An evaluation of three tropical ley legumes for use in mixed farming systems on clay soils in southern inland Queensland, Australia

A. M. WHITBREAD, B.C. PENGELLY AND B.R. SMITH
CSIRO Sustainable Ecosystems/APSRU, Brisbane, Australia

Abstract

In the mixed grain-livestock producing subtropical regions of northern Australia, declines in the fertility of cropping soils combined with an increasing demand for high quality forage have prompted many producers to consider greater use of ley or phase pastures in their farming systems. The recently released tropical legumes, Lablab purpureus cv. Endurance and Macroptilium bracteatum cv. Juanita, and a previously commercially available legume cultivar, Clitoria ternatea cv. Milgarra, were compared at 3 on-farm sites across southern inland Queensland. L. purpureus produced its highest biomass in the first (range 1595–7037 kg/ha DM) and second years (range 4717–6150 kg/ha DM) but high plant mortality and an absence of seedling regeneration resulted in poor dry matter production in the third year. While C. ternatea produced low biomass in the first season (<1277 kg/ha DM), yields increased progressively, reaching 4047 kg/ha DM by the third year. Virtually all of the original plants of this species survived and 15–28 seedlings/m² established from high soil seed reserves, ensuring a persistent pasture. Biomass production of M. bracteatum in Years 2 and 3 was relatively stable on the sites with the deeper soil profiles (Downfall Creek and Brigalow) and ranged from 3382 to 4940 kg/ha DM. At one site, cropping activities over the previous 20 years had depleted soil nitrate-N content measured to 1.2 m prior to the legume phase, to 27–34 kg/ha N. Following the 3 seasons of legume production and a 12-month fallow, soil nitrate-N increased to 168–223 kg/ha N. At another site, soil nitrate-N contents of 177–180 kg/ha N were measured in the soil profiles to 1.5 m following the legume leys compared with only 74 kg/ha N in a continuous-wheat treatment. Management strategies to capitalise on this additional soil N are discussed.

Introduction

In the temperate southern Australian farming areas, ley-farming systems, i.e., alternately growing crops and short-term pastures, have been used for more than 50 years to maintain soil fertility, break the cycles of plant- and soil-borne pathogens and provide high quality forage for livestock enterprises. Annual pasture legumes such as barrel medic (Medicago truncatula), strand medic (M. littoralis) and subterranean clover (Trifolium subterraneum) are used extensively in legume-only pastures for this purpose (Bellotti 2001). Deep-rooted perennial legumes, particularly lucerne (Medicago sativa), are playing an increasingly important role in southern cropping zones where high rates of biological nitrogen fixation (BNF) and increased water use are high priorities (Dear et al. 2003). Until recently, interest in ley farming in the mixed grain-livestock producing subtropical regions of northern Australia has been limited for 2 main reasons. Firstly, many of the soils used for cereal production in these areas are self-mulching clays derived from basaltic parent material with high initial fertility. However, > 30 years of continuous cropping have depleted soil organic matter to an extent where external nitrogen additions are required to maintain the high grain protein levels which are characteristic of this region. Secondly, while lucerne and annual medics (Medicago spp.) have been introduced successfully in many mixed farming enterprises in southern Queensland and northern NSW, their use in central Queensland has been limited due to low...
and unreliable winter rainfall, disease constraints and serious bloat risk in cattle. Appropriate legume species were therefore unavailable.

A combination of high cattle prices in the late 1990s, declines in grain protein concentration and lower returns from cereal production, prompted farmers to consider growing pastures on land usually used for cereal production. They sought pasture systems that utilised legumes to fix nitrogen biologically and produce large quantities of high quality fodder to fatten cattle rapidly (Conway et al. 2001). In central Queensland, the area sown to C. ternatea has increased from 500 ha in 1996–97 to 30 000 ha in 1999–2000 (Doughton et al. 2001). These authors attribute the widespread adoption to a combination of a well adapted plant, readily available seed and the impact of the farming systems framework of research, development and extension.

