
Stylosanthes seabrana Unica

Fig. 33 Mean herbage yields and percentage leaf of legumes grown with eight different grasses in small swards at 'Whitewater'. Error bars represent two standard errors of the mean.

6 May 2020



13 May 2021.



Grasses:
Brachiaria brizantha Mekong
Bothriochloa insculpta TGS125652B
Digitaria milanjiana Jarra
Panicum coloratum ATF714
Panicum maximum Gatton
Panicum hybrid Massai
Urochloa mosambicensis TGS1012
No grass (Mulato 2) *Brachiaria* hybrid

Legumes:
Clitoria ternatea Milgarra
Desmanthus composite Progardes
Mactroptilium atropurpureum TGS84989
Macroptilium gracile TGS849
Stylosanthes guianensis ATF3308
Stylosanthes hamata Amiga
Stylosanthes scabra Seca
Stylosanthes seabrana Unica

Table 18 Mean total herbage (grass + legume) yields and percentage legume leaf content of grasses and legumes grown at 'Whitewater', May 2021. The 95% least significance level was used for pairwise comparisons.

Total herbage yield (T DM/ha)

Comparisons are within a row (within a grass variety)

	Clitpria ternatea Milgarra	*Desmanthus* spp. Progardes	*Macroptilium atropurpureum* TGS84989	*Macroptilium gracile* TGS849	*Stylosanthes hamata* Amiga	*Stylosanthes guianensis* ATF3308	*Stylosanthes scabra* Seca	*Stylosanthes seabrana* Unica
Bothriochloa insculpta TGS125652B	5.40 a	4.53 a	5.55 a	4.76 a	6.07 ab	5.11 a	6.46 ab	9.79 b
Brachiaria brizantha Mekong	15.01 e	6.46 c	9.93 cd	13.74 de	1.91 a	2.27 ab	9.17 c	6.01 bc
Digitaria milanjiana Jarra	4.34 a	3.13 a	5.09 a	5.54 a	2.39 a	4.99 a	5.22 a	5.53 a
Panicum coloratum ATF714	6.38 b	3.46 ab	5.43 ab	3.29 ab	1.80 a	3.41 ab	5.08 ab	5.69 ab
Panicum maximum Gatton	5.81 a	5.38 a	7.05 a	8.42 a	7.11 a	7.18 a	4.66 a	8.18 a
Panicum hybrid NuCal	7.87 b	5.16 ab	5.76 ab	3.11 a	4.83 ab	4.63 ab	4.36 ab	7.89 b
Urochloa mosambicensis TGS1012	6.49 a	6.40 a	6.41 a	8.56 a	6.42 a	5.75 a	7.26 a	7.01 a
No grass[1]	3.80 a	1.23 a	0.78 a	0.09 a	1.73 a	0.04 a	2.24 a	13.41 b

Comparisons are down a column (within a legume variety)

	Clitpria ternatea Milgarra	*Desmanthus* spp. Progardes	*Macroptilium atropurpureum* TGS84989	*Macroptilium gracile* TGS849	*Stylosanthes hamata* Amiga	*Stylosanthes guianensis* ATF3308	*Stylosanthes scabra* Seca	*Stylosanthes seabrana* Unica
Bothriochloa insculpta TGS125652B	5.40 ab	4.53 ab	5.55 b	4.76 bc	6.07 bc	5.11 b c	6.46 bc	9.79 bc
Brachiaria brizantha Mekong	15.01 c	6.46 b	9.93 c	13.74 d	1.91 a	2.27 ab	9.17 c	6.01 ab
Digitaria milanjiana Jarra	4.34 ab	3.13 ab	5.09 b	5.54 bc	2.39 ab	4.99 b c	5.22 abc	5.53 a
Panicum coloratum ATF714	6.38 ab	3.46 ab	5.43 b	3.29 ab	1.80 a	3.41 abc	5.08 ab	5.69 a
Panicum maximum Gatton	5.81 ab	5.38 b	7.05 bc	8.42 c	7.11 c	7.18 c	4.66 ab	8.18 ab
Panicum hybrid NuCal	7.87 b	5.16 ab	5.76 b	3.11 ab	4.83 abc	4.63 b c	4.36 ab	7.89 ab
Urochloa mosambicensis TGS1012	6.49 ab	6.40 b	6.41 bc	8.56 c	6.42 c	5.75 b c	7.26 bc	7.01 ab
No grass[1]	3.80 a	1.23 a	0.78 a	0.09 a	1.73 a	0.04 a	2.24 a	13.41 c

[1] These were Mulato2 plots (very low establishment)

Table 18 continued:

Percentage leaf content

	Clitpria ternatea Milgarra	*Desmanthus* spp. Progardes	*Macroptilium atropurpureum* TGS84989	*Macroptilium gracile* TGS849	*Stylosanthes hamata* Amiga	*Stylosanthes guianensis* ATF3308	*Stylosanthes scabra* Seca	*Stylosanthes seabrana* Unica
Mean across grasses	43.52 b	36.70 ab	61.12 c	37.58 ab	66.24 c	33.58 a	44.57 b	31.27 a

The means are predicted means required to complete statistical analysis and very closely approximate the measured values (no transformation required). They serve to illustrate differences between the grass x legume combinations.

Figure 34 The research site at DAF 'Spyglass' (red earth, Charters Towers) in 2021. (top) February (left) grass strips (right) Unica + TGS125652B (middle) August (bottom) November.

4.6 Plant growth - grass-legume combinations at 'DAF Spyglass'

The 7 grass x 9 legume experiment at 'DAF Spyglass', near Charters Towers, was sown on 5 February 2020 under favourable growing conditions. Grasses dominated the plots initially and management during 2022 sought to increase legume content. The plots were slashed in October 2020 to 're-set' growth for the first true growing season and this was repeated in mid-December 2021 after grazing beginning in May. Growing conditions were excellent in all years with annual values surpassing the long-term average (556 mm) and median (509) rainfall (Table 12).

Changes in cover and plant growth stage were collected over two full growing seasons after establishment and biomass was assessed in second season as for 'Whitewater' (Table 19). An early start (December) and drying phase in March (resulting in some grasses beginning to hay off) prompted biomass assessments on 16 March 2021, although a further 90 mm fell in April after sampling (Fig. 34). Grazing began in May. Biomass sampling was not conducted during 2022 because the experiment was grazed twice over the wet season to suppress competition from grasses and sampling would have provided results of limited use.

4.6.1 Plant persistence and cover

Splines of green cover, along with mean initial plant populations are presented in Figures 35 and 36 with statistical analysis in Appendix 10.19. Grass cover at the end of the growing season varied considerably with some grasses dominating plots e.g. TGS1012 *Urochloa* mosambicensis (74% ground cover) and Mekong *Brachiaria brizantha* (44%) with the others ranging from 9 to 24% (see Section 4.2.2). Legume cover was low overall and less than 20% of ground cover in all plots. Legumes with the highest cover at the end of the first season were Amiga and Unica stylos.

Live (green) grass cover increased for all grasses in the first growing season reaching close to 100% for TGS1012 by March and 50-75% for most of the others (Fig. 36). ATF714 *Panicum coloratum* was the least dominant grass. Cover declined thereafter with drying conditions and grazing during 2021 but increased again by March 2022 despite the wet season grazing. Overall, the grasses remained dominant at this site by the end of the 2021-22 wet season.

The legumes continued to have relatively low cover values after grazing in 2021-22. The stylos (Amiga, Seca and Unica) had the highest legume covers, but none of these exceeded 50%, even when grown with ATF714, the grass with lowest cover. Legume cover was highest, overall, when legumes were grown with ATF714 (low cover), although Unica stylo grew well in combination with TGS125652B *Bothriochloa insculpta* and Jarra *Digitaria milanjiana*. Amiga, Seca and Unica *Stylosanthes* were the only legumes with covers above 20% (in March 2021) prior to grazing) when grown with TGS1012 and TGS125652B, but these also declined the next year after grazing. Cover measurements were ceased in March 2022 in preparation for this report. It is considered likely that legume cover would increase as grasses hay off in the dry season and the legumes maintain growth.

There were no significant grass x legume interactions on grass or legume cover over the duration of the experiment. However, the three-way interaction of grass x legume x time was significant (P = 0.02) for legume cover, indicating potential competition effects of grasses on legumes at certain times. Interactions for legume and grass cover were highly significant between grasses and between legumes and at different sampling times (Appendix 10.19).

Fig. 35 The effect of grass competition on legume plant populations and cover, 'DAF Spyglass'.

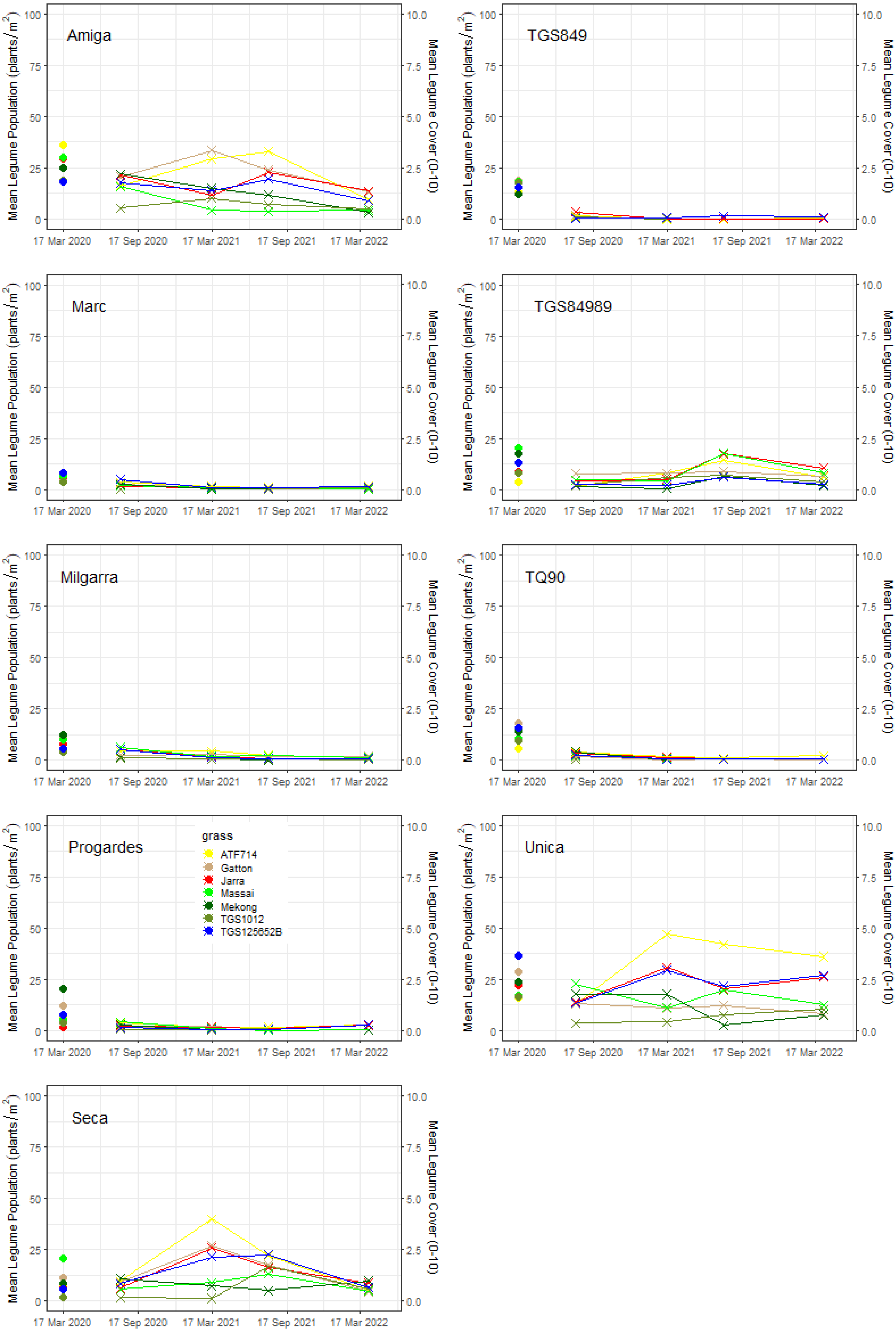
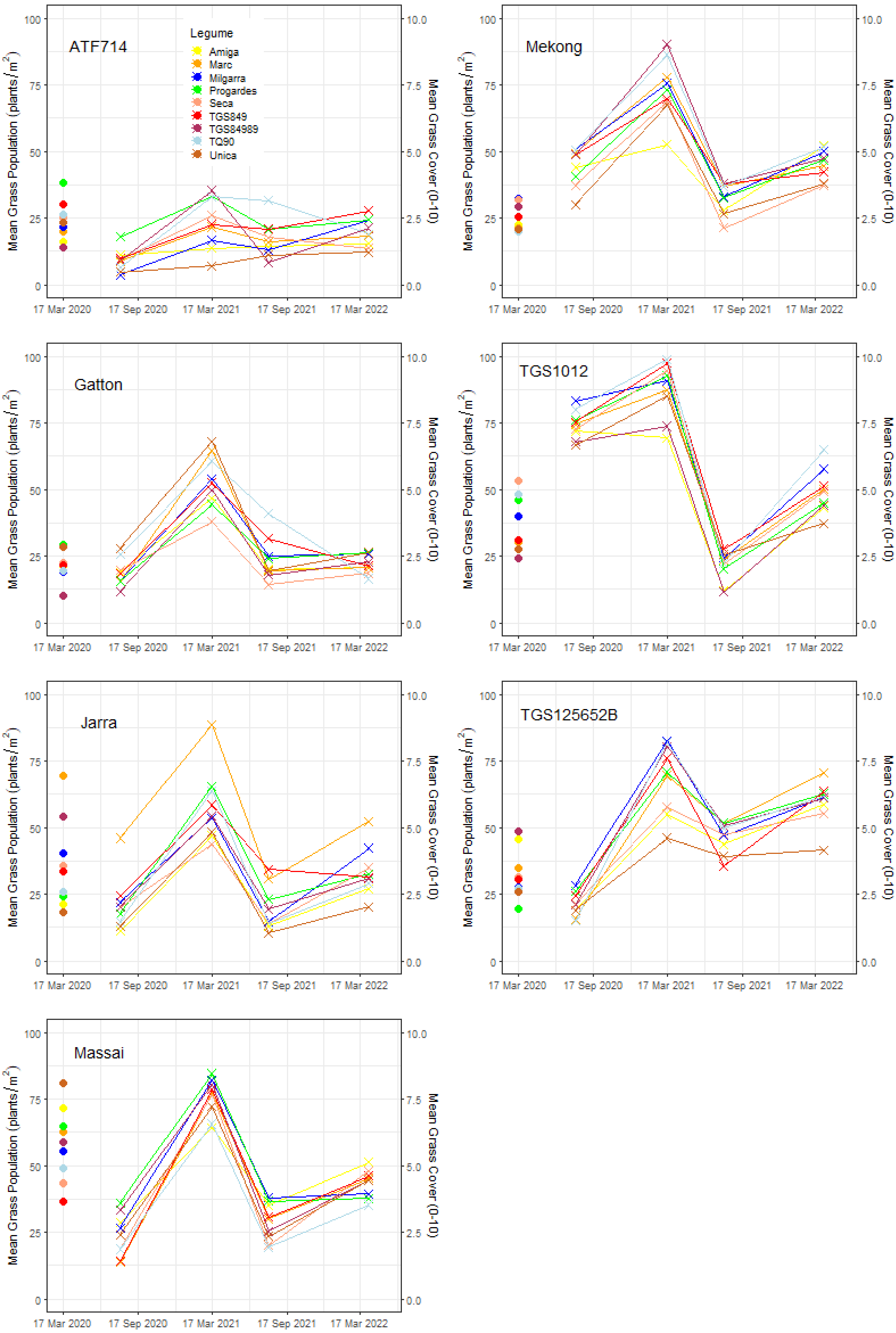


Fig. 36 The effect of legume competition on grass plant populations and cover, 'DAF Spyglass'.



4.6.2 Herbage yield

Plant biomass was sampled on 16 March 2021: grass and legume yields are presented in Figs. 37 and 38, and the statistical analysis in Appendix 10.20. Grass yields were very high, in the order of 4-5 T DM/ha for Mekong *Brachiaria brizantha*, Massai and Gatton *Panicum* spp. and 2-4 T DM/ha for TGS1012 *Urochloa mosambicensis*, TGS125652B *Bothriochloa insculpta* and Jarra *Digitaria milanjiana*. ATF714 *Panicum coloratum* yielded lowest (1-2 T DM/ha), as it did at 'Whitewater', for most combinations. Differences in grass yields pooled across companion legumes were significantly higher for the erect 'tussock' forming grasses (Mekong, Massai and Gatton).