The benefits of using legume-based pastures to overcome soil fertility decline have been well documented (Dalal et al. 1991; Dimes et al. 1996; Jones et al. 1996). While much of the early research built on the experience of southern Australia and the use of winter-growing legumes (Johnson and Lloyd 1991; Lloyd et al. 1991; Irwin et al. 2001), extensive research in the past 20 years has focused on tropical legumes for use on clay soils (Clem et al. 1996, 2001; Jones and Rees 1997; Pengelly and Conway 2000). As a result, a number of the tropical legume cultivars that are adapted to heavy-textured soils have been commercialised in the last 12 years.

The study described in this paper compares 3 new perennial tropical summer-growing legumes that have been released as a result of a decade or more of R, D and E, viz. Lablab purpureus cv. Endurance (Liu 1998), Macropodanthus bracteatum cv. Juanita (B.C. Pengelly, unpublished data) and Clitoria ternatea cv. Milgarra (Hall 1985, 1990, 1992). On-farm experiments were conducted at 3 locations in southern inland Queensland to measure dry matter production, plant survival and seedling recruitment under grazing. Soil nitrogen dynamics and subsequent cereal production were also studied at 2 of the sites.

**Materials and methods**

**Site description**

On-farm experiments were undertaken in southern inland Queensland at Brigalow (26°50’S, 150°51’E) on a deep grey vertosol soil, Condamine (26°52’S, 150°7’E) on a grey vertosol and Downfall Creek (26°16’S, 150°11’E) on a black vertosol (Table 1). The soil at the Brigalow site has the highest plant-available water capacity (PAWC) to 1.8 m of 217 mm, while the shallower soils at the other 2 sites held less water (Table 1). All sites had been used for continuous crop production for >25 years as reflected by the low organic C concentrations. PAWC is calculated from the field determination of the water content of the drained upper limit minus the water content of the lower limit of water extraction by wheat following the procedure of Dalgleish and Foale (1998). The original native vegetation that was associated with these sites is also listed in Table 1.

**Legume evaluation phase**

At Downfall Creek on December 3, 1998 and at Condamine on January 11, 1999, inoculated seed of L. purpureus cv. Endurance, C. ternatea cv. Milgarra and M. bracteatum (CPI 55769) was sown into 1 ha plots (fenced separately, no replication) at 18, 11 and 6 kg/ha, respectively. At the Brigalow site on November 10, 1997, seed of L. purpureus cv. Endurance and M. bracteatum

---

**Table 1. Location, soil type, total organic carbon concentration (0–15 cm), plant available water capacity (PAWC) and planting date for the 3 on-farm sites.**

<table>
<thead>
<tr>
<th>Site</th>
<th>Property name</th>
<th>Soil type</th>
<th>Native vegetation</th>
<th>Depth (m)</th>
<th>Organic C (%)</th>
<th>PAWC1 (wheat) (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condamine</td>
<td>Toston</td>
<td>Grey vertosol</td>
<td>Brigalow1, Belah2</td>
<td>~1.2</td>
<td>1.2</td>
<td>168</td>
</tr>
<tr>
<td>Downfall Creek</td>
<td>Lyndale</td>
<td>Black vertosol</td>
<td>Brigalow and Eucalyptus spp.</td>
<td>~1.5</td>
<td>1.2</td>
<td>191</td>
</tr>
<tr>
<td>Brigalow</td>
<td>Karingal</td>
<td>Grey vertosol</td>
<td>Brigalow</td>
<td>&gt;1.8</td>
<td>1.1</td>
<td>217</td>
</tr>
</tbody>
</table>

1 PAWC = Plant available water capacity in the estimated soil depth for each site.
2 Total organic carbon not measured at the Condamine site.
3 Brigalow = Acacia harpophylla.
4 Belah = Casuarina cristana.
only was sown into 17 × 4.5 m plots (3 replications). The Condamine site received 11.5 kg/ha P and 9.5 kg/ha S in the form of single superphosphate prior to planting and the legume seeds were direct drilled into standing wheat stubble. The other 2 sites were sown with conventional combines into cultivated seedbeds and did not receive basal P and S application.

At the Brigalow site, an additional continuous-wheat treatment was grown in winter 1998 and 1999 without fertiliser N (described in the next section). The experiment at Brigalow was replicated 3 times and laid out in a randomised complete block design. The herbicide Spinnaker® (active ingredient = 700 g/kg Imazethapyr) was sprayed on the C. ternatea and M. bracteatum at 400 mL/ha 3–4 weeks after planting and again in the following summer period to control grass weeds in the second season. Spinnaker® is a group B herbicide (inhibitors of the enzyme acetolactate synthase). The wetting agent Hasten® (1% v/v) was tank-mixed with the Spinnaker® on both occasions.

Cattle first grazed the pastures at 85, 93 and 101 days after planting at the Downfall Creek, Condamine and Brigalow sites, respectively. The 1 ha paddocks at Condamine and Downfall Creek were grazed by 15–20 cattle for 3 weeks. Ten head of cattle grazed the small plots at Brigalow for 3 days only to restrict trampling damage and this site was not grazed again during the 3 seasons of legume growth. In the second and third seasons, the Condamine and Downfall Creek sites were grazed in December and again in late summer for 2–3 weeks.

Cereal assay phase

At the Brigalow site, plots in the continuous-wheat treatments were sown (cv. Kennedy) on June 10, 1998 and harvested on November 5, 1998. These same treatments were sown on July 9, 1999 and harvested on November 11, 1999.

All plots, including the legume plots, were sprayed with glyphosate, a knockdown herbicide, on February 10, 2000. In order to assay the effect of the legume pastures, all plots were sown with 40 kg/ha of cv. Hartog on June 22, 2000. However, due to low subsoil water reserves and rainfall, this crop died soon after emergence. On November 8, 2000, Sorghum bicolor cv. Buster was sown into all plots at 4.5 kg/ha and was harvested on April 4, 2001. After a 15-month fallow, during which weeds were controlled by glyphosate application and an application of Ally®, a final wheat crop (cv. Kennedy) was sown across all plots at a planting rate of 40 kg/ha on June 23, 2002 and harvested on October 22, 2002.

At the Downfall Creek site, the legume pastures were sprayed with herbicide on May 15, 2001 (glyphosate + Starane®) and September 2, 2001 (MCPA + Ally®) and the area cultivated twice in September 2001. These plots were kept weed-free during summer, were sown to wheat (cv. Kennedy) on June 28, 2002 at 28 kg/ha and were harvested on October 29, 2002.

There was no cereal assay phase at the Condamine site.

Plant measurements

At the Brigalow site, calibrated yield ratings (visual ranking of legume biomass calibrated using quadrat cuts of legume biomass in Replicate 1) were used to measure legume biomass: prior to the first grazing (March 10, 1998), termed Year 1; on February 26, 1999, termed Year 2; and on February 9, 2000, termed Year 3 (Figure 1).

At the Condamine and Downfall Creek sites, 6 permanent transects at evenly spaced intervals across each of the 1 ha paddocks were marked and sites along these transects became the permanent sampling points for the legume biomass harvests and soil nutrient samplings. All legume biomass harvests were estimated with cuts of the above-ground legume material in 0.5 m² quadrats at 3 positions adjacent to each of the permanent transect sites. At the Downfall Creek site, the Year 1 harvest was taken on February 26, 1999, Year 2 yield was the total of cuts taken on November 30, 1999 and in February–March 2000 and Year 3 yield was the total of cuts on November 28, 2000 and March 2, 2001. At Condamine, the Year 1 harvest was taken on April 14, 1999, Year 2 yield was the total of cuts taken on December 2, 1999 and January 5 or 19, 2000 and the Year 3 harvest was taken on December 13, 2000 (Figure 1). To estimate plant material remaining after harvest, a second biomass cut was taken in Years 1 and 2 following grazing.