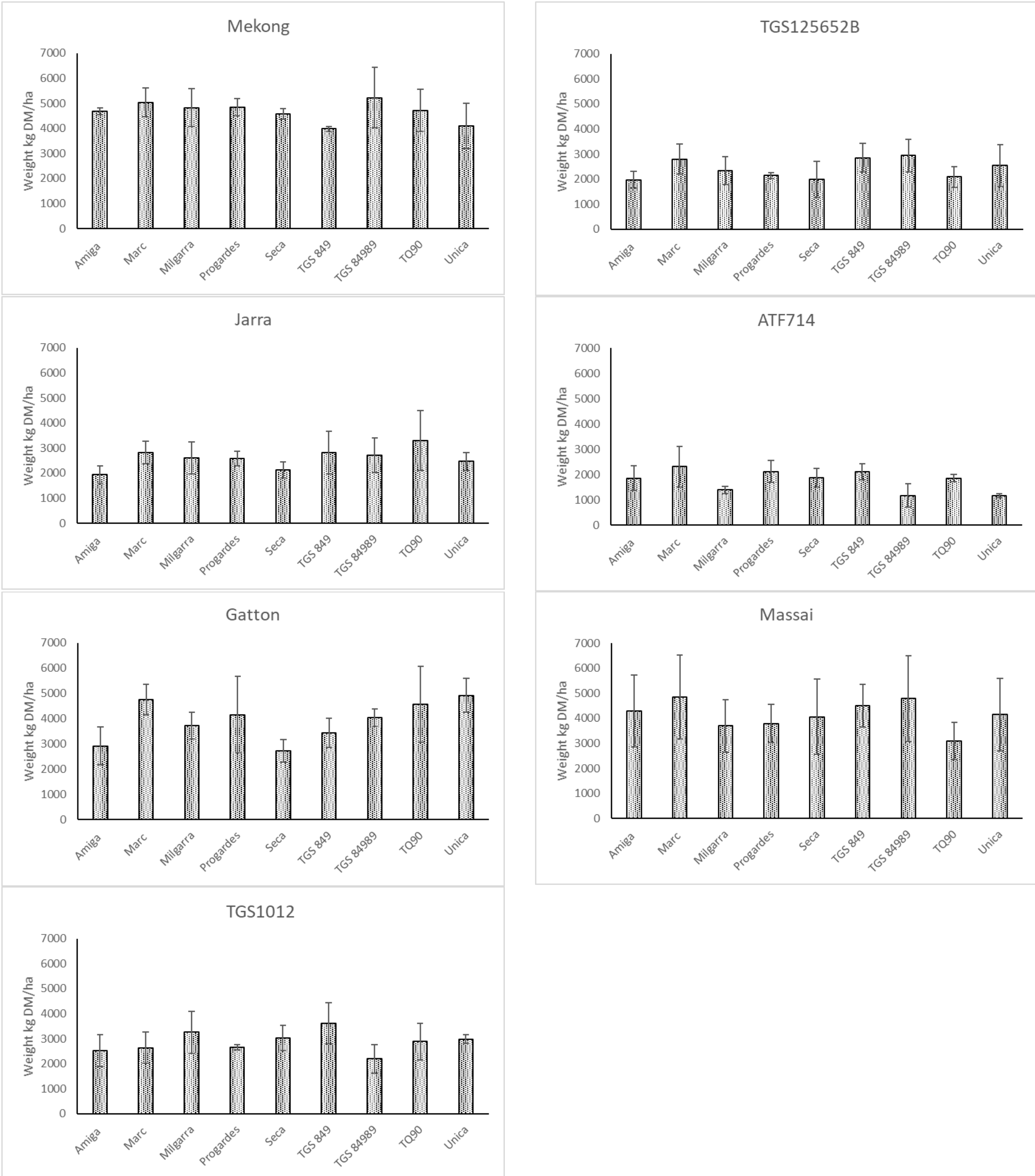
In contrast, legume yields were low, mostly less than 200 kg DM/ha. The notable exceptions were Unica (500 -1500 kg DM/ha), Seca (up to 1000) and Amiga (up to 500) stylos. The highest yielding legume treatment was Unica growing with either Jarra or TGS 125652B. Trends in percentage legume leaf were similar to those at 'Whitewater', being highest in the TGS 849 and TGS 84989 *Macroptilium* spp. (~60%), next highest in Milgarra *Clitoria ternatea* and Amiga *Stylosanthes hamata* (~40%) and lowest in the other *Stylosanthes* and *Desmanthus* spp.. Again, Unica had higher biomass yields but lower percentage of leaf than Seca or Verano (Fig. 38, Table 19).

Total plant biomass (dominated by grass) ranged from ~1.9 to 5.3 T DM/ha depending on the combination of grass and legume (Table 19) and was highest in the Gatton x Unica and Mekong x TGS 84989 treatments, although there were many combinations over 4 T DM/ha. The combinations with the highest legume yields, Unica x Jarra and Unica x TGS 125652B yielded 4.0 and 3.9 T DM/ha respectively.

There was a relatively weak grass x legume interaction for Legume biomass (herbage yield), but a stronger interaction for grass biomass (likely reflecting the strong influence of grass type on grass biomass (Appendix 10.20). Low legume biomass probably contributed to no measurable influence on grass yield, whereas the type of grass did appear to influence legume yield: e.g. Seca and Unica yields were low when grown with TGS1012, Mekong or Massai compared to the other grasses. Interestingly, they produced relatively high yields when grown with TGS125652B, another dominant grass.

The analysis of variance showed significant main effects for total biomass (grass + legume), grass biomass and legume biomass, but no significant interactions i.e. combinations of grass and legume (Appendix 10.19). Pooled total biomass was found to be significantly higher in plots containing Mekong, Massai or Gatton (~4.1-4.7 T DM/ha), simply reflecting the growth of these lines. The kind of legume, however, had no measurable effect on total biomass. As expected, pooled grass biomass differed significantly between lines, but was not influenced by legume type. Pooled legume biomass was, however, influenced by grass type, being highest in combination with ATF714 compared to Massai, Mekong and TGS1012.

Fig. 37 Mean herbage yields of grasses grown with nine different legumes in small swards at 'Spyglass' (red earth, Charters Towers), sampled 16 March 2021. Error bars represent two standard errors of the mean.



Grasses:
Brachiaria brizantha Mekong
Bothriochloa insculpta TGS125652B
Digitaria milanjiana Jarra
Panicum coloratum ATF714
Panicum maximum Gatton
Panicum hybrid Massai
Urochloa mosambicensis TGS1012

Legumes:
Clitoria ternatea Milgarra
Desmanthus virgatus Marc
Desmanthus composite Progardes
Desmanthus leptophyllus TQ90
Macroptilium atropurpureum TGS84989
Macroptilium gracile TGS849
Stylosanthes hamata Amiga
Stylosanthes scabra Seca
Stylosanthes seabrana Unica

Fig. 38 Mean herbage yields of legumes grown with seven different grasses in small swards at 'DAF Spyglass', sampled 16 March 2021. Error bars represent two standard errors of the mean.

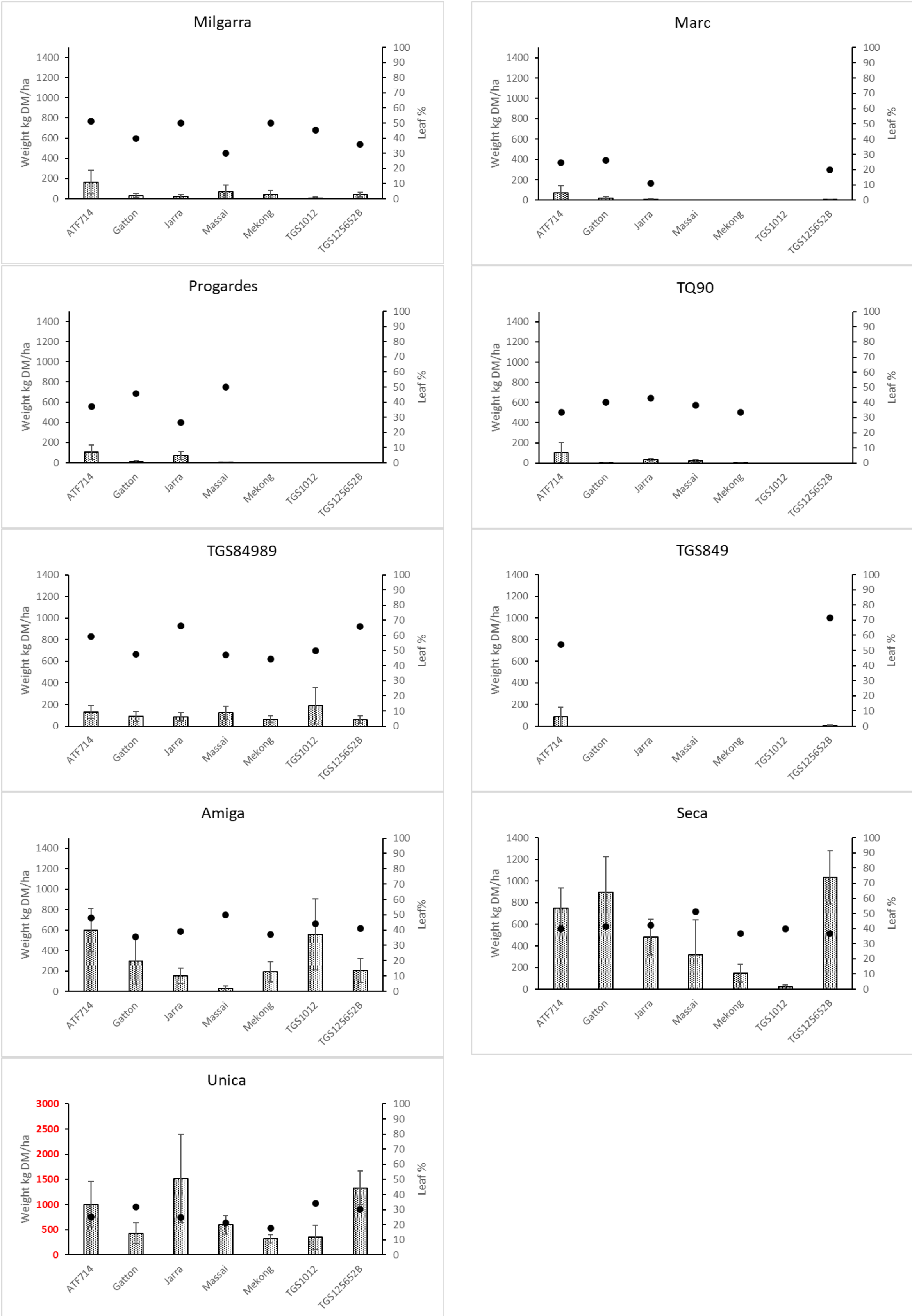


Table 19 Mean total herbage (grass + legume) yields and percentage legume leaf content of grasses and legumes grown at 'DAF Spyglass', March 2021.

Total herbage yield (T DM/ha) (no transformation required)

	Clitpria ternatea Milgarra	*Desmanthus* spp. Progardes	*Desmanthus leptophyllus* TQ90	*Desmanthus virgatus.* Marc	*Macroptilium atropurpureum* TGS84989	*Macroptilium gracile* TGS849	*Stylosanthes hamata* Amiga	*Stylosanthes scabra* Seca	*Stylosanthes seabrana* Unica
Bothriochloa insculpta TGS125652B	2.38	2.14	2.09	2.80	2.00	2.85	2.17	3.02	3.87
Brachiaria brizantha Mekong	4.87	4.84	4.71	5.04	5.28	3.98	4.87	4.72	4.42
Digitaria milanjiana Jarra	2.64	2.64	3.34	2.82	2.81	2.82	2.08	2.62	3.98
Panicum coloratum ATF714	1.55	2.22	1.96	2.38	1.30	2.20	2.46	2.63	2.16
Panicum maximum Gatton	3.76	4.17	4.57	4.77	4.13	3.44	3.21	3.62	5.35
Panicum hybrid Massai	3.76	3.80	3.12	4.85	4.90	4.50	4.31	4.37	4.75
Urochloa mosambicensis TGS1012	3.27	2.66	2.88	2.64	2.39	3.62	3.08	3.05	3.34

LSD (0.95%) between: grass = 1.08; legume = 0.59; grass x legume = 1.78

Percentage leaf content

Legume	*Clitpria ternatea* Milgarra	*Desmanthus* spp. Progardes	*Desmanthus leptophyllus* TQ90	*Desmanthus virgatus.* Marc	*Macroptilium atropurpureum* TGS84989	*Macroptilium gracile* TGS849	*Stylosanthes hamata* Amiga	*Stylosanthes scabra* Seca	*Stylosanthes seabrana* Unica
Mean across grasses	42.6 b	38.0 b	38.4 c	19.8 a	60.4 c	54.3 c	40.7 b	39.9 b	26.1 a

95% LSD = 10.27

4.7 Pasture feed quality

4.7.1 Plant growth over the season

The development (progress towards seeding) and haying-off of all grasses and legumes were recorded over a series of wet and dry seasons and are summarised in Appendix 10.21. Grass and legume growth started from essentially dormant plants each year with the first substantial rainfall of the wet season, (December or January). Flowering tended to be late (May-June) in the year of establishment as sowing was conducted in mid- to late- wet season. Thereafter, flowering tended to be earlier for most grasses and legumes with timing depending on the onset of the wet season. The notable exceptions were the grasses and legumes with stronger apparent photoperiodic controls for flowering (under longer nights), including: *Grasses* – Mekong *Brachiaria brizantha,* Massai and NuCal *Panicum* hybrids (very late) and (slightly earlier) TGS125652B *Bothriochloa insculpta*; *Legumes* – Nina (ATF3308) *Stylosanthes guianensis* and TGS84989 *Macroptilium atropurpureum*. Very early flowering types included: *Grasses* – ATF714 *Panicum coloratum* and TGS1012 *Urochloa mosambicensis; Legumes* – TGS849 *Macroptilium gracile* and Milgarra *Clitoria ternatea*.

Haying off was earlier in the grasses than for the legumes and the legumes consistently had lower hay-off ratings as the dry season progressed. The exception was TGS849 *M. gracile* which tended to die off after flowering as conditions became dry. Most grasses had hayed off and were dormant by August-September and did not resume growth until higher rainfalls (typically storms). The legumes, however, maintained green leaf until this time and some continued to produce new leaves (TGS84989 *M. atropurpureum*). The *Desmanthus* lines rapidly resumed leaf production after rainfall, although also tended to shed leaves as conditions became dry. The *Stylosanthes* plants tended to retain leaf, but were slower to respond to rainfall. All plants (grasses and legumes) tended to be dormant by October/November, with no appreciable growth unless there were early storms.

Pasture feed quality was monitored over the growing seasons as the plants matured. Herbage samples were collected during the wet (February / March) and dry (May / June) seasons at a range of sites during 2020 and 2021. Sampling was always conducted when there was an appreciable amount of feed present and the plants were reasonably mature (i.e. not on very young growth following grazing or early season rainfall). The samples were dried (70°C) to constant weight: the legumes were separated into leaf and stem fractions and weighed separately. The grasses were weighed as whole samples. Key feed quality indices for all samples are presented in Appendix 10.22 and selected data are described below with particular emphasis on crude protein (a proxy for nitrogen content) and metabolisable energy (a proxy for digestibility) contents as these influence feed intake and therefore growth.

4.7.2 Grasses vs legumes

The grasses were of poorer feed quality than the legumes (Table 20). Crude protein levels of whole (stem + leaf) samples were higher in the wet season than the dry season but always below values considered beneficial for ruminant growth (6-7%). Metabolisable energy levels approached the levels required for cattle maintenance and growth (7.5-8%). Dietary selection for leaf, particularly in the wet season, would be required to achieve moderate levels of growth.

The crude protein and metabolisable energy contents of grasses and legumes sampled in May (when first round weaning is often conducted) on two soil types at 'Junction Creek' near Charters Towers are presented in Fig. 39. All represent whole plant samples (leaf + stem). The feed quality of the grasses (dots) by May (previously ungrazed) was generally poor with crude protein levels below 6%

and metabolisable energy levels below 7 MJ/kg. The highest quality grasses included *Brachiaria* (Mulato 2), *Digitaria* (Jarra) and *Panicum* (NuCal/Massai, Gatton, Bambatsi, ATF714). In comparison, whole plant samples of legumes collected at 'Junction Creek' had higher crude protein content (7-13%) with similar or slightly higher metabolisable energy levels: the twining legumes TGS84989, Juanita and Milgarra were of higher quality than the shrub legumes although Amiga stylo was also of relatively high quality. Similar results were measured at 'Whitewater', a more fertile environment, at the same time (Fig. 40). Here, legumes were split into leaf (triangle) and stem (dots) components. The stems had similar feed value to the grasses, whereas the leaves of all legumes were of high feed value (15-21% crude protein and 8-10 MJ/kg metabolisable energy). Again, the twining legumes (and Amiga stylo) tend to be of higher quality, having higher levels of metabolisable energy and/or protein than the shrub legumes (Desmanthus and most Stylosanthes).

4.7.3 Legume feed quality

Additional analyses were conducted to assess legume feed quality of the better performing legumes and the influence of sampling (eating) time and leaf and stem components on this (Appendix 10.23). The data were grouped based on sample time into 'wet' (January-March) and 'dry' (May-August) seasons. Data were sourced from B.NBP.0766 and B.NBP.0812 and included samples collected during herbage yield assessments from a range of growing environments (soil type and rainfall) over six years. Key results are summarised in Tables 22 and 23.

Legume leaf quality (crude protein and metabolisable energy) was considerably higher than stem for all legumes (Table 22). Leaf feed quality pooled across all sampling times exceeded those required for moderate levels of animal growth. Legumes of particularly high feed quality included *Clitoria ternatea* and *Stylosanthes hamata*. *Desmanthus* leaf had particularly high levels of metabolisable energy. The protein contents of legume stems were also relatively high (compared to grasses) in the twining legumes and *S. hamata*, but not for the other legumes.

Pooled analysis comparing the influence of component and sample time on crude protein contents revealed samples collected in the wet season had significantly higher leaf and stem values than those collected in the dry season (Appendix 10.23). This was in the order of only 10% for leaves, but 40% for stems, presumably reflecting the relatively immature level of stem development in the wet season compared to later in the year. Similar analyses for metabolisable energy revealed no significant differences between wet and dry season growth.

The above data illustrate the importance of considering leaf and stem components when estimating the amounts of useful feed for cattle at different times of the year. Expected values of crude protein and metabolisable energy for leaf and stem components of the key legumes studied are presented for reference in Table 23. These enable a reasonable estimate for feed quality for samples collected in the wet or dry seasons by separating dried leaf and stem when estimating herbage yields (relatively easy to do).

Table 20 Key feed quality indices of grasses sampled during 2020 and 2021.

Species	Crude protein (%)	Acid Digestible Fibre (ADF) (%)	Neutral Digestible Fibre (NDF) (%)	Lignin (%)	Non-fibre carb. (%)	Metab. energy (ME) (MJ/kg)
Bothriochloa insculpta						
Wet	5.0	45.2	68.6	5.0	15.7	6.59
Dry	2.9	44.2	71.9	4.8	14.6	5.91
Bothriochloa pertusa						
Wet	4.4	37.4	66.4	4.1	18.8	6.92
Dry	3.0	42.8	69.7	4.4	16.6	6.46
Brachiaria brizantha						
Wet	6.5	43.4	68.9	4.8	13.9	6.69
Dry	4.0	40.9	71.0	4.8	14.4	6.16
Brachiaria decumbens						
Wet	3.3	40.4	71.1	4.5	15.1	6.20
Dry	2.6	43.4	74.6	5.9	12.3	5.26
Brachiaria hybrid						
Wet	5.8	33.3	63.4	3.2	20.3	7.64
Dry	3.8	37.8	68.1	4.2	17.5	6.78
Cenchrus ciliaris						
Wet	5.2	40.6	65.7	3.9	18.6	7.21
Dry	3.5	45.6	70.8	4.2	15.1	6.34
Chloris gayana						
Wet	4.6	43.0	74.1	4.6	10.9	5.34
Dry	2.9	45.7	75.8	5.9	10.6	4.95
Dichanthium aristatum						
Wet	4.2	38.2	68.6	2.9	16.8	6.85
Dry	2.1	43.8	71.8	4.1	15.5	6.15
Dichanthium sericeum						
Dry	2.9	47.1	73.6	4.8	12.7	5.77
Digitaria eriantha						
Dry	2.9	41.8	69.7	3.7	16.8	6.49
Digitaria milanjiana						
Wet	5.1	44.3	69.3	4.7	14.9	6.55
Dry	4.5	39.1	66.0	4.4	18.9	7.08
Heteropogon contortus						
Wet	3.9	42.2	71.0	4.3	14.6	6.20
Dry	2.7	48.2	72.7	5.9	14.1	5.70
Panicum coloratum						
Wet	5.4	40.3	69.0	5.6	14.9	6.43
Dry	4.4	39.3	69.8	5.3	15.1	6.28
Panicum hybrid						
Wet	6.0	43.0	67.8	4.4	15.5	6.92
Dry	4.1	41.7	71.2	4.0	14.1	6.28
Panicum maximum						
Wet	5.1	46.2	70.4	5.4	13.8	6.22
Dry	4.0	45.0	69.4	5.5	16.1	6.26
Urochloa mosambicensis						
Wet	5.3	43.8	68.4	5.3	15.5	6.61
Dry	3.9	39.7	67.9	4.5	17.6	6.73

Table 21 Key feed quality indices of legumes sampled during 2020 and 2021.