Established seedlings of each legume were counted in twenty 1 m² quadrats (50 quadrats were used for the L. purpureus treatments) before the first harvests at Condamine and Downfall
Figure 1. Total monthly rainfall at: (a) Brigalow site (November 1997–October 2002); (b) Downfall Creek; and (c) Condamine sites (November 1998–October 2002).

- Year 1 biomass samplings
- Year 2 biomass samplings
- Year 3 biomass samplings
Ley legumes for clay soils

At Brigalow, counts were taken in 2 quadrats for each replicate. To determine the numbers of surviving original plants and newly recruited seedlings, the same sampling procedures were employed prior to the first harvests in Years 2 and 3.

At all 3 sites, surface soil samples (0–10 cm) were collected from 10 cm diameter cores after seed set to determine the amount of seed contained in the topsoil. At the Brigalow site, 12 soil samples were collected randomly across each plot and bulked. These samplings were taken in the spring of Years 2 (October 20, 1998) and 3 (September 10, 1999). At the Condamine and Downfall Creek sites, the surface soil samples were collected at 4 points within each treatment in the spring of Years 2 (September 7, 1999) and 3 (October 23, 2000). Legume seed was recovered from the soil samples by washing seed from the soil using the technique of Jones and Bunch (1988).

Soil measurements

Soil samples for nitrate analysis were collected at the beginning of the trial (December 1998), again in the third season of legume growth (November 2000) and pre-sowing and post-harvest (May and November 2002) of the wheat assay phase at Downfall Creek. At the Brigalow site, samples were collected following the legume-wheat phase in June 2000 and again pre-wheat sowing and post-wheat harvest (June and November 2002). Plots were sampled to a depth of 1.5 m using a vehicle-mounted hydraulic soil-coring device and cut into the following increments: 0–15, 15–30, 30–60, 60–90, 90–120 and 120–150 cm. These were then dried (<80°C), ground (<2 mm) and analysed for nitrate-N using the method of Keeny and Nelson (1982). Subsamples were dried at 100°C and water content was determined. Nitrate and soil water content (SW) were calculated to 1.5 m depth at Brigalow and 1.2 m depth at Downfall Creek using the procedures of Dalgleish and Foale (1998). Soil water content was calculated as amount of water contained in the soil above the lower extractable limit of wheat.

Statistical analysis

The data from the replicated treatments at Brigalow were analysed as a fully randomised factorial design of 3 treatments × 3 replicates and mean separation was tested using Duncan’s multiple range test (DMRT) at P<0.05. All data were found to be normally distributed and were not subjected to transformation. Due to financial and logistical constraints, the experiments at the Downfall Creek and Condamine sites were unreplicated, with the result that spatial variability on the treatments could not be properly interpreted. Within each treatment, however, the stratified transect sites were considered as replicates and analysed using ANOVA procedures. The sites were carefully selected on the basis of the uniformity of soil type and similarity to the surrounding soil-vegetation association. Soil variation across these sites was minimal as indicated by the low standard error of the means, which were calculated from the permanent transect sampling points to indicate variation.

Results

In the 2 months prior to planting of the legumes, all sites received more than 100 mm of rainfall resulting in good stored soil water. The moisture content to 1.5 m depth measured at sowing only for Downfall Creek was 115 mm indicating that the profile was 60% full (PAWC = 191 mm, Table 1). Germination of the 3 species at all sites was above 66% resulting in excellent establishment. Rainfall received between sowing and the first dry matter harvest (the day before the plots were grazed) was 245, 361 and 371 mm at the Condamine, Downfall Creek and Brigalow sites, respectively (Figure 1).

Legume production

Condamine. Despite good germination and establishment, dry matter production in Year 1 was low for all legumes and reached a maximum of 1595 kg/ha DM in the *L. purpureus* treatment (Figure 2). A dry period, where only 2 separate falls of 5 and 9 mm of rain were received over the preceding 41 days, contributed to this low plant production. With the exception of a high *L. purpureus* biomass in Year 2, plant production at Condamine remained low throughout the trial and was related to low rainfall (Figure 1) and low plant population.

Downfall Creek. At Downfall Creek, *L. purpureus* produced more biomass in Year 1 than other legumes and realised a maximum of...
A.M. Whitbread, B.C. Pengelly and B.R. Smith

6150 kg/ha DM in Year 2 before declining to <2 t/ha in the third season (Figure 3) due to death of the original plants and the absence of seedling recruitment. *M. bracteatum* also increased in yield from Year 1 to Year 2 and declined slightly in the third year. *C. ternatea* production increased with each successive season (Figure 3) reflecting its strong persistence and seedling recruitment.

**Brigalow.** Legume production at Brigalow was very high, especially in Year 1 with dry matter production of *M. bracteatum* and *L. purpureus* at 101 days exceeding 7 t/ha DM (Figure 4). There was a decline in dry matter production in Years 2 and 3 corresponding with loss of some of the original plants. Light grazing at this site resulted in high plant survival and good biomass production of *L. purpureus* compared with the other sites where its production was very poor in the third season.

**Measurement of plant material that remained following grazing** showed that, on average, 75, 60 and 64% of the *C. ternatea*, *M. bracteatum* and *L. purpureus* legume material initially on offer, respectively, was consumed by the cattle (data not shown). The remainder was mainly stem material, fallen leaves and dead plants.

**Plant dynamics**

Almost all of the original *C. ternatea* plants survived throughout the trials at Condamine and Downfall Creek (Figure 5). The apparent slight increase in the number of original plants present in spring of Year 3 was due to the difficulty in distinguishing original plants from those self-sown in Year 2. The large increase in seedling numbers, measured in spring in Years 2 and 3, is a result of the large quantity of seed being set (Table 2). Average seed weight for each legume, measured in spring of Year 2, is listed in Table 2.
Ley legumes for clay soils

Average seed weight: 
- C. ternatea = 24 seeds/g,
- M. bracteatum = 165 seeds/g,
- L. purpureus = 5.5 seeds/g.

While there was a large decline in the numbers of original M. bracteatum plants persisting into Years 2 and 3 (Figure 6), high seedling recruitment in the spring of Year 3 compensated for plant mortality. Soil seed numbers increased from 119 seeds/m² in Year 2 to 363 seeds/m² in Year 3 at Condamine, while at Downfall Creek large amounts of seed present in Year 2 (823 seeds/m²) had declined to 330 seeds/m² in Year 3 (Table 2). This decline was associated with high numbers of seedlings (73 plants/m²) in Year 3, reflecting the favourable seedling recruitment conditions during this time.

For L. purpureus, plant population density was lowest at Condamine. While the original population of plants largely persisted until the spring of Year 2 (Figure 7), there was a substantial decline in numbers of original plants in the third year. No seed of this legume was produced and hence no seedlings established at any of the sites.

**Figure 6.** Survival of original plants of M. bracteatum at Condamine, Downfall Creek and Brigalow over 3 years. (Bars represent s.e.).

Cereal assay phase

**Brigalow.** Spraying the legumes with herbicide on February 10, 2000 left a 4-month fallow period prior to sampling for soil water and nitrate. In the continuous-wheat treatments, there was a 7-month fallow period from the 1999 wheat crop until the June 2000 soil sampling that resulted in significantly more soil water being stored (Table 3). Soil nitrate-N following lablab was significantly higher than following M. bracteatum or continuous-wheat (Table 3). The wheat crop planted in June 2000 failed to grow on all treatments due to drought during winter (Figure 1). The second attempt at planting a cereal assay crop was with sorghum in November 2000 with grain yield of 1329 kg/ha on the

**Figure 7.** Survival of original plants of L. purpureus at Condamine, Downfall Creek and Brigalow over 3 years. (Bars represent s.e.).