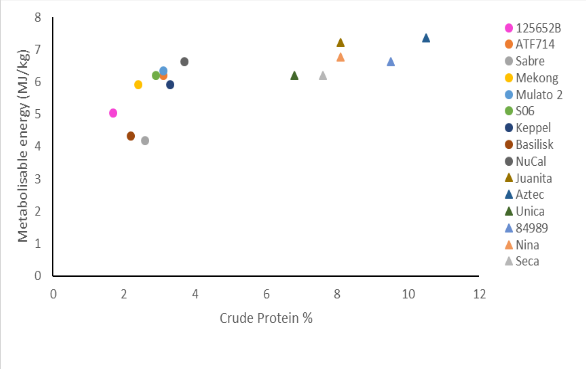
Species	Crude protein (%)	Acid Digestible Fibre (ADF) (%)	Neutral Digestible Fibre (NDF) (%)	Lignin (%)	Non-fibre carb. (%)	Metab. energy (ME) (MJ/kg)
Centrosema brasilianum						
Wet						
Whole	12.1	44.0	53.7	13.7	23.7	6.92
Dry						
Whole	8.4	39.5	47.5	9.3	33.6	8.08
Clitoria ternatea						
Wet						
Leaf	18.6	34.8	46.6	9.4	24.4	8.29
Stem	12.4	51.3	68.6	12.0	8.6	5.38
Whole	16.9	40.3	49.7	10.2	22.9	7.79
Dry						
Leaf	20.3	32.6	44.9	7.0	24.1	9.04
Stem	10.1	52.3	66.8	12.9	12.4	5.67
Whole	13.1	45.3	59.7	11.2	16.7	6.68
Desmanthus spp.						
Wet						
Leaf	14.1	17.4	27.2	7.3	48.2	10.24
Stem	7.1	53.2	63.2	13.4	19.2	5.87
Whole	10.3	40.0	42.7	14.0	36.5	7.86
Dry						
Leaf	16.5	23.8	29.1	10.0	43.7	9.76
Stem	6.0	54.6	65.8	13.4	17.7	5.57
Whole	7.7	50.8	60.2	14.7	21.5	6.16
Macroptilium atropurpureum						
Wet						
Leaf	17.3	38.9	49.9	8.2	22.3	8.15
Stem	12.6	52.5	68.7	12.5	8.3	5.34
Whole	14.4	41.9	52.3	10.3	22.8	7.57
Dry						
Leaf	15.7	37.8	47.4	8.6	26.3	8.51
Stem	9.3	50.2	61.2	11.4	18.8	6.59
Whole	13.0	46.0	54.8	11.3	21.6	7.19
Macroptilium bracteatum						
Wet						
Whole	13.6	42.0	52.3	9.2	23.7	7.71
Dry						
Leaf	11.2	44.0	50.2	10.5	28.0	7.64
Stem	5.8	60.1	64.9	12.4	18.9	5.77
Whole	9.0	48.0	56.4	10.2	23.8	7.35
Macroptilium gracile						
Wet						
Whole	19.7	29.1	39.1	7.0	30.7	9.37
Dry						
Leaf	14.7	35.7	45.4	7.7	29.2	8.94
Stem	8.0	44.8	53.7	8.6	27.5	7.93
Whole	17.3	43.4	52.9	10.4	19.2	7.50

Cont.

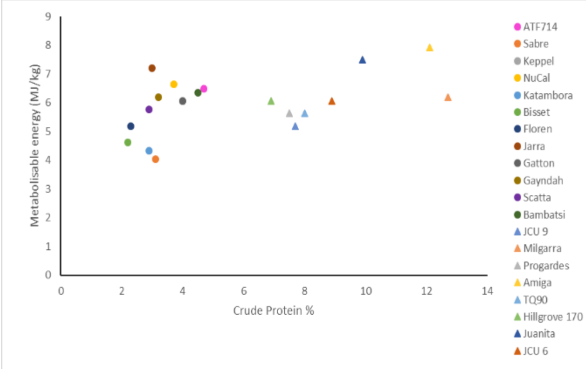
Species	Crude protein (%)	Acid Digestible Fibre (ADF) (%)	Neutral Digestible Fibre (NDF) (%)	Lignin (%)	Non-fibre carb. (%)	Metab. energy (ME) (MJ/kg)
Stylosanthes guianensis						
Wet						
Whole	10.2	49.5	59.1	12.1	20.2	6.49
Dry						
Leaf	13.6	38.6	49.3	10.3	26.4	8.00
Stem	6.8	62.0	69.5	12.2	13.1	5.23
Whole	8.1	51.2	60.3	11.5	20.7	6.78
Stylosanthes hamata						
Wet						
Leaf	16.9	29.1	44.7	6.9	27.9	8.83
Stem	11.8	49.0	58.8	10.3	18.9	6.81
Dry						
Leaf	17.4	33.1	43.5	6.9	28.4	9.30
Stem	9.7	50.8	58.8	10.4	20.7	7.07
Whole	13.1	42.0	51.7	9.3	24.6	7.83
Stylosanthes scabra						
Wet						
Leaf	16.0	29.2	39.6	7.4	33.9	9.20
Stem	8.0	58.4	69.6	12.7	11.9	4.99
Whole	9.5	44.7	52.6	9.9	27.4	7.57
Dry						
Leaf	13.9	35.2	41.9	10.7	33.6	8.53
Stem	6.5	57.0	68.5	13.2	14.4	5.21
Whole	8.9	50.6	61.0	11.9	19.6	6.42
Stylosanthes seabrana						
Wet						
Leaf	16.5	31.4	44.8	8.0	28.3	8.68
Stem	7.8	57.2	70.0	13.8	11.6	4.87
Whole	11.1	46.6	57.1	12.4	21.4	6.71
Dry						
Leaf	15.7	33.8	45.0	9.2	28.7	8.51
Stem	6.2	56.8	69.1	13.8	14.1	5.10
Whole	8.8	49.0	61.0	12.2	19.6	6.34
Stylosanthes viscosa						
Wet						
Whole	15.8	38.0	45.7	9.7	28.0	8.22
Dry						
Leaf	12.8	33.5	39.3	7.9	37.4	9.08
Stem	6.6	52.6	62.1	12.6	20.8	6.06

Fig. 39 The relationship between metabolisable energy and crude protein of grasses (circles) and legumes (triangles) sampled at 'Junction Creek' (red and black basalt, Charters Towers) on 20 May 2020.

Red basalt



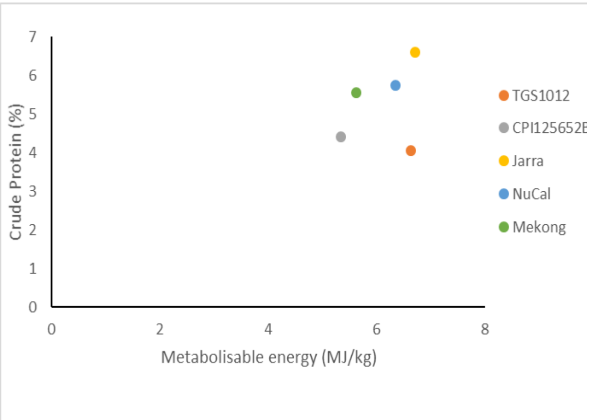
Black basalt

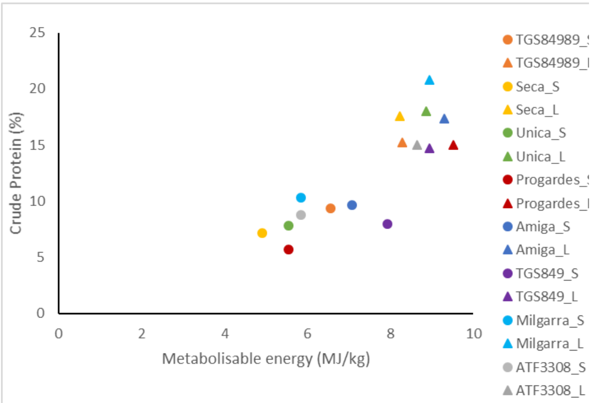


Grasses
Bothriochloa insculpta TGS125652B, Bisset
Bothriochloa pertusa Keppel
Brachiaria brizantha Mekong
B. decumbens Basilisk
Brachiaria hybrid Mulato2
Cenchrus ciliaris Gayndah
Chloris gayana Sabre, Katambora
Digitaria milanjiana Jarra
Dichanthium sericeum Scatta
D. aristatum Floren
Heteropogon contortus S06
Panicum coloratum ATF714
Panicum hybrid NuCal/Massai
Panicum maximum Gatton
Urochloa mosambicensis

Legumes
Clitoria ternatea Milgarra
Desmanthus spp. Progardes, TQ90, JCU6, JCU9, Hillgrove170
Macroptilium atropurpureum Aztec, TGS84989
M. bracteatum Juanita
M. gracile TGS849
Stylosanthes hamata Amiga
S. guianensis Nina (ATF3308)
S. scabra Seca
S. seabrana Unica

Fig. 40 The relationship between metabolisable energy and crude protein of grasses and legumes sampled at 'Whitewater' (red basalt, Mt. Surprise) on 6 May 2020.





Grasses
Bothriochloa insculpta TGS125652B
Brachiaria brizantha Mekong
Digitaria milanjiana Jarra
Panicum coloratum ATF714
Panicum hybrid NuCal/Massai
Urochloa mosambicensis

Legumes
Clitoria ternatea Milgarra
Desmanthus spp. Progardes
Macroptilium atropurpureum TGS84989
M. gracile TGS849
Stylosanthes hamata Amiga
S. guianensis ATF3308
S. scabra Seca
S. seabrana Unica

Table 22 Predicted means of legume protein and energy content of stem and leaf components based on multi-site data collected over six years in north Queensland

Crude protein (% dry weight)

Legume species	Leaf		Stem	
Clitoria ternatea	18.64	a	9.83	f
Desmanthus spp.	14.09	de	6.45	g
Macroptilium atropurpureum, M. gracile	15.42	bc	9.52	f
Stylosanthes guianensis	13.78	ce	6.95	g
S. hamata	16.23	b	10.21	f
S. scabra	14.79	bcd	7.46	g
S. seabrana	15.92	b	6.85	g

Average 95% LSD = 1.68

Metabolisable energy (MJ/kg DM)

Legume species	Leaf		Stem	
Clitoria ternatea	8.45	bc	5.11	f
Desmanthus spp.	9.67	a	5.73	e
Macroptilium atropurpureum, M. gracile	8.28	c	5.85	e
Stylosanthes guianensis	8.14	bc	5.36	e
S. hamata	8.84	bc	6.84	d
S. scabra	8.98	b	5.06	f
S. seabrana	8.59	bc	4.89	f

Average 95% LSD = 0.72

Table 23 Predicted mean protein and energy contents of legume components sampled during the wet (January-March) and dry (May-August) seasons based on multi-site data collected over six years in north Queensland.

Crude protein (% dry weight)

Legume species	Component	Wet season	Dry season
Clitoria ternatea	Leaf	19.4	17.9
	Stem	11.3	8.4
Desmanthus spp.	Leaf	14.0	14.1
	Stem	7.1	5.8
Macroptilium atropurpureum, M. gracile	Leaf	17.1	13.8
	Stem	11.9	7.2
Stylosanthes guianensis	Leaf	-	13.8
	Stem	-	7.0
S. hamata	Leaf	17.1	15.4
	Stem	11.8	8.7
S. scabra	Leaf	15.1	14.5
	Stem	8.5	6.4
S. seabrana	Leaf	16.1	15.7
	Stem	7.8	5.9

Metabolisable energy (MJ/kg DM)

Legume species	Component	Wet season	Dry season
Clitoria ternatea	Leaf	8.50	8.40
	Stem	4.87	5.34
Desmanthus spp.	Leaf	10.09	9.25
	Stem	5.86	5.59
Macroptilium atropurpureum, M. gracile	Leaf	7.98	8.59
	Stem	5.26	6.44
Stylosanthes guianensis	Leaf	*	8.14
	Stem	*	5.36
S. hamata	Leaf	8.89	8.79
	Stem	6.60	7.08
S. scabra	Leaf	9.08	8.88
	Stem	4.87	5.25
S. seabrana	Leaf	8.59	8.57
	Stem	4.61	5.16

4.8 Selection by cattle

Grazing was conducted during 2020, 2021 and 2022 at 'Junction Creek' and 'Whitewater' and 2021 and 2022 at 'DAF Spyglass' (Table M10). Grazing was conducted May to August mostly using weaners and cattle removed when it was considered most leaf had been removed plus small stems. Grazing was conducted over the wet season at 'DAF Spyglass' during 2022 to suppress grass growth in an attempt to encourage legumes. Grazing ratings were completed after each grazing event: the grass and/or legume in each plot was rated for grazing pressure on a whole-plot basis with '0' being completely untouched and '5' grazed to crowns in more than 80% of plants (Table M9). Grazing rating values over 3 (80% of plants eaten including leaves and small stems) were considered to represent palatable plants. Hay-off ratings were recorded and used as a covariate for grazing level.

4.8.1 Small-plot adaptation studies – 'Junction Creek'

The small-plot studies enabled the comparison of a wide range of grasses and legumes with 'standards' for the land-types. Data are only presented here for 2020 as the values in 2021 were very similar. The 2020 season was extended by useful (59 mm) May rainfall which prolonged plant growth. Please refer to Appendix 10.25 for summarised data.

The grasses and legumes had moderate to high hay-off ratings by the time they were grazed in August and had all set seed. Despite the advanced growth stages, the grasses were all well-grazed at both sites, and to crowns in most instances (Fig. 41). The notable exceptions were S06 black speargrass (*H. contortus*) (red site) and Medway Indian couch (*B. pertusa*) (both sites). Keppel Indian couch was also poorly grazed on the black soil site along with Bisset *B. insculpta*9 (Fig. 42). All of these lines were stemmy (reproductive stems) and had high hay-off ratings.

Rankings of grazing rating are presented in Appendices 8.25. Grasses with high grazing levels covered a wide range of taxa indicating most are highly palatable. The apparent low palatability of black speargrass and Indian couch compared to the other grasses has implications for the management of sown grass pastures where these species are widely naturalised.

The legumes were all at advanced hay-off stages when grazed and some (notably *Macroptilium and Desmanthus* lines) had shed leaves. All legumes were grazed and there was less variability between lines at the advanced growth stages: there were very few green legume leaves left in the plots after grazing. In some legumes (notably *Desmanthus*) new shoots growing from crowns were protected by thicker stems (the thinner stems having been grazed) (Fig. 41). The legumes were grazed more completely on the red soil site, overall. Some stemmy legumes which had shed leaves (e.g. JCU 6, a large *Desmanthus*) were poorly grazed at the black soil site, but well grazed at the red soil site. Overall, the most grazed were the twining herbaceous legumes (*Centrosema, Clitoria* and *Macroptilium*) and the smaller less-woody stylos.

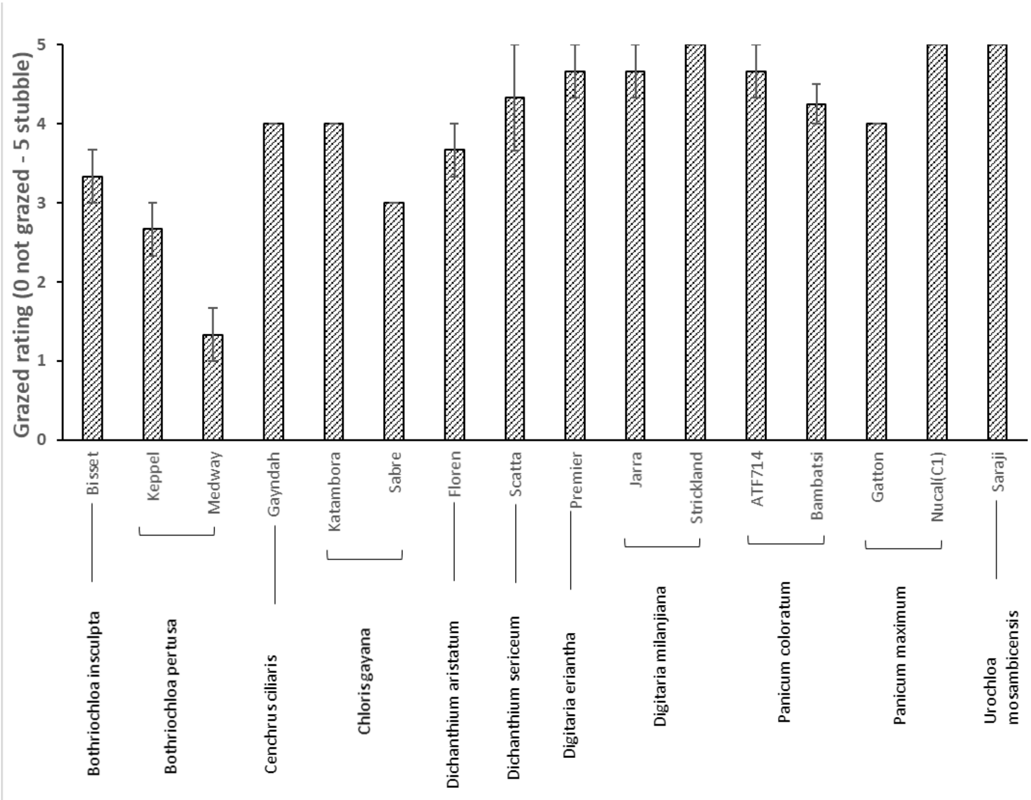
Grazing rating of the grasses (but not the legumes) was found to be negatively related to hay stage indicating those grasses with lower hay ratings were preferentially grazed whereas selection of legumes did not seem to be influenced (Appendix 10.25):

Legumes: Junction Creek Red	r = 0.217 (p = 0.058 not significant)
Legumes: Junction Creek Black	r = 0.106 (p = 0.394 not significant)
Grasses: Junction Creek Red	r = -0.628 (p < 0.001 significant)
Grasses: Junction Creek Black	r = -0.599 (p < 0.001 significant)

Fig. 41 Grazing of the experimental plots at 'Junction Creek', 2020. Top – August JC black soil site (right) high grazing ratings for most grasses; Bottom – JC Red August (left) poor acceptance of grazing black speargrass compared to other grasses (right) well-grazed desmanthus and growing shoots

Fig. 42 Mean grazing ratings for grasses and legumes measured on 6 August 2020 at 'Junction Creek' (black soil site). The plots were grazed by 17 weaners for 4 days prior to assessment. Error bars represent two standard errors of the mean.