- **Table 2.** The number of seedlings and soil seed numbers of 3 ley legumes at 3 sites in spring of Years 2 and 3 after sowing.

<table>
<thead>
<tr>
<th></th>
<th>Seedlings (no./m²)</th>
<th>Soil seed (no./m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Year 2</td>
<td>Year 3</td>
</tr>
<tr>
<td>Condamine</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C. ternatea</td>
<td>1.9</td>
<td>13</td>
</tr>
<tr>
<td>M. bracteatum</td>
<td>2</td>
<td>20</td>
</tr>
<tr>
<td>Downfall Creek</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C. ternatea</td>
<td>10</td>
<td>28</td>
</tr>
<tr>
<td>M. bracteatum</td>
<td>20</td>
<td>73</td>
</tr>
<tr>
<td>Brigalow</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M. bracteatum</td>
<td>2</td>
<td>18</td>
</tr>
</tbody>
</table>

Average seed weight: C. ternatea = 24 seeds/g, M. bracteatum = 165 seeds/g, L. purpureus = 5.5 seeds/g.

While there was a large decline in the numbers of original M. bracteatum plants persisting into Years 2 and 3 (Figure 6), high seedling recruitment in the spring of Year 3 compensated for plant mortality. Soil seed numbers increased from 119 seeds/m² in Year 2 to 363 seeds/m² in Year 3 at Condamine, while at Downfall Creek large amounts of seed present in Year 2 (823 seeds/m²) had declined to 330 seeds/m² in Year 3 (Table 2). This decline was associated with high numbers of seedlings (73 plants/m²) in Year 3, reflecting the favourable seedling recruitment conditions during this time.

**Table 3.** Grain yield of wheat from the continuous-wheat treatments in Years 1 and 2, starting soil water (SW) and nitrate-N content (0–1.5 m) in June 2000 and grain yield of the assay sorghum phase in April 2001 at Brigalow.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Wheat grain yield 1998 (kg/ha)</th>
<th>Fallow length (months)</th>
<th>June 2000</th>
<th>April 2001 Sorghum yield (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1998</td>
<td>1999</td>
<td>SW (mm)</td>
<td>NO₃-N (kg/ha N)</td>
</tr>
<tr>
<td>Continuous-wheat</td>
<td>3360</td>
<td>2037</td>
<td>7</td>
<td>36 a¹</td>
</tr>
<tr>
<td>M. bracteatum</td>
<td>4</td>
<td>0 b</td>
<td>59 b</td>
<td>428 b</td>
</tr>
<tr>
<td>L. purpureus</td>
<td>4</td>
<td>4 b</td>
<td>101 a</td>
<td>388 b</td>
</tr>
</tbody>
</table>

¹ Means within columns followed by a different letter are significantly different according to DMRT (P<0.05).
continuous-wheat treatments exceeding that on the legume treatments (388–428 kg/ha; P<0.05).

Prior to the second assay crop in 2002, no significant difference was measured in soil water between treatments. Soil nitrate-N levels on treatments where *M. bracteatum* or *L. purpureus* had been grown were more than double those measured in the continuous-wheat treatments and this trend continued through to the post-harvest sampling (Table 4). Grain yields exceeded 3 t/ha on all treatments at an average grain protein concentration of 13.5%.

**Downfall Creek.** The low soil nitrate-N contents measured prior to the establishment of the legumes reflect the nutrient depletion as a result of the previous wheat crops (Table 5). By November 2000, following 2 seasons of legume growth, soil nitrate-N content on all treatments had increased from the initial levels with the greatest increase following the *L. purpureus* pasture. The highest soil nitrate-N content was measured during May 2002, prior to wheat being sown across the treatments. Within the legume treatments, the *L. purpureus* plots generally had the highest nitrate-N content, although differences between treatments were not significant (P>0.05) at any of the sampling times. Total soil organic carbon, measured at intervals throughout the trial, showed constant concentrations of 1.2 and 0.8% in the 0–15 and 15–30 cm depths, respectively (data not presented), that were not influenced by the legume treatments.