Grasses



Legumes

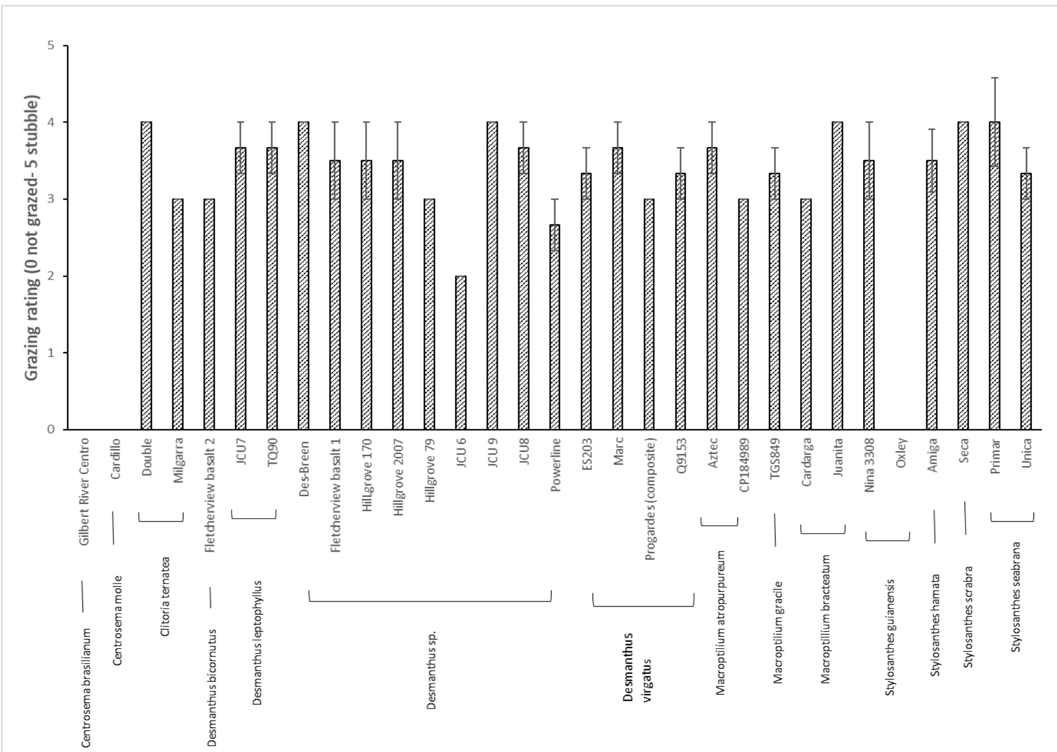
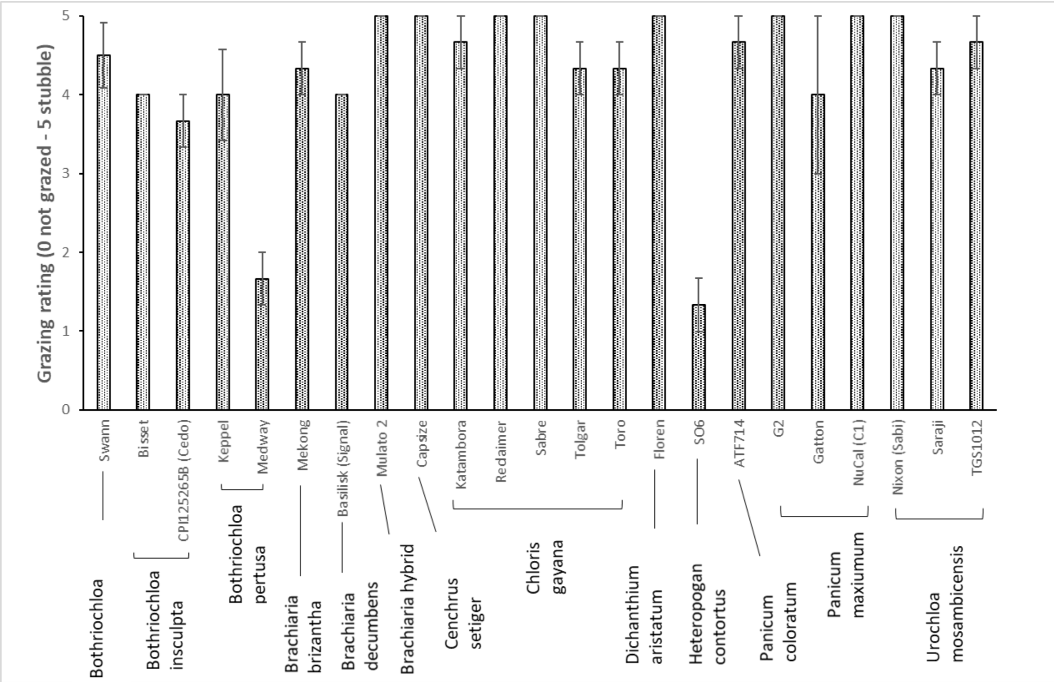
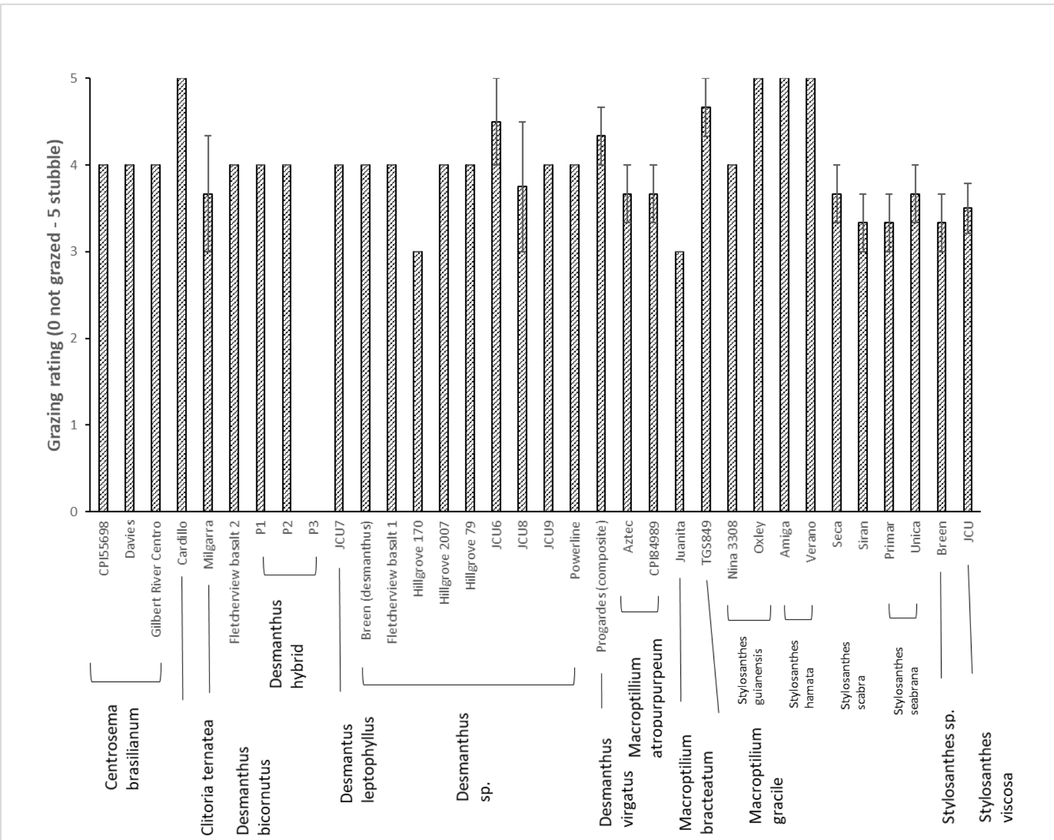


Fig. 43 Mean grazing ratings for grasses and legumes measured on 7 August 2020 at 'Junction Creek' (red soil site). The plots were grazed by 15 weaners for 4 days prior to assessment. Error bars represent two standard errors of the mean.

Grasses



Legumes



4.8.2 Larger-scale grass x legume combination studies

Combinations of grasses and legumes were grazed at year 2 at the grass x legume combination plots at 'Whitewater' and 'Spyglass' (also year 3 at 'Whitewater' (Fig. 44) enabling the investigation of the potential effect of companion plants on grazing of grasses or legumes. Grazing was heavier overall at the 'Whitewater' site in July 2020 than July 2021, but this may simply reflect grazing pressure. Overall, all grasses and legumes were well-accepted by cattle, but there were substantial differences in animal preference which were immediately obvious when inspecting the sites.

Summary statistics for 'Whitewater' 'DAF Spyglass' and 'Huonfels' are presented in Appendices 10.28, 10.29 and 10.30, along with rankings based on grazing level. Key grass x legume sward data are presented below. There were consistent differences in grazing ratings of grasses between sites (vertical axes): Jarra *Digitaria milanjiana* was consistently well eaten whereas TGS125652B *Bothriochloa insculpta* had lower grazing ratings (Fig. 45). It should be noted, TGS125652B was grazed very heavily at 'DAF Spyglass' prior to seeding (data not presented), so it seems animal preference was influenced by the presence of seedheads during the 2020/21 assessments. The *Panicum* spp. tended to have moderate values, but ATF714 and NuCal (syn. Massai) were preferentially grazed at 'Whitewater. Mekong *Brachiaria brizantha* was moderately grazed. High levels of residue tended to be left in Mekong plots compared to the other grasses, attributed to thick stems and trampling of the tall stems.

The spread of grazing ratings were similar for the grasses and legumes grazed at the same time (horizontal axes). The *Stylosanthes* lines (Seca, Unica and Amiga) were consistently rated highly compared to the other legumes, although Progardes *Desmanthus* was well-grazed at 'Whitewater'. Interestingly, the *Macroptilum* (TGS84989) ranked poorly in 2021 compared to 2020, although was eaten: many plants had shed leaves by the time they were grazed and this likely contributed to poorer selection by livestock. The *Clitoria* (Milgarra) lines were moderately grazed overall.

There was limited evidence of interactions between grasses and legumes for grazing pressure, and in general the grasses and legumes had similar values when grown with different legumes (i.e. were relatively consistent within their horizontal (grasses) or vertical (legumes) bands). An exception was Amiga, a low growing *Stylosanthes*, which was poorly eaten when growing within the unpalatable TGS125652B and TGS1012 at 'Whitewater' (presumably because cattle avoided the plot or could not find the legume), but had higher ratings in NuCal and Gatton *Panicum* plots which were more attractive to cattle. This effect may warrant consideration when selecting combinations of grasses and legumes.

In 2020, correlations between the hay stage rating and grazing score were calculated for grasses and legumes at 'Whitewater'. The correlations were both very weak, but were considered significant based on the large sample size.

Legumes: $r = -0.178$ ($p = 0.014$ significant, $n=190$)

Grasses: $r = 0.196$ ($p = 0.012$ significant, $n = 165$)

Fig. 44 Grazing of the experimental plots at 'Whitewater', July 2021.

Weaners introduced 10 June

Residual (stems only remaining) of erect and low-growing grasses

Heavy grazing of ATF714 *Panicum coloratum*

Moderate grazing of Gatton *Panicum* and Milgarra *Clitoria*

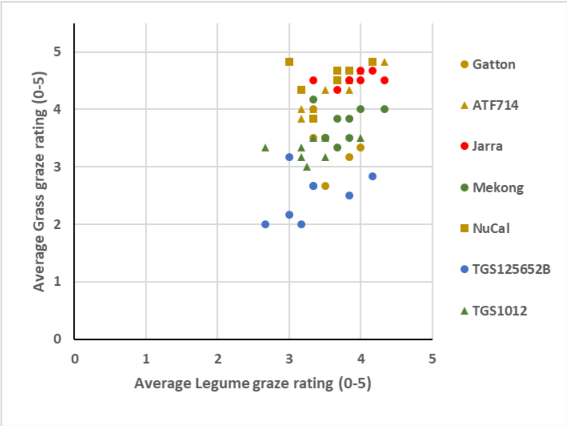
Heavy grazing of *Stylosanthes*

Heavy grazing of TGS84989 *Macroptilium*

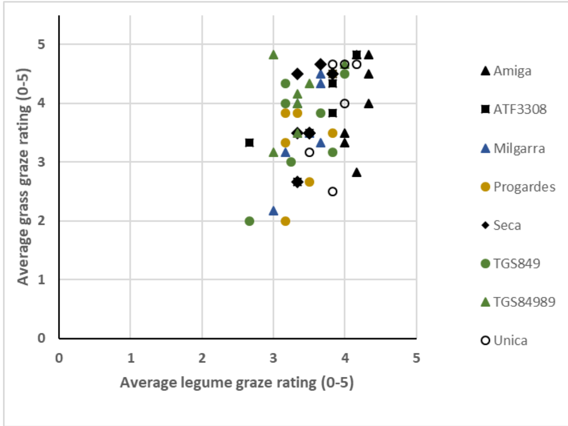
Fig. 45 Mean grazing ratings for legumes and grasses grown in combinations during 2021. The colours represent taxa groups (genus level).

'Whitewater' 20 July 2020 (10 weaners for 40 days)

Grasses

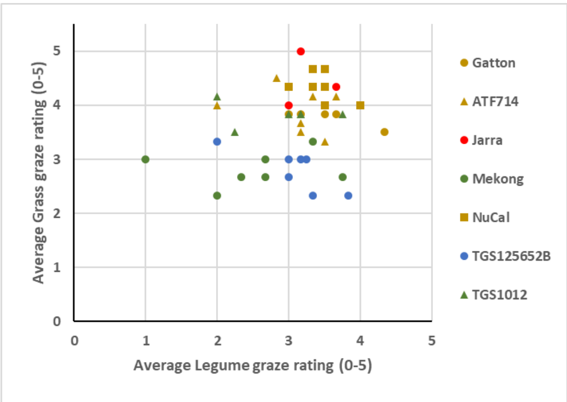


Legumes

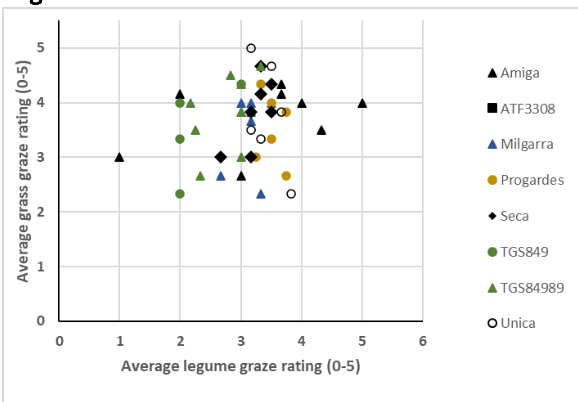


Whitewater', 17 July 2021 (18 weaners for 40 days)

Grasses

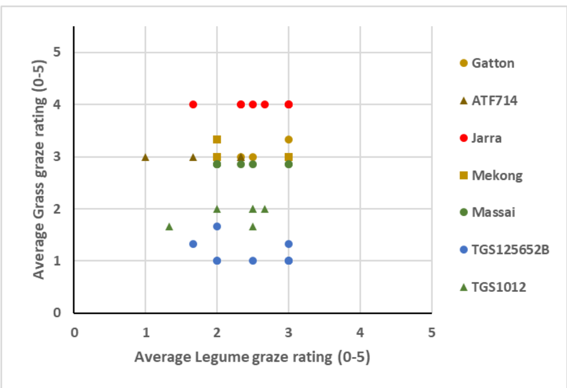


Legumes

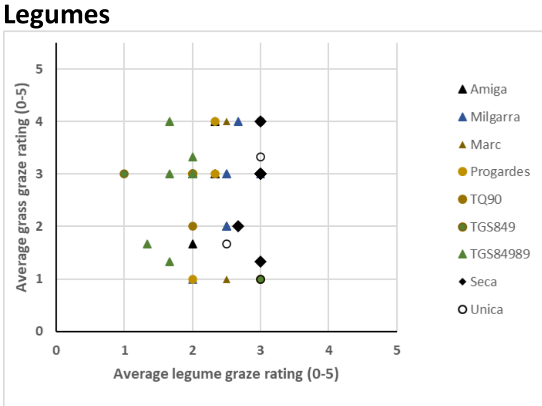


'DAF Spyglass', 5 June 2021. (28 heifers for 14 days)

Grasses



Legumes



5. Bio-economic analyses of 'production paddock' systems

5.1 Marginal analysis at paddock scale

5.1.1 Testing scenarios

A series of economic analyses were completed by DAF agricultural economists to estimate the marginal value of developing 'production paddocks' using strips in north Queensland of either:
(1) legumes + grasses, or
(2) legumes only.

The analyses drew on data generated in this project (B.NBP.0812) and the pre-cursor project (B.NBP.0766) and used the approach developed by DAF and collaborating agencies to identify the best options for improving business profitability and resilience in seasonally dry areas on Queensland through the Drought and Climate Adaptation Program (DCAP). To enable comparisons of developing production paddocks with other on-property interventions, the analysis used the same approach as that used to assess the profitability of over-sowing legumes (stylos) or fertilising stylos on infertile soils in the Gulf of Carpentaria region (Bowen et al., 2019).

Two land-types were assessed, drawing principally on the 'Whitewater' and 'DAF Spyglass' sites:

(1) infertile soils requiring P and S fertiliser (red earths in the Charters Towers / Mt. Surprise region)
(2) fertile soils requiring S fertiliser only (red basalt in the same region).

Two pricing scenarios were used to test the response of the economic statistics to sale price.

5.1.2 Method and parameters

The overarching approach was to:

(1) nominate key production parameters required to estimate dry matter intake and therefore carrying capacity using the QuickIntake spreadsheet developed for northern Australian beef herds (McLennan and Poppi, 2016).

(2) estimate marginal benefits at the paddock level using the following variables: herbage production, feed quality, utilisation, a nominated stock class and grazing period, and animal liveweight gain.

Measures of herbage biomass and feed quality were sourced from B.NBP.0812 and B.NBP.0766 field data relating to the land types listed above (Table 24). A master data set of herbage yield, management and growing environment was compiled for both projects and legume and grass+legume combinations which performed in the upper quartile and were considered sustainable were selected for analysis. These were:

1. Grass-legume: all (4) combinations of *Stylosanthes scabra* and *S. seabrana* with *Bothriochloa insculpta* and *Digitaria milanjiana* (3rd year data for red basalt, 2 for the red earth) (B.NBP.0812).
2. Legume only: combinations of *Stylosanthes scabra* and *S. seabrana* (3rd year data) (B.NBP.0766).

Table 24 Key parameters used for bio-economic assessment of grass+legume and legume strips (submitted to QuickIntake).

Scenario	1		2		2b		3		4		4b	
Soil	Infertile (red earth)						Fertile (red basalt)					
Treatment	Native		Grass+ legume		Legume only		Native		Grass+ legume		Legume only	
	Legume	Grass	Legume	Grass	Legume	Grass	Legume	Grass	Legume	Grass	Legume	Grass
Median annual pasture yield (kg DM/ha)	none	1500	917	2254	1778	900	none	2900	2020	3098	3296	1450
Utilisation of pasture (%)	23		40		31		22		41		37	
Mean legume content (%)	0		29		66		0		39		69	
Mean annual diet DMD (%)	49.5		52.0		51.1		49.5		52.1		51.1	
Mean annual steer LWG (kg/hd)	100		170		170		120		200		200	
Daily LWG (kg/hd/d)	0.27		0.47		0.47		0.33		0.55		0.55	
Jan	0.70		0.80		0.80		0.90		0.90		0.90	
Feb	0.80		1.15		1.15		1.00		1.20		1.20	
Mar	0.60		1.01		1.01		1.00		1.10		1.10	
Apr	0.5		0.64		0.64		0.80		0.90		0.90	
May	0.40		0.47		0.47		0.20		0.80		0.80	
Jun	0.20		0.45		0.45		0.05		0.50		0.50	
Jul	0.10		0.33		0.33		0.00		0.30		0.30	
Aug	0.00		0.20		0.20		0.00		0.20		0.20	
Sep	0.00		0.15		0.15		0.00		0.20		0.20	
Oct	-0.05		0.15		0.15		-0.05		0.20		0.20	
Nov	-0.05		0.14		0.14		-0.05		0.10		0.10	
Dec	0.05		0.17		0.17		0.10		0.22		0.22	

Table 25 Management of various scenarios of introducing legume strips into native pasture in north Queensland.

Scenario	1	2	2b	3	4	4b
Soil	Infertile (red earth)			Fertile (red basalt)		
Treatment	Native	Grass+ legume	Legume only	Native	Grass+ legume	Legume only
Fencing and waters	Y	Y	Y	Y	Y	Y
Fertiliser (base)	-	SSP (200 kg/ha)	SSP (200 kg/ha)	-	Sulphur (30 kg/ha)	Sulphur (30 kg/ha)
Cultivation	-	Chisel x 2	Chisel x 2	-	Chisel x 2	Chisel x 2
Herbicide	-	Glyphosate	-	-	Glyphosate	-
Legume seed	-	2 kg/ha	2 kg/ha	-	2 kg/ha	2 kg/ha
Grass seed	-	3 kg/ha		-	3 kg/ha	
Fertiliser (supp.,) Every 5 years	-	SSP (100 kg/ha)	SSP (100 kg/ha)	-	Sulphur (30 kg/ha)	Sulphur (30 kg/ha)

The data related to sampling collected at the end of the wet season (mid-March red earth grass+legume) or May (all other situations). Note: these do not account for herbage production after the sampling dates, but May sampling is considered to account for 80%+ of annual biomass.

The annual herbage yields of the native grasses were based on DAF records for A condition pasture (without tree thickening) for the red earth and yields of land in good condition near Charters Towers and historical recorded data for the red basalt soils (2900 kg/ha) (Ash et al., 2011). The same native grass yields (per hectare) were used for the native grass components for the sown strip treatments, but halved assuming 50% of the paddocks were sown to strips. Based on researcher observations in the study region, it was considered the stylos would spread into the (fertilised) native grass areas adjacent to the strips, but this would be greater on the more open infertile red earth pastures than those on the fertile red basalt (stronger grass competition). It was assumed the native grasses would not spread significantly into the legumes strips, or that the sown grasses would spread into the native pastures. The P fertiliser on the red duplex soils was considered to slightly increase native grass yield (20%) between the sown strips, but not on the red basalt (no fertiliser P) (Table 25).

Mean diet dry matter digestibility (DMD) values were calculated using metabolisable energy (ME) values from herbage samples collected at the same time as the biomass samples (linked data as described in this report): ME = 0.172 DMD-1.71 (CSIRO 2007, R Dixon *pers. comm.*). Values for the sown grasses and legumes were relatively low (51-52 % DMD) because feed quality had declined by time the samples for the analysis were collected and higher measured wet season values were not included in the analysis in order to link herbage yield and quality; considerably higher values would be expected if wet-season herbage was included (Hill et al., 2009). Herbage digestibility did, however, represent the feed available in the early to mid- dry season, the target period for the research. The feed values of the native pastures were based on those used for DCAP analysis (infertile soils, Georgetown) (Bowen et al., 2019).

Pasture utilisation was estimated by nominating residual pasture values for the native grass systems to provide at least 50% cover at the end of the dry season based on 2021 DAF data (Rolfe et al., 2022 in press), whereby 50% cover was achieved across a range of land-types in the Gulf with residual pasture yields of 630-780 kg DM/ha. Values were checked with long term sustainable values (Hunt, 2008). Residual values of 900 and 1500 kg DM/ha were nominated for the red earth and red basalt soils respectively, and a further 250 and 750 kg DM/ha for losses through detachment. The total residual (target residual + losses) was subtracted from the annual pasture yield and expressed as a percentage of yield. A similar process was used for the sown pasture systems, but the total residual values were increased to 1900 kg DM/ha for the red earth and 3000 kg DM/ha for the red basalt soils to allow for higher levels of biomass overall (more stemmy material).

Cattle live weight gain data were based on historical DAF research of liveweight gains on native pastures and recent research experience of fertilised legume/grass pastures on the target soils. The red earth native grass production was based on supplemented cattle on an infertile soil near Mareeba (Springmount, CP Miller, DAF internal data and as cited by Coates et al., 1997) and red basalt on land in A condition near Charters Towers (as cited by McLennan et al, 1988). The DCAP (Gulf) analysis was used for reference for the infertile soil type (Bowen et al., 2019). Animal production using fertilised legume strips on the red earth was conservatively adjusted (revised down to 170 kg/hd/yr to allow for strips) from recent animal (and pasture) production (241 kg hd/yr) from a monitored fertilised buffel grass/stylo and Wynn cassia paddock at 'Pinnarendi', Mt Garnet (B.BGP.0400) (Lemin pers. comm.). Production on the red basalt using strips was estimated at 200 kg/hd/yr, based on revised down production of fertilised (S only) legume pastures near Mt Surprise and allowing for pasture strips ('Meadowbank', J Rolfe and B English, DAF internal data). The distribution of liveweight gain over the year was based on the fertilised grass/legume pasture at Pinnarendi for the red earth soil, and allowance was made for lowered animal production on the basalt soil in winter (cool conditions) (after Miller et al., 1982).

The method employed for the economic analysis was similar to the DCAP analysis used to assess the effect of over-sowing stylos on infertile soils or fertilising existing stylos in the Gulf (Bowen et al., 2019) and is described in detail in Annexure 1. The broad strategy was to compare the profitability of steers introduced at 176 kg/hd on 15 June (weaned), following a birth weight mid-December of 30 kg, and grazed for 12 months on the specified pastures (production paths based on the above parameters and QuickIntake results). Six scenarios were run in the first instance using a five year average for sale (and purchase) prices and again using current values).

A series of animal growth paths were calculated using the QuickIntake analysis and published data, where possible for, mean stock entry rates and animal behaviour. Birth and weaning weights were based on Beef CRC data and animals were expected to walk 7 km/day (McLean and Blakely, 2014).

The cost of establishing and maintaining pastures (including supplementary fertiliser P or P+S), as described in Table 25, were estimated using current prices and included labour (contract rates). All equipment was depreciated and bank interest charges were factored into costs. Livestock costs were calculated using the same approach as for DCAP: all charges (e.g. freight, commissions, insurance) were included in the analysis. Cattle prices were based on a 5 year average to date. The analyses were projected over 30 years and the annualised results adjusted for a 100 ha paddock to enable comparison across the treatments.

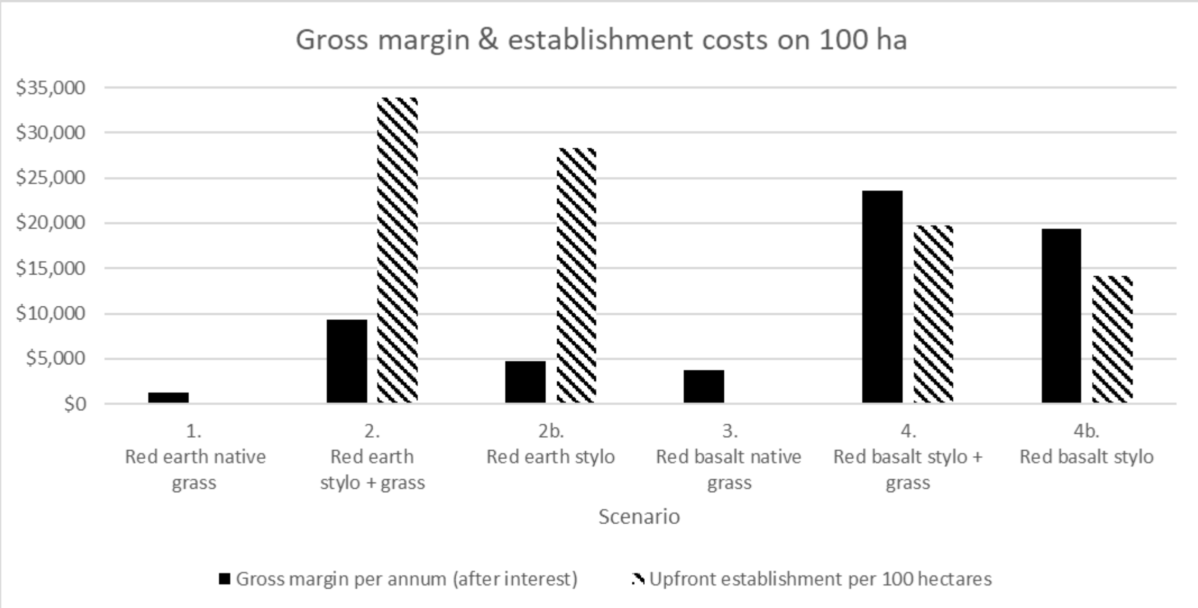
5.1.3 Results

The full results of the paddock level marginal analyses are presented in Annexure 1, with summarised statistics in Appendix 10.31 and key statistics in Table 26.

Table 26 The economic performance of various scenarios of introducing legume strips into native pasture in north Queensland (using 5 year and 12 month prices, 100 ha over 30 years).

	Scenario 1 native grass infertile red earth	Scenario 2 stylo + grass infertile red earth	Scenario 2b stylo infertile red earth	Scenario 3 native grass fertile red basalt	Scenario 4 stylo + grass fertile red basalt	Scenario 4b stylo fertile red basalt
Livestock Sales	$12,119	$45,896	$29,157	$22,047	$73,260	$60,051
Forage growing costs	$0	$4,390	$4,025	$0	$2,128	$1,763
Total Expenses	$10,432	$35,297	$23,660	$17,535	$47,763	$39,171
Gross Margin (5 year prices)	**$1,687**	**$10,599**	**$5,497**	**$4,513**	**$25,497**	**$20,881**
Gross Margin (12 month prices)	$2,483	$16,478	$9,217	$6,419	$36,062	$29,522
Kilograms of liveweight gain per hectare	12	66	42	25	114	94
Hectares per AE for 12 months	11.5	3.4	5.4	6.6	2.2	2.7
Upfront establishment per 100 hectares	$0	$33,933	$28,332	$0	$19,760	$14,158
Kg grass per hectare	1500	2254	900	2900	3098	1450
Kg stylo per hectare		917	1778		1971	3296

Fig. 46 Annualised gross margin (30 years) and initial establishment costs of three pasture development scenarios on red earth and red basalt soils in north Queensland.



The native grass pastures were capable of only low stocking rates, particularly on the infertile red earth. The use of legumes was estimated to double stocking rates on both soils and the addition of grasses to the legumes resulted in a tripling of stocking rates overall. This is consistent with previous DAF results for weaner production on fertilised stylo pastures on infertile soils near Georgetown (Anon, 1994) and supports recent analyses of business profitability in seasonally dry north Queensland (Rolfe et al., 2016). Faster animal growth rates on the sown pastures treatments, presumably due to the higher energy diet during the dry season, further increased the production benefit.

The costs of establishing the pasture strips were significant and it was assumed establishment was successful at the first attempt, whereas failure can be expected in some years due to inadequate rainfall. The costs of establishing, and maintaining the pastures was higher on the red earth soil due to the application of fertiliser P as single superphosphate (Fig. 46). Application rates and frequency were calculated based on soil test results and the requirements for legumes in seasonally dry areas of Queensland (Peck et al., 2015; Gilbert and Shaw, 1987). Higher growth legume growth responses (but also cost) would be expected at higher phosphorous application rates.

The annualised gross margins using prices averaged over the last five years indicate significant benefits for establishing legume and grass+legume strips compared to unfertilised native pastures (based on the assumptions of the analysis). The benefit was greatest on the red basalt soils, which were more productive overall (pasture yield) and there was no requirement to apply phosphorous fertiliser to support legume growth. The use of cattle prices recorded over the previous 12 months (for purchases and sales) resulted in considerably higher gross margins (41 to 68 % depending on scenario) than when using 5-year average prices (Table E3).

The results were summarised in two short papers presented at the 2022 Australian Association for Animal Sciences conference (Cox et al., 2022; Finlay and Cox, 2022).

5.2 Economic analysis at a whole-property scale

5.2.1 Testing scenarios

A series of whole-of-business assessments were completed to estimate the financial implications of developing legume-based 'production paddocks' in north Queensland. The analyses drew on the paddock-scale analyses presented above but examined two separate model properties in the Burdekin region: mixed soils property including red earths near Charters Towers, and a basalt-soil property representative of the northern end of the catchment. The scenario analysis was similar to that used for the DCAP studies to compare interventions on beef properties as described above and the same team of economists were employed.

Scenario 1: 'Burdekin' property with steers on native pastures on infertile red earth soils

- Either had an area planted to stylo and grass pastures and became Scenario 2. All steers eventually grazed sown stylo and grass pastures growing on infertile red earth soils. Phosphorus (P) and Sulphur (S) fertilisers were applied.
- Or had an area planted to stylo only and became Scenario 2b. All steers eventually grazed sown stylo-based pastures growing on infertile red earth soils. Phosphorus (P) and Sulphur (S) fertilisers were applied

Scenario 3: 'Basalt' property with steers on native pastures on fertile red basalt soils

- Either had an area planted to stylo and grass pastures and became Scenario 4. All steers eventually ran on stylo and grass pastures growing in fertile red basalt soils. Sulphur fertiliser was applied.
- Or had an area planted to stylo only and became Scenario 4b. All steers eventually grazed stylo-based pastures growing in fertile red basalt soils. Sulphur fertiliser was applied.

Both properties were breeding and growing enterprises and had total property areas of 25,000 ha. The 'Burdekin' property was considered marginal for soil P and P-supplements were fed during the dry season to reduce breeder liveweight loss, whereas these were not required on the fertile basalt soils. A urea based supplement was fed during the dry season for both properties. Continuous mating was used with two weaning musters per year.

The sown pasture scenarios were developed using the inputs described for the marginal analysis; grass+stylo or stylo only strips covering 50% of paddocks established and managed as 'production paddocks'. Fertiliser P+S fertiliser was used for the 'Burdekin' property and S only on the 'Basalt' property. The following key assumptions were made for the analysis:

1. steers were grazed on the sown pastures paddocks for 12 months, entering in June
2. to allow for establishment failure or poor strike rates, pastures were re-sown in year three at 20% of the original development costs
3. Full establishment of 'production paddocks' took 3 years (to get into full production)
4. all steers entered the production paddocks at the same weight (183 kg/animal) and age (6 months)
5. replacement fertiliser would be required to maintain pasture productivity
6. herbage yields in the 'production paddocks' were discounted by 25% from field trial values to compensate for 'sub-optimal' management, poor seasons and grazing by kangaroos etc.

The scenarios/strategies were assessed for their potential impact on:

1. the current net worth of the beef property (impact assessed as net present value (NPV) of the change).
2. the maximum cumulative cash deficit/difference between the two strategies (peak deficit).
3. the number of years before the peak deficit is achieved (years to peak deficit) and
4. the number of years before the investment is paid back (payback period).

For each scenario, changes in available herbage yield were used to change herd structures and animal performance on an annual basis and then compare expected and alternative productivity and profitability over a 30-year investment period.

5.2.2 Method and parameters

The production capacity for the ‘production paddock’ scenarios on either the ‘Burdekin’ or ‘Basalt’ properties were calculated as for the marginal production paddock analysis, but the results modified using the assumptions for sub-optimal management (above)(Tables 27 and 28). Changes in herd structures were determined using available feed and economic models run using annual steps to estimate the effects of herd costs, incomes and management strategy. The Breedcow and Dynama programs (Version 6.02; Holmes et al. 2017) were applied to test the relative and absolute value of alternative legume establishment strategies. These models were considered to incorporate appropriate economic and financial frameworks and are highly suited to the type of analysis undertaken. Where there was a herd build-up due to the introduction of production paddocks, consideration of different build-up strategies (rates) were tested.

The area of pasture, native or sown, required to raise steers was based on the overall herd structure. Total available plant biomass available for consumption (utilisation) was divided by steer intake based on size using QuickIntake (McLennan and Poppi, 2019). More productive areas required smaller areas of ‘production paddocks’ to grow steers: e.g. ‘Burdekin’ native grass (+buffel) required 4035 ha, whereas the ‘Basalt’ native pasture required 2090 ha. The breeder herd was then allocated the rest of the 25 000 ha property and supplied weaner steers to the steer growing system. A series of alternative growth paths and herd structured followed over the analysis.

Discounted cash flow (DCF) techniques were applied to look at the marginal returns associated with any additional capital or resources invested within farm operations. The DCF analysis was compiled in real (constant value) terms, with all variables expressed in terms of the price level of the current year (2022). It was assumed that future inflation would equally affect all costs and benefits.

The standard methods of farm management economics (Malcolm et al. 2005) were applied to consider the difference between alternative management strategies for the same property. The relative riskiness of alternative strategies were identified, where possible. As it is usual for the comparison to be between an investment in a relatively low-input, low-output operation and other more intensive operations, an assessment of the risks can be critical.

Table 27 Assumed forage and steer growth parameters for native grass and stylo-grass pastures grown on infertile red earth soil type (Burdekin property)

Biological parameter	Scenario 1 Native grass	Scenario 2 Stylo + grass pasture		Scenario 2b Stylo only	
		Stylo	Grass	Stylo	Grass
Median, annual pasture biomass production (kg DM/ha)	1,500	688	1,691	1,334	675
Utilisation of annual biomass growth (%)	23	40	40	31	31
Average, stylo content in the diet across the year (%)	0	29		66	
Average, annual diet DMD of grazing cattle (%)	49.5	52		51.1	
Average, annual steer LWG (kg/head)	119	172		172	
Daily live weight gain (kg/day); annual average	0.33	0.47		0.43	
January	0.4	0.7		0.7	
February	0.9	0.8		0.8	
March	0.8	0.6		0.6	
April	0.6	0.85		0.85	
May	0.5	0.62		0.62	
June	0.27	0.6		0.6	
July	0.15	0.44		0.44	
August	0.1	0.26		0.26	
September	0.1	0.2		0.2	
October	0	0.2		0.2	
November	0	0.19		0.19	
December	0.15	0.23		0.23	
Carrying capacity (ha/AE)[A]	9.53	3.2		5.1	
Area required to meet steer demand for 1 year (ha)	7.63	3.10		4.88	

DM, dry matter; DMD, dry matter digestibility; LWG, live weight gain.

[A] AE defined in terms of the forage intake of a 2.25 year old, 450 kg *Bos taurus* steer at maintenance, consuming a diet of the specified DMD and walking 7 km/day (McLean and Blakeley 2014).

Table 28 Assumed forage and steer growth parameters for native grass and stylo-grass pastures grown on fertile red basalt soil type (Basalt property)

Biological parameter	**Scenario 3 Native grass**	**Scenario 4 Stylo + grass pasture**		**Scenario 4b Stylo only**	
		Stylo	Grass	Stylo	Grass
Median, annual pasture biomass production (kg DM/ha)	2,900	1,478	2,324	2,472	1,088
Utilisation of annual biomass growth (%)	22	41	41	37	37
Average, stylo content in the diet across the year (%)	0	39		69	
Average, annual diet DMD of grazing cattle (%)	49.5	52		51.1	
Average, annual steer LWG (kg/head)	119	200		200	
Daily live weight gain (kg/day); annual average	0.33	0.55		0.55	
January	0.9	0.9		0.9	
February	1	1		1	
March	1	1		1	
April	0.8	1		1	
May	0.2	0.8		0.8	
June	0.05	0.59		0.59	
July	0	0.3		0.3	
August	0	0.2		0.2	
September	0	0.2		0.2	
October	-0.05	0.2		0.2	
November	-0.05	0.19		0.19	
December	0.1	0.22		0.22	
Carrying capacity (ha/AE)[A]	5.15	1.98		2.40	
Area required to meet steer demand for 1 year (ha)	4.11	2.09		2.56	

DM, dry matter; DMD, dry matter digestibility; LWG, live weight gain.

[A] AE defined in terms of the forage intake of a 2.25 year old, 450 kg *Bos taurus* steer at maintenance, consuming a diet of the specified DMD and walking 7 km/day (McLean and Blakeley 2014).

Key parameters used to compare the various scenarios included:

- Net Present Value - the net returns (the net difference in operating profit as adjusted) over the life of the investment, expressed in present day terms
- Internal Rate of Return – 5% represented the opportunity cost of spending the funds in alternative ways
- Peak deficit – including the number of years until peak deficit and the payback period in years.

All costs included labour where applicable (contracting equivalents) and depreciation for equipment and cattle prices were based on a 5-year average from October 2016 to October 2021 (Table 29). A scenario with recent 12 month prices was also conducted.

5.2.3 Results

The full results for the property level analyses are presented in Annexure 2, key statistics summarised below.

Investing in all 'production paddock' systems was found to be profitable when analysed over 30 years using a discount rate of 5%, a five-year price average and the slow herd build-up strategy (Table 30). However, returns were substantially higher, and payback times shorter, on the fertile red basalt ('Basalt' property) soils than for the infertile red earth systems ('Burdekin') where phosphorous fertilisers were not required (sulphur only), and pasture growth rates were higher. The internal rate of return for developing 'production paddock' systems was ~ 10% on the infertile 'Burdekin' land type compared to ~ 30% on the fertile 'Basalt' land type. Investing in stylo-grass pastures is also likely to be more profitable than stylo-only pastures on red earth 'Burdekin' soil types, whereas there was little difference on the 'Basalt' soil types (both improving profit). Stylo-grass pastures added ca. $58,000 - $102,000 extra profit per year over 30-years to the Burdekin and Basalt representative properties, respectively. This compared to ca. $25,000 - $103,000 for stylo-only pastures on Burdekin and Basalt properties.

The adoption of a quick herd build-up strategy (by retaining and growing more livestock) increased the profitability of all systems over the 30 years (Fig. 47), although the benefit was generally in the order of 10-20%. Changes in livestock prices compared to the 5-year average also influenced the relative profitability of the systems (Fig. 48). In particular, the stylo system on the infertile ('Burdekin') system was considered unprofitable if prices decreased by 25%. This sensitivity to cattle price movements was attributed in part to the ongoing fertiliser requirements when compared to requirements on the fertile red basalt representative property.

It should be noted that these predicted returns are dependent on the assumptions used including the relative yields, utilisation rates, diet quality and animal performance from grazing of stylo-grass pastures under North Queensland conditions over 30 years. Whilst every effort was made to ensure that the assumptions used in each scenario were realistic and validated where possible with data from the trial plots, caution should always be applied when interpreting the results. To counter this, conservative estimates used within the analysis, including: herbage yields which likely underestimate annual production because they were measured before the end of the growing season; further discounting of these yields for 'sub-optimal' management, and; assumed partial failure of establishment. For a more robust analysis, these results should be validated by property level measurements of animal and pasture performance.

Table 29 Direct pasture development costs for Burdekin red earth and red basalt soil types.

Establishment costs

	Pasture variety	Item or treatment	Rate of application	Cost/unit	Number of applications	% of area treated	Cost per hectare
Burdekin red earth	**Scenario 2 Stylo + grass**	Chisel plough	1	$38.77/ha	2	50	$38.77
		Pasture planter	1	$16.18/ha	2	50	$16.18
		Stylo seed	2 kg/ha	$20/kg	1	50	$20.00
		Grass seed	3 kg/ha	$25/kg	1	50	$37.50
		Fertiliser spreader	1	$7.84/ha	1	50	$3.92
		Fertiliser (SSP)	200 kg/ha	$1/kg	1	50	$100.00
		Linkage spray rig	1	$4.35/ha	1	50	$2.18
		Roundup CT	1.5 L/ha	$11/L	1	50	$8.25
		Total					*$227*
	Scenario 2b Stylo	Chisel plough	1	$38.77/ha	2	50	$38.77
		Pasture planter	1	$16.18/ha	1	50	$8.09
		Stylo seed	2 kg/ha	$20/kg	1	50	$20.00
		Fertiliser spreader	1	$7.84/ha	1	50	$3.92
		Fertiliser blend (SSP)	200 kg/ha	$1/kg	1	50	$100.00
		Total					*$171*
Red basalt	**Scenario 4 Stylo + grass**	Chisel plough	1	$38.77/ha	2	50	$38.77
		Pasture planter	1	$16.18/ha	2	50	$16.18
		Stylo seed	2 kg/ha	$20/kg	1	50	$20.00
		Grass seed	3 kg/ha	$25/kg	1	50	$37.50
		Fertiliser spreader	1	$7.84/ha	1	50	$3.92
		Granulated sulphur	30 kg/ha	$1.10/kg	1	50	$16.50
		Linkage spray rig	1	$4.35/ha	1	50	$2.18
		Roundup	1.5 L/ha	$11/L	1	50	$8.25
		Total					*$143*
	Scenario 4b Stylo	Chisel plough	1	$38.77/ha	2	50	$38.77
		Pasture planter	1	$16.18/ha	1	50	$8.09
		Stylo seed	2 kg/ha	$20/kg	1	50	$20.00
		Fertiliser spreader	1	$7.84/ha	1	50	$3.92
		Granulated sulphur	30 kg/ha	$1.10/kg	1	50	$16.50
		Total					*$87*

Fertiliser maintenance applications

Soil type	Item or treatment	Rate of application	Cost/unit	Number of applications	% of area treated	Cost per hectare
Burdekin Red earth *Scenario 2* *Scenario 2b*	Fertiliser spreader Fertiliser blend (SSP)	1 100 kg/ha	$7.84/ha $1/kg	1 1	100 100	$7.85 $100.00
Red basalt *Scenario 4* *Scenario 4b*	Fertiliser spreader Granulated sulphur	1 30 kg/ha	$7.84/ha $1.10/kg	1 1	100 100	$7.85 $33.00

Table 30 Returns for investing in stylo-grass or stylo-only pastures for steers from weaning to sale with a slow herd build-up on infertile red Burdekin and fertile red basalt soil types using five-year average cattle prices between 2016 and 2021

The comparison is the same land type with native pastures only. All terms are defined in the Glossary of terms and abbreviations.

Factor	Burdekin stylo + grass Scenario 2	Burdekin stylo-only Scenario 2b	Basalt stylo-grass Scenario 4	Basalt stylo-only Scenario 4b
Period of analysis (years)	30	30	30	30
Discount rate for NPV	5.00%	5.00%	5.00%	5.00%
NPV	$900,210	$390,386	$1,578,078	$1,592,793
Annualised NPV[A]	$58,560	$25,395	$102,656	$103,613
Peak deficit (with interest)[B]	-$624,892	-$796,870	-$248,779	-$192,430
Year of peak deficit	6	6	3	3
Payback period (years)[C]	13	18	5	4
IRR[D]	13%	9%	32%	37%

[A]**Annualised (or amortised) NPV** (net present value) is the sum of the discounted values of the future income and costs associated with a farm project or plan amortised to represent the average annual value of the NPV. A positive annualised NPV at the required discount rate means that the project has earned more than the 5% rate of return used as the discount rate. In this case it is calculated as the difference between the base property and the same property after the management strategy is implemented. The annualised NPV provides an indication of the potential average annual change in profit over 30 years, resulting from the management strategy.

[B]**Peak deficit** is the maximum difference in cumulative net cash flow between the implemented strategy and the base scenario over the 30-year period of the analysis. It is compounded at the discount rate and is a measure of riskiness.

Fig. 47 Net present value over 30 years from investing in stylo pastures for steers on Burdekin red earth and red basalt soil types compared with native pasture on the same soil type with slow and quick herd build-up strategies.

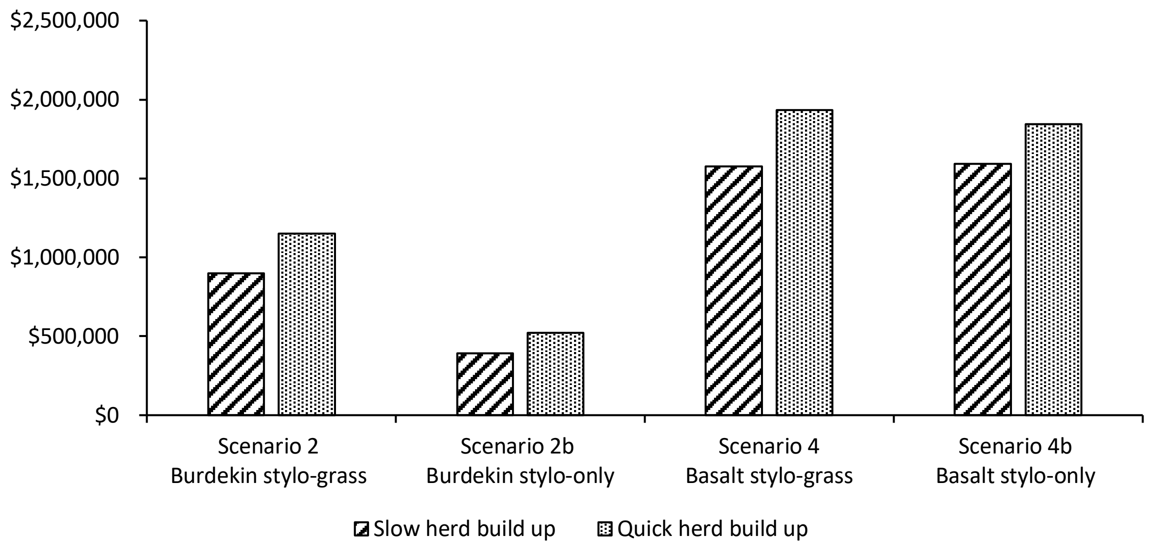
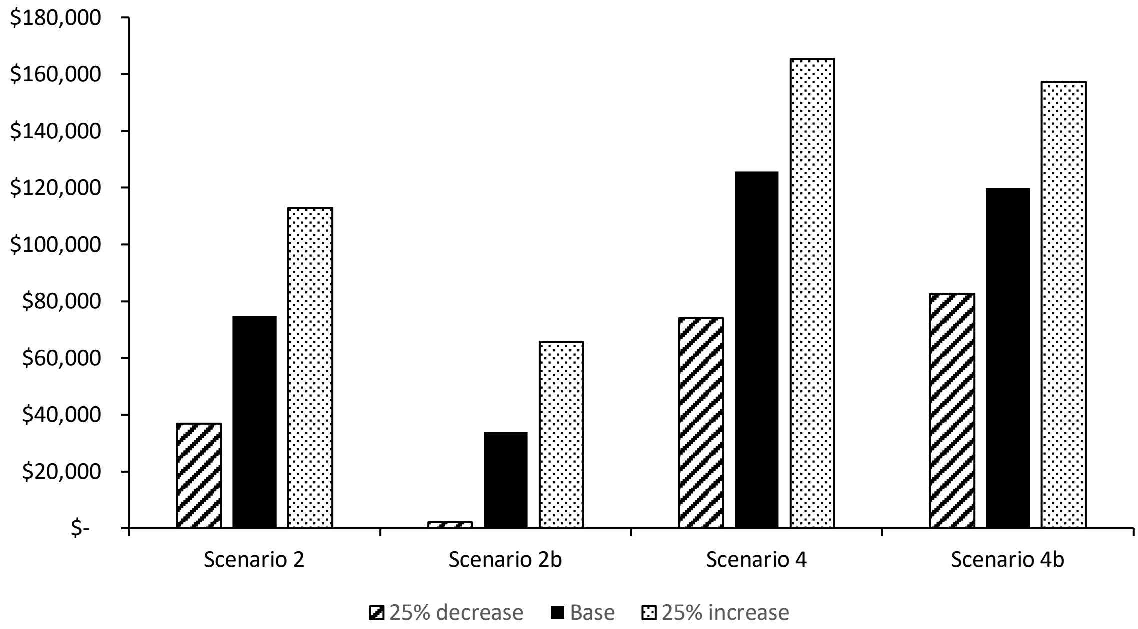


Fig. 48 Impact on annual profit (annualised NPV) when cattle prices increase or decrease by 25% from 2016-2021 average (base) across all scenarios using a quick herd build-up strategy.



6. Promoting adoption of production paddock systems

6.1Seed production to support adoption

Seed production was completed at DAF Walkamin for lines which were persistent and productive in the precursor project (B.NBP.0766) but were yet to be commercialised. The methods used to produce, clean and store the seeds are described in Section 2.4. The seeds were used to establish the four grass x legume experiments and to generate seed to make the transition to commercial seed production. For this, at least 5 kg (preferably 30+) of true-to-type seed was required. Reserves of the early-generation lines were kept in long-term storage at DAF Walkamin in case of commercial mishap.

Seed production was completed from the onset of the project and ceased in 2021 although most of the seed production occurred in 2015-17 (ahead of project schedule). Seed from the first few years of the project were used to establish the new on-property experiments and subsequent seed harvests were cleaned and placed in storage at DAF Walkamin until there was sufficient seed, and there was the opportunity, to grow the first small-commercial seed crops which in turn were used to generate the plant seed required to up-scale seed production. All lines were public cultivars and supplied to the seed companies which had previously contracted DAF to produce early generation seed of the lines. The exception was the first crop of 'Massai' *Panicum* hybrid for which a test crop was grown near Tolga on the Atherton Tablelands in collaboration with an independent seed cleaning company.

The methods used to produce the seed crops at DAF Walkamin were all broadly successful, although slow initial growth of ATF714 *Panicum coloratum* and lack of selective herbicide options meant it was difficult to suppress grass weeds (particularly *Eragrostis*) which dominated some crops. Moderate to high seed yields were achieved for all of the seed lines, but there were crop failures principally due to poor synchronisation of flowering associated with daylength (crop time-tabling). The use of a range of 'starting' times has produced some useful agronomic information, particularly with respect to 'starting' dates; either sowing for legumes or cutting and fertilising for the grasses (Table 31) (Appendix 10.33).

Panicum coloratum ATF714

Harvests with moderate yields during January, March and April indicate this line behaves as a conventional seed crop with little or no photoperiodic influence on the flowering time. The seeds are presented well for combine harvesting, with seed heads in the upper canopy at a height of ~15 to 50 cm. Crops should be possible whenever growing conditions are suitable (but will clearly be more expensive when grown under irrigation). Flowering seems relatively well synchronised when crops are started during the wet season, but mature seeds are held relatively loosely within panicles and the crops are prone to damage by strong winds and heavy rainfall. Seed yields were low to moderate yields (26 to 80 kg cleaned seed/ha equivalent) to date, but have been increased as crop management improved. Slow establishment means it competes poorly with weeds if they cannot be controlled otherwise (herbicides).

Panicum maximum x *P. infestum* hybrids

Massai and NuCal grew similarly as seed crops. Relatively consistent harvest times, despite a range of starting dates, indicates a relatively strong short-day photoperiodic response for flowering. Poor results using very early (January) or very late (April) starting dates indicates it is critical to start crops before April: February/March seems the optimum time and this is consistent with other grasses with relatively strong photoperiodic responses for flowering when grown in north Queensland. This means that there is the opportunity for only one or two (under dry-season irrigation) seed crops per year. These grasses continue to have exceptionally vigorous growth, and the approach of planting the crops in 1 m rows, while unconventional for Australia (but used in south-east Asia), appears to benefit seed production through enabling the exposure of tillers to light when they receive suitable photoperiods for flowering. Moderate to high (83 to 260 kg/ha) cleaned seed yields have been achieved to date. As for many *Panicum maximum*, the seedhead tends to be presented above the leaf canopy. This makes it relatively easy to combine harvest, but susceptible to wind damage.

Urochloa mosambicensis TGS1012

TGS1012 is behaved similarly to other *Urochloa mosambicensis* seed crops (Nixon, Saraji). Flowering appears unaffected by photoperiod and there is a rapid resumption of flowering after cutting and fertilising during summer months and two or three crops should be possible over one wet season. This crop is very well suited to combine harvesting and seed production with a minimum of irrigation. Plant growth is extremely vigorous and the crop rapidly forms a dense canopy. Moderate to high seed yields (142 and 232 kg/ha) have been achieved when crops have been cut back and fertilised. The 2018 seed crop was disappointing yielding only 50 kg/ha: this crop was relatively 'open' and weather during harvest was not optimal for seed production.

Macroptilium atropurpureum TGS84989

Early yields of TGS84989 were promising (~330 kg cleaned seed/ha), although it is recognised these were from weed mats so a high proportion of presented seed was recovered. TGS84989 grew extremely vigorously as a first year crop with only minor damage due to wet conditions (suspected *Rhizoctonia*) during the 2017-18 wet season. The very late flowering after a December sowing is an important consideration for commercial seed production: late sowing could be advantageous as this would reduce the amount of 'bulk' in the canopy. Although presented well for harvest (above the canopy), there is a risk harvesting could be impeded by early storm weather as occurred in October 2017 (see above); the return crop produced an excess of material which may have contributed to disease during 2018. A suggested approach to producing seed of TGS84989 is to sow relatively late (say, March) in anticipation of an October seed crop: irrigation will be needed.

Macroptilium gracile TGS849

Seed production of TGS849 was relatively simple: the crop established readily during summer and began flowering a few months after sowing. There appears to be no significant photoperiodic effect for flowering. It has a relatively low canopy, however, and many inflorescences are presented within it meaning low harvesting heights will be required if completed using a combine harvester. The one crop to date indicated good seed yield potential (428 kg/ha), although once again, this was on weed mat. Poor regrowth, and eventual death, in the second year indicates this should be treated as an annual seed crop.

Table 31 Seed lines grown by DAF to support commercial adoption

Species and identifier	Flowering control[1]	DAF seed yields (kg/ha)	Harvest method	Transfer for commercial production
Panicum coloratum ATF714	Minor	26-80	Direct head	Yes. Additional seed increase stage in southern Queensland[2].
Panicum hybrid Massai and NuCal(C1)	Significant	7-260	Direct head	Yes. Trial commercial crop in north Queensland. Yet to be harvested.
Urochloa mosambicensis TGS1012	Minor	14-232	Direct head	Yes. Commercial seed production in north and south Queensland
Macroptilium atropurpureum TGS84989	Significant	327-339	Fallen seed	Yes. Commercial seed production in north Queensland.
Macroptilium gracile TGS849	Minor	428	Fallen seed	Yes. Commercial seed production yet to begin.

1 Minor – no indication of photoperiodic effects. Best yields of grasses in summer and winter harvest for legumes. Significant – behaves as a short-day plant (late flowering): every year for grasses and very late for the legume in the first year but earlier in subsequent years.

2 Small-scale seed increase undertaken in southern Queensland where there was perceived less weed pressure.

Bothriochloa insculpta TGS125652B, a mid-season flowering blue grass, performed well in the experiments. Seed increase was conducted by DAF for a seed company but they have elected to not pursue commercial seed production for now. Bisset, a later flowering public cultivar, is commercially available and a likely suitable alternative, at least in the short term.

6.2 Promotion of research findings

B.NBP.0812 was primarily a research project. However, extension events were undertaken to promote the use of legumes in north and central Queensland, the newer concept of 'production paddocks' and to present and discuss the technical findings from the project. Field days using the research trial and commercial examples of best practice were combined with presentation at industry events (BeefUp forums, Beef Australia) and other media to create awareness (FutureBeef podcast, media articles (radio, print)) (Fig. 49). Applied science conferences (NABRUC and AAAS) were used to extend the results to researchers and attending producers (Appendix 10.34). The advent of covid19 and associated restrictions of travel and public events resulted in the postponement and cancelling of some extension events during 2020 and 2021. Examples of extension activities are provided in Table 32.

Resulting from the promising field data and economic analyses for legume ‘production paddock’ systems, DAF internally invested in the development of a 80 ha replicated grazing-level scale experiment at DAF Spyglass Research Facility. The experiment targets the answering of producer queries on what legume system is the most profitable: shrub legumes (desmanthus or stylos), which are relatively easy and inexpensive to establish, or leucaeana, which is more productive but more expensive to establish and requires specialised planting equipment. The experiment acts as a practical demonstration of introducing legumes using ‘strip systems’ into fertilised grass pastures and will generate key economic data based on animal performance. The experiment comprises four treatments: stylos, desmanthus, leucaena and grasses. With the exception of leucaena (Redlands new psyllid tolerant variety), the other legume and grass treatments include a range of species and lines to identify those with best long-term performance. The experiment was prepared (surveyed, boundary fences) during 2020, sown in February 2021 and first grazed late 2021. Establishment was excellent, with the stylos (2.4 T DM/ha in strips only 6 months after sowing) producing the most vigorous growth in the first year. The site is to be used managed with a producer reference group and used to promote the concept of ‘production paddocks’ (first field days held).

Table 32 Examples of project extension conducted over the project.

Activity	When	Comments
Field days and producer workshops		
DAF and landcare field day Moura	April 2018	Field walk at 'Unumgar' and discussion, ~ 50 graziers, advisers and companies.
DAF and Northern Gulf NRM Beef Forum, Georgetown	April 2018	Presentation on sown legumes and 'production paddock' systems. Weather affected, ~ 15 graziers.
DAF field day, Mt. Surprise	May 2018	Leucaena and production paddocks (Pinnarendi and Whitewater), ~20 graziers and industry.
DAF and Dalrymple Landcare field day, Charters Towers	Apr. 2019	Field walk at Junction Creek for a 'black soil' field day, ~55 graziers, DAF staff and industry
DAF field day, Mt Garnet	Nov. 2020	Presentation on legume options and field walk, Goshen, ~20 graziers and bank representatives
DAF field day, Mt Garnet	Mar. 2021	Presentation and field walk. Leucaena and production paddocks (Pinnarendi and Whitewater), ~15 graziers.
DAF field day, Charters Towers	Aug. 2021	Field walk at DAF Spyglass to demonstrate the new DAF legume pasture systems project established, 10 producers.
DAF and Leucaena Network field day, Mt Garnet	Mar. 2022	Field walk and research update: Leucaena and production paddocks (Pinnarendi and Whitewater), ~20 graziers and other industry
DAF industry update, Mt Garnet	May 2022	Field walk and presentation of financial analyses to support industry staff (seed companies, rural suppliers). Delayed by poor weather, 9 attendees.
Industry events		
BeefUp, Karumba	Oct. 2018	Presentation on sown legumes and 'production paddock' systems, ~120 graziers, researchers and industry.
BeefWeek, Rockhampton	May 2018	Project profile for promotion at the DAF tent.
BeefUp, Charters Towers	Sept. 2018	Presentation on 'production paddocks' and field walk at DAF Spyglass. ~ 200 graziers, researchers and industry.
BeefWeek, Rockhampton	May 2021	Seminar: New legumes for grass-fed beef production in northern Australia (Cox, Lemin and Peck, all DAF), ~120 people, mostly graziers and other beef industry
BeefUp, Charters Towers	Jun 2021	Presentation: *Legumes for dry-season feeding in north Queensland* (Cox), ~50 graziers and other beef industry
Conferences		
NABRUC, Brisbane	August, 2019	Poster paper on the seed production characteristics of the new grasses and legumes from the project.
Leucaena Network Conference, Townsville	Sept. 2020	Presentation on 'production paddocks' and project overview, ~80 delegates, mostly producers.
Australian Association of Animal Sciences conference, Cairns	July 2022	Two presentations and short-papers: (1) Economic analysis of sown stylo and/or grass pastures on red earth and red basalt soils in north Queensland (Finlay and Cox) (2) Pasture legumes for high-quality dry-season cattle forage on red basalt soils in north Queensland (Cox et al)
Other		
DAF podcast	2022	FutureBeef Podcast 3: Making your pasture make you money (Lemin, Cox, English, Rolfe). Benefits and management of legume-based pastures in northern Australia with a focus on north Queensland.
Newsletter		Northern Muster articles

Fig. 49 Examples of extension events and the ‘production paddock’ research and demonstration site under development at DAF Spyglass to compare legume systems.

Field day at ‘Unumgar’, near Moura, April 2018.

Graziers and industry representatives at ‘BeefUp’, DAF ‘Spyglass’, September 2018.

DAF Spyglass 80 ha ‘production paddock’ experiment showing cultivated strips which were sown to either stylo, desmanthus, leucaena or grasses. Inset – stylo in August 2021.

7. Conclusion

7.1 Knowledge gaps

This project sought to progress the adoption of pasture legumes using 'production paddocks', principally in the seasonally dry zone of north Queensland, through:

1. addressing technical knowledge gaps on plant selection and establishment methods
2. generating expected values for feed volume and quality, and
3. providing preliminary economic assessments at a business level using four adoption scenarios compared to current state (unfertilised native pastures).

The project built on B.NBP.0766, which expanded on, and updated, multi-site pasture legume adaptation testing conducted in north Queensland during the 1970s-1990s (Clem and Hall, 1994; Hall and Walker, 2005). That project identified well-adapted and productive legumes and grasses for key land-types in north and central Queensland (Cox et al., 2019), and provided yield and feed quality estimates when soil nutrient (P, S) was supplemented, but used commercially unrealistic establishment methods and did not assess legume performance when grown with grasses.

To address these knowledge gaps, the current project used larger experimental areas and commercially realistic sowing rates and establishment methods to test well-adapted legume and grass productivity when grown as combinations on commercial properties on key beef production land-types (red basalt, duplex and red earth soils in north Queensland and brown clays in central Queensland). Small-plot individual assessments (legumes and grasses) were also conducted on two new land-types in north Queensland (red and black basalt soils under low-moderate rainfall), which were omitted from B.NBP.0766. Bio-economic options analyses were conducted for the use of legume only or grass+legume strips on low fertility (red earth) and high fertility (red basalt) soils in north Queensland, drawing on yield and quality data from the two projects. The results were promoted through a range of extension processes, including field days, beef industry forums and national events and DAF media.

7.2 Key findings

The research program demonstrated excellent potential for legume-based production paddock systems in north Queensland. High yields of moderate to high quality forage in the early- to mid- dry season was achieved in legume only and grass+legume experiments across land-types and over years in north Queensland. The assessments were completed over a run of moderate to high rainfall seasons (associated with neutral and *La Nina* phase SOI) compared to long-term records. Bio-economic analyses using data for red earth and red basalt environments showed adoption of stylo and stylo+grass systems to be to be highly profitable at paddock and business levels.

7.2.1 Legumes and grasses for red and black basalt soils in low-moderate rainfall areas

Well-adapted grasses and legumes were identified for both black and red basalt soils representing the low-moderate rainfall (~550 mm aar) land-type near Charters Towers, an area representing ~6000 km^2 (close rainfall match) for the red basalt (clay) and ~2100 km^2 for the black clay (vertisol) landtypes. The assessments using replicated small plots grazed during the dry season were conducted between 2018 and 2022, with all years having higher rainfall than for long-term values. Under these conditions, native pastures yields in the order of 2.5 to 3.5 T DM/ha could be expected for land in A condition (Queensland Government, 2022).

Red basalt

- The best legumes for persistence (long-term cover) and yield were *Stylosanthes seabrana*, and *S. scabra* followed by *Macroptilium bracteatum*. Other legumes either failed to persist or produced low yields despite being persistent. Legume yields for the best adapted legumes were high: 7-9 T DM/ha for 7 months growth 3.5 years after sowing with higher yields in previous years; leaf content was relatively low when sampled, in the order of 1.5 to 2.0 T DM/ha. All legumes were well-accepted by cattle when grazed in the dry season.
- There was a wide range of well-adapted and productive grasses identified for this land-type. Black speargrass (*Heteropogon contortus*), the naturalised species for the land-type was persistent and productive, yielding 5 T DM/ha in year four. However, it was stemmy and highly unpalatable compared to most of the other grasses. The best performing grasses were creeping bluegrasses (*Bothriochloa insculpta*) and a range of *Brachiaria* spp. with yields between 3 and 6.5 T DM/ha. A range of Rhodes grasses (*Chloris* gayana) performed well early but declined in cover (and yield) over time. Late flowering varieties of Indian couch (*Bothriochloa pertusa*) produced excellent cover, but moderate yields.

Black basalt

- The legumes were assessed under high levels of competition from the naturalised grass (*Dichanthium aristatum*) which reduced legume cover markedly 2.5 years after sowing. The best legumes under these conditions were *Stylosanthes seabrana* (but failed in one year), *Macroptilium atropurpureum* and a range of *Desmanthus* spp. These were mostly newer legumes. Butterfly pea (*Clitoria ternatea*) produced moderate yields. Herbage yields were reduced by the grass competition but still exceeded 2 TDM/ha despite low sample cover for the better performing lines, reaching 3-6 T DM/ha for some *Desmanthus* and *S. seabrana*, although most of this was stem by the time it was sampled in June.
- Most grasses established strongly initially and invasion by the *Dichanthium* was less than for the legumes. Most had high levels of cover. Very high yields were maintained by some grasses, notably the more palatable *Dichanthium aristatum* sown variety (Floren) and the creeping bluegrasses (Bisset) (8-10 T DM). The Rhodes and late-flowering Indian couch grasses also had high yields, although appeared to be declining compared to earlier rankings. A range of grasses produced 2-3 T DM/ha, including Bambatsi *Panicum coloratum*, Gayndah *Cenchrus ciliaris* and two cultivars of *Digitaria milanjiana*. All sown grasses were well-grazed, particularly in comparison with the naturalised *Dichanthium*.

7.2.2 The establishment of production paddock systems

Establishment was assessed using methods suited to 'strip' systems whereby only strips are cultivated into native grassland and sown with legumes or grass+legumes. This enables the development of a seedbed between trees and reduces the cost of establishing a large legume population quickly within larger areas. It also reduces the risk of failure or soil erosion associated with poor or extremely heavy rainfall after sowing, respectively.

Methods tested ranged from rapid preparation with tines and glyphosate to make a rough seedbed over a few days to repeated cultivation and herbicide application over months. In all cases, seed of the selected grasses and legumes was broadcast at commercially recommended rates and rolled after sowing once it was considered the season had started and there was forecast rainfall. Either sulphur or phosphorous+sulphur fertiliser was incorporated with the cultivation shortly before sowing.

Initial germination of most legumes and grasses was high and surpassed levels required for a vigorous pasture regardless of preparation method or rainfall after sowing. The highest mean legume populations were small-seeded legumes, particularly stylos (up to 80 seedlings/m^2) and lowest for the large-seeded butterfly pea (*Clitoria ternatea*)(up to 20 plants/m^2) with other legumes intermediate. The grass populations showed a similar range to the legumes, with TGS1012 *Urochloa mosambicensis* and Basilisk *Brachiaria decumbens*, both large-seeded grasses, having consistently high initial plant populations. Legume and grass plant populations were highly variable between sample points using these preparation systems indicating variation in distribution or micro-environment for establishment.

Rainfall after establishment until the onset of the following wet season greatly influenced seedling survival, subsequent growth (and cover) and the opportunity to graze in the first season after sowing. Wet years were found to favour grasses and rapid growth overall (enabling light grazing six months after sowing) with the slower growing legume seedlings becoming overrun. Dry years favoured legumes because they survived better than grasses, but poor overall growth meant grazing would not be possible until the end of the next wet season (12-14 months after sowing). Very low rainfall (48 mm for the dry season) after sowing at one site resulted in a >80% decline in grass seedlings, but <50% decline of legume populations by the end of the season. The stylos and desmanthus were particularly resilient legumes and sabi (*Urochloa mosambicensis*) and creeping bluegrasses *Bothriochloa insculpta*) the most resilient grasses. All showed a remarkable capacity to grow following summer rainfall, with best grasses or legumes yielding 6-8 T DM/ha by May when grown in combination.

7.2.3 Competition between grasses, legumes and weeds in fertilised systems

Grass and legume growth was vigorous when fertiliser phosphorous and sulphur was applied to overcome perceived soil deficiencies based on recommendations from prior research in north Queensland. Cover was very high at all sites during the wet season (mostly >90% after establishment regardless of treatment) and there was considerable competition between plants.

The rudimentary methods used to prepare land for sowing into long-term native pastures (cultivation with a single application of glyphosate) effectively controlled adult plants and one generation of seedlings where rainfall allowed. However, there remained a reservoir of seeds to compete with the sown grasses and legumes, including naturalised low value plants: grader grass (*Themeda quadrivavlis*), early flowering Indian couch (*Bothriochloa pertusa*). At the red basalt site, these were present in plots where there was no sown grass (only legume) three years after sowing, unless sown to *S. seabrana* or *Desmanthus* spp. which competed most strongly with these grasses.

The relative competitive capacities of grasses and legumes were shown to greatly influence legume content:

- Grasses which established vigorously and maintained cover (*Bothriochloa insculpta, Urochloa mosambicensis*) suppressed legume growth for all but the most competitive legumes (*Clitoria ternatea, Stylosanthes seabrana*, *S. scabra*), whereas less competitive grasses allowed a greater range of legumes to grow.
- Grasses which either had strong running growth habits (Jarra *Digitaria milanjiana*) or a capacity to recruit plants from seed (ATF714 *Panicum coloratum*) had the capacity to compensate for poor initial populations and compete with most legumes.
- The effect of legume competition on grasses took longer to manifest and was less consistent. Some legumes failed to persist (*S. guianensis*, *M. gracile*) whereas others were

dominant when sown with less-competitive grasses (*S. seabrana* followed by *S. scabra* and *C. ternatea* depending on site). The new atro (TGS84989 *Macroptilium atropurpueum*) occasionally dominated plots and competed well by climbing, but was suppressed by grasshoppers in some summers.

7.2.4 Herbage yield and quality of legume-based production paddocks

Very high herbage yields were achieved over the 5-7 month growing periods (typically December to June) when using fertilised grass + legume combinations (subsequent dry season growth was not measured). Combined yields were 5-9 T DM/ha (up to 13) on red basalt and 3-5 T DM/ha (up to 5.3) on red earth soils. These are two to over three times the annual yields expected for these land classes (Queensland Government, 2022). Some key points:

- Grass and legume yields tended to increase on both soil types over time, except for the legumes which failed to persist (*S. guianensis*, *M. gracile*) or were sporadically damaged by grasshoppers (*Macroptilium atropurpueum)*.
- Total yields were highest for the combinations containing the competitive grasses (*Bothriochloa insculpta, Brachiaria brizantha, Urochloa mosambicensis*) or the competitive legumes (notably *S. seabrana*). Grass content tended to be higher than legume content, except when competitive legumes were grown with less competitive grasses, whereupon the legumes yielded highest.
- Combinations of the following produced high yields with a good grass-legume balance:
  - red basalt: Grasses – *B. insculpta, D. milanjiana, P. maximum*+hybrid*, U. mosambicensis*; Legumes – *C. ternatea, S. scabra, S. seabrana*
  - red earth: Grasses – *B. insculpta, D. milanjiana, P. maximum*+hybrid Legumes – *S. hamata, S. scabra, S. seabrana*

High levels of feed quality were measured in the early to mid- dry season, when the levels of dietary nitrogen (~1% or 6.25 % crude protein (CP) required for rumen function) and metabolisable energy (~7.5 MJ/kg) levels black speargrass pastures are normally below those required for animal growth, requiring selective grazing to optimise animal nutrition resulting in low stocking rates and poor livestock productivity (as cited by McLennan et al., 1988).

- Feed value was substantially higher for legumes than grasses on a whole plant basis and was highest for CP and ME for both in the wet season when plants had finer stems and were less mature.
- Grass CP and ME on a whole plant basis were all below the 'critical values' for growth during the wet and dry seasons, meaning selective grazing (grazing leaf over stems) would be required to optimise intake. Values were lowest in the black speargrass.
- Legume leaf (and fine stems), however, was of very high quality, even in the dry season: CP 13-20% and ME 7.6-10.2 MJ/kg. Legume stems mostly exceeded CP requirements for rumen function but had marginal values for ME. Legumes with twining habits (*Clitoria ternatea* and *Macroptilium atropurpureum*) or fine stems (*S. hamata*) had higher CP values than the high-yielding shrubby (self-supporting) types (*Stylosanthes* and *Desmanthus*).
- Leaf content during the dry-season was highest in the twining or fine-stemmed legumes (~40-60%) compared to the shrubby types (~25-40%).

7.2.5 Economic performance of legume-based production paddock systems in north Queensland

Bio-economic scenario analyses using herbage yield and quality data from B.NBP.0766 and B.NBP.0812 combined with historical, peer-assessed animal performance data for the assessed land-types, mean 5-year cattle prices and current costs found the introduction of 'production paddocks' to be highly profitable on infertile red earths and fertile red basalt soils in the Herbert and Burdekin catchment areas.

The additional herbage yield and high quality of feed (particularly legumes) compared to native grasslands resulted in highly profitable systems (discounted over 30 years) when introduced into the target land-types as strips, either as legumes alone (*S. seabrana* and *S. scabra*) or legumes (same) + grasses (*Bothriochloa insculpta* and *Digitaria milanjiana*).

- The pasture production benefit more than tripled animal production (liveweight gain/ha compared to unfertilised native grassland – also fenced) when legumes only were introduced increasing to a four to five-fold benefit with grasses + legumes.
- Input costs were highest on the red earth due to the application of phosphorous+sulphur fertiliser at planting and for periodic maintenance, compared to the red basalt soil (sulphur fertiliser only). The inclusion of grass also increased costs in the grass+legume strips.
- On a paddock basis (standardised 100 ha) annualised gross margins over 30 years and establishment costs were as follows:

	Red earth (P+S fertiliser)			**Red basalt (S fertiliser)**		
	Native	Stylo+grass	Stylo	Native	Stylo+grass	Stylo
Gross margin/ha	$13	$93	$47	$38	$236	$193
Costs to establish	-	$33,072	$27,470	-	$16,372	$10,770

- When the production paddocks were incorporated (<10% of total property area) into representative properties to grow young steers within the Burdekin (red earth) and Herbert/Burdekin (red basalt) breeder systems (using the production paddock costs for the marginal analysis), the following were achieved compared to the native grass scenario using a 5% discount rate over 30 years:

	Red earth (P+S fertiliser)		**Red basalt (S fertiliser)**	
	Stylo	Stylo+grass	Stylo	Stylo+grass
Annualised NPV	$58,560	$25,395	$102,656	$103,613
Peak deficit (with interest)	$624,800	$796,900	$248,800	$192,430
Payback period (years)	13	18	5	4
IRR	13%	9%	32%	37%

- The results were responsive to cattle prices, with the red basalt soil remaining highly profitable with a 25% decline on price, but the legume only system on red earth was unprofitable.

7.3 Benefits to industry

Key limits to business profitability (and debt servicing) in seasonally dry areas of north Queensland include high costs of production per head and poor returns associated with limited access to premium priced (weight-for-age) markets (finishing) and low breeder turnoff associated with poor heifer re-conception (Rolfe et al., 2016). Through addressing improved nutrition during the dry season by integrating persistent and productive legumes in to native pastures, this project has targeted the improved nutrition of key livestock classes required to improve business cash-flow and debt servicing.

The adoption of legumes is considered to be the best method to increase business resilience in seasonally dry areas of northern and central Queensland (Bowen et al., 2019; Bowen and Chudleigh, 2018) but adoption has been poor in north Queensland. This project has produced bio-physical and economic data to support the integration of legumes into beef businesses in seasonally dry areas of north Queensland through 'production paddock' systems. These enable higher levels of production over historical systems of broadcasting mostly stylos into native pastures and can be used to improve the nutrition of high-value livestock classes such as weaners, heifers and steers. Benefits include improved long-term business profitability through increasing the productivity and feed quality of native grass pastures and improved business resilience during dry periods through introducing legumes which persist under dry environments and respond when it rains.

7.3.1 Practical application at a business level

Legumes and grasses have been identified from the previous (NBP.0766) and current (B.NBP.0812) studies which are well-adapted to key land-types in north (mostly) and central Queensland and form productive combinations of grasses and legumes. Most of these are now commercially available, although newer cultivars of some species (*Macroptilium atropurpureum, Panicum* hybrids, *Urochloa mosambicensis*) are in earlier stages of commercial production following pre-commercial seed multiplication by DAF.

The project assessed the introduction of legumes into native pastures as 'strip' systems into discrete paddocks (say 200-500 ha) and supplementing soils available phosphorous and sulphur with fertiliser before planting and periodically there-after to maintain productivity. The systems enable a halving of the area required to grow livestock compared to native pastures and impart higher liveweight gains. Stocking rates in the order of 3-5 ha/AE could be run on red earth compared to 9.5 ha/AE on native pasture; the results are similar to LWG studied conducted on red earth soils within the region using fertilised long-term grass/legume (stylo + Wynn cassia)(Lemin et al, 2022).

The paddocks are relatively simple to implement with excellent establishment achieved using minimal cultivation and herbicide application even when there is poor rainfall after sowing. However, development requires planning to secure seed, fertiliser and equipment and the value proposition should be considered based on an assessment of current costs and expected market prices. Also, there are significant up-front costs and relatively short planting windows (wet season) which means they are best implemented progressively in stages. The costs are broadly half those of implementing leucaena pastures in north Queensland on a similar soil type (Bowen et al., 1999). The skills and equipment required to develop the production paddocks are readily achievable by most beef producers, although some specific knowledge is required to minimise the risk failure. There would be benefits of sharing equipment and expertise between neighbours and sourcing other technical advice (DAF, advisers) as required. Importantly, legume pastures have proven productive over the long term if managed appropriately, meaning that they should not require re-planting once established.

The use of production paddocks should provide more resilience to enterprises in the seasonally dry tropics by increasing livestock growth rates and therefore cash flow (weaner/steer sales) through turning off animals earlier or achieving higher sale weights. This can in turn decrease the amount of nitrogen supplements required for growth during the mid- to late- dry season and improve profitability without increasing stocking rates beyond sustainable levels. In dry years, they can be used to reduce reliance on drought feeding of breeders (animal welfare). Greater growth rates could theoretically improve heifer conception rates, but this is yet to be assessed.

7.3.2 Broader benefits to the red meat industry

The area represented by the on-property assessments in this, and the pre-cursor, study includes the moderate (600-900 mm AAR) rainfall belt north and west of Bowen in Queensland. This area contains ~30% of the total Queensland herd, which had an annual total value ~$5.7 billion farm gate in 2017 (Queensland Government, 2019). This includes the northern black speargrass, Aristida-Chrysopogon and Bothriochloa/Chloris zones extended in a 300-400 km sub-coastal band from Cape York to Bowen, covering the 550-750 mm aar rainfall belt (~22 Mha)(as described by Tothill and Gillies, 1992), but results can be applied further south into the black speargrass belt in central Queensland and west into the northern Gulf zone. The area broadly approximates the Einasleigh Uplands (100% of bioregion), eastern Gulf Plains (40%), Desert Uplands (50%) and northern sections of the Brigalow Belt (20%). Based on the analysis by Peck et al (2022), this area includes ~1450 businesses and contains ~2.25 million cattle or 21% of the Queensland herd.

Most enterprises breed and raise young steers and the key limitation to business productivity is seasonal supply of feed from native pastures. This becomes a substantial industry issue during extended dry periods as producers struggle with debt servicing. The use of sown legumes is a well-established method to improve seasonal supply and quality of feed for grazing in north Queensland and key land-types of the study area have long been considered suitable for legume adoption: Northern spear-grass: 12.1 Mha (natural carrying capacity of 5-15 ha/hd), Aristida-Chrysopogon: 2.3 Mha (18-30), Bothriochloa/Chloris: 8.0 Mha (6-10)(Tothill and Gillies, 1992).

The benefits of the introduction of legumes into native pastures in northern Australia is well known. These include; 10-30% increases in pasture production, 30-60 kg/head/year liveweight gain benefits, 20-30% increase in gross margins (McIvor and Gardener 1995; Hall et al. 2004; Ash et al. 2015). Estimations of industry benefits from the application of technologies should be treated with caution. However, substantial long-term annual benefits are considered to accrue if legumes are adopted broadly in north Queensland (Box 1). The production system investigated in this project (fertilised legumes in designated paddocks) can provide a significant lift in productivity over extensive (broadcast, no fertiliser systems) approaches used in the past. The two systems are complementary, both contributing to higher production capacity of businesses and the industry overall.

Box 1. Estimation of the benefit of adoption legumes in seasonally-dry north Queensland
In the seasonally dry zone, representing ~ 2.25 M hd, a typical herd structure includes ~30% weaners and steers which are grown and sold (allowing for replacement breeders). If it is presumed a long term stylo adoption (broad-scale, no fertiliser) ***of only 20%*** of the properties (affecting 20% of total cattle), approximately 135 000 hd steers and weaners would benefit from sown legumes each year. At an extra 40 kg/hd/yr and a sale price of $4/kg, the gross benefit would be $21.6 M/yr ($108 M pa for 100% adoption). For a business turning off 1000 weaners or steers, this equates to an additional $160 000 pa (before costs). This does not account for natural spread of stylos from where sown or increased stocking rates by using stylos in 'weaner paddocks' (see above). Neither does it account for better cattle weight-for-age or cull cow weight advantages and reproductive performance.

8. Future research and recommendations

Through identifying well-adapted and productive legumes for legume and legume+grass strip systems, providing regional estimates of herbage yield and quality and completing business level economic analysis of legume strip systems in north Queensland, this project has addressed many knowledge gaps required for adoption of production paddock systems. Higher performing grass and legume lines have also been progressed through the DAF seed program to early commercial production by commercial companies. Validation by graziers on larger scales across regions is now required to build confidence in the systems.

Well-adapted and productive legumes have been developed and commercialised (or in advanced stages of commercialisation) which can be used in extensive (historical) and more intensive (‘production paddock’) grazing systems for many key land types used for beef production in north Queensland. Recent economic analyses present the adoption and management of legumes as the most achievable way for landholders (with sound grazing land practice) in seasonally dry areas to achieve long-term sustainability and profitability (Bowen et al., 2019). The economic analyses from this project indicate ‘production paddocks’ can further this benefit (Finlay and Cox, 2022).

Historically low adoption of legumes in northern Australia (Cooksley, 2004) presents a significant opportunity to increase beef industry productivity in northern Australia. Despite significant benefits of legume adoption to productivity, adoption in north Queensland remains stubbornly low (<10% of producers, English *pers. comm.* 2022) and stylo (the key legume sold) sales are in the order of ~ 20-30 T/year) (M. Knowles *pers. comm.* 2022). A key challenge for adoption is to promote and demonstrate the ‘value proposition’ of legume adoption to graziers with limited ‘farming’ back-grounds and to invest in systems which can be reliably established at reasonably low cost.

8.1 Recommendations for future research

Many key research questions for the development of legume production paddocks have now been addressed and graziers are also becoming more familiar and using complementary research (e.g. adjusting management based on SOI, adopting automated infrastructure and pasture monitoring technology) which will enhance successful adoption of more intensive pasture systems. There is, however, a need to refine management methods based on commercial-scale plantings and management to develop more reliable messages for beef producers and reduce the cost of adoption over time.

R1. At commercial scale and under commercial grazing management, measure animal liveweight gain and use to refine business level economic analyses for production paddocks on land-types representing high and low fertility soils.

The research to date has been on a small-scale to identify best bet methods for developing production paddocks. This now needs to be scaled up to commercial conditions and animal performance measured to validate the production and economic benefits estimated to date. In doing so, practical producer questions should be addressed. Some key queries to date include:

- Is it better to establish production paddocks using strips or broadcasting? If I use strips, will the legumes spread into the surrounding pasture?
- Should I invest in less expensive systems to establish stylos or consider more expensive but also more productive systems like leucaena?
- How much benefit do I get from applying fertiliser phosphorous or sulphur? How do I know when to reapply? (see R2)

- What is the best way to graze my pasture to get good livestock performance and maintain long-term pasture health?

R2. *Identify optimum rates of fertiliser phosphorous and sulphur required to optimise legume (and pasture) growth.*
Fertiliser application represents a key driver of productivity (but also cost) (Finlay and Cox, 2022) on some soils and previous work looking at legume response rates in north Queensland has been limited to a limited range of land-types (e.g. Shaw et al., 1994). Conduct dose-type *experiments on different land types and legumes and trace nutrient sinks (plant vs soil).*

R3. Test the influence of seed coatings on the establishment performance of grass and legume seeds used for production paddocks compared to uncoated seeds across a range of dry-land environments.
The success of establishment is a key determinant of pay-back rates for sown pasture systems. Anecdotal evidence by pasture researchers over some 20 years indicate coated seeds impart no significant benefits (other than distribution or chaffy seeds) and may result in poorer establishment under marginal rainfall conditions.

R4. Assess the effectiveness of nitrogen fixation by legumes across land-types.
A key reason for legumes in pasture systems is to fix atmospheric nitrogen and improve nitrogen cycling for increased overall pasture growth (Peck et al., 2011). Some legumes readily form productive associations with native rhizobia, but inoculation of seed with specific strains is recommended for others including those well-suited to different north Queensland soils and which performed well within this study (*S. seabrana*, *Desmanthus* spp.)(Cook et al., 2005). Small-plot nitrogen response trials or sampling for effective rhizobium strains across different land-types would indicate where particular care is required to inoculate seeds, under which practices it is most successful and whether further development is required (new strains).

8.2 Recommendations for future adoption

Actions which encourage beef producers to either sow legumes for the first time, or build on previous adoption, should be prioritised. In doing so, it would be very useful to develop methods for keeping abreast of new sowings and the practices which are most effective.

R5. *Complete activities to estimate the level of adoption of legumes in north Queensland to focus future DAF extension and adoption activities and investment more broadly.*
The level of legume adoption in north Queensland (or more broadly in Queensland, with the exception of leucaena) has not been measured for decades and estimates of adoption are based on seed sales. Such estimates do not accommodate for failed sowings, spread of legumes over time or the mismanagement of stylo pastures rendering them unproductive. Systematic surveys (e.g. roadside) could be used to overcome these knowledge gaps. Alternatively, the 160 DAF land-type assessment sites (Shaw et al., 2022) could be revisited to update trends in land condition and legume productivity.

R6. Promote the adoption of production paddock systems through commercial scale demonstrations.
Use on-property research demonstrations and new regionally dispersed demonstration sites to encourage producer-to-producer knowledge exchange and encourage activities which increase producer knowledge and skills in the adoption of legumes. Small group extension is more likely to be successful, although there may be a role for workshops facilitated by technical experts.

The activities and focus should be producer-led as much as possible and measurements completed where possible to quantify benefits or otherwise.

R7. Coordinate legume adoption with the seed industry.
Legume seed is currently grown (mostly) in north Queensland by private seed growers mostly marketing through seed companies and is sold across northern Australia. The price and supply of seed of certain legumes to beef producers can limit adoption and there is a need to coordinate seed production with growing demand. This may also encourage examining the role of seed coating and effective management of seeds for optimum establishment performance. This includes rhizobium seed inoculants, treatment of dormancy and storage prior to sowing.

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