Stored soil water measured in May 2002 showed that the soil profile under the *C. ternatea* treatments was much drier than under the other legume treatments (Table 6), reflecting the

| Table 4. The pre-sowing soil water content (SW) and nitrate-N (0–1.5 m) and the final grain yield, protein concentration and soil nitrate-N content (0–1.5 m) of the 2002 assay wheat phase at Brigalow. |
|---------------------------------|-----------------|-----------------|-----------------|-----------------|
| Treatment                      | Pre-sowing June 2002 | Harvest Nov 2002 |
| SW (mm)                        | NO$_3^-$N (kg/ha N) | Yield (kg/ha) | Protein (%) | NO$_3^-$N (kg/ha N) |
| Continuous wheat               | 146 a           | 74 b       | 4243 a       | 12.6 a       | 7 b         |
| *M. bracteatum*                | 109 a           | 180 a     | 3169 a       | 14.1 a       | 83 a        |
| *L. purpureus*                 | 133 a           | 177 a     | 3408 a       | 13.8 a       | 84 a        |

1 Means within columns followed by a different letter are significantly different according to DMRT (P≤0.05).

| Table 5. Soil nitrate-N content (0–1.5m) measured prior to the legume phase (December 1998), after 2 seasons of legume growth (November 2000) and before and after the 2002 wheat crop at Downfall Creek. |
|------------------------------------------|-----------------|-----------------|-----------------|-----------------|
|                                          | (kg/ha N) | (kg/ha N) | (kg/ha N) | (kg/ha N) |
| *C. ternatea*                            | 33 (6.1)$^1$   | 44 (6.2)   | 191 (20)   | 96 (17)    |
| *L. purpureus*                           | 27 (4.1)   | 96 (18.6)  | 223 (17)   | 135 (21)   |
| *M. bracteatum*                          | 34 (2.7)   | 68 (1.7)   | 168 (29)   | 78 (35)    |

1 s.e. shown in brackets.

| Table 6. The pre-wheat extractable soil water content (SW), final grain yield and protein concentration and total N uptake in plant tops at Downfall Creek (0–1.5 m). |
|------------------------------------------|-----------------|-----------------|-----------------|-----------------|
| Treatment                                | May 2002 | Grain yield | Protein (%) | Total tops N uptake |
|                                          | SW (mm) | (kg/ha)     | (%)           | (kg/ha N)       |
| *C. ternatea*                            | 84 (11.8)$^1$ | 1917 b$^2$  | 16.0 (0.7)   | 66 (8.2)      |
| *L. purpureus*                           | 133 (2.2)  | 2603 a (108) | 16.1 (0.2)   | 80 (4.1)      |
| *M. bracteatum*                          | 127 (3.9)  | 2667 a (201) | 16.5 (0.1)   | 88 (3.6)      |

1 s.e. shown in brackets.

2 Means within columns followed by a different letter are significantly different according to DMRT (P≤0.05).
highest biomass production in Year 3 in this treatment (Figure 2). Grain yields following *L. purpureus* and *M. bracteatum* were higher (P<0.05) than following *C. ternatea*, reflecting the higher pre-sowing SW. Total N in tops was also higher on these treatments. Grain protein (16.0–16.5 %) reflected the very high available nitrate levels in all treatments.

**Discussion**

*Legume production*

*L. purpureus* and *M. bracteatum* out-yielded *C. ternatea* between sowing and the first grazing (~100 days) and continued to produce well into the second season. However, low plant survival and lack of seedling recruitment resulted in a sharp decline in biomass production of *L. purpureus* in the third season. This decline was less pronounced at Brigalow and was probably due to the plants being grazed only in the first season. While 73–93% of the original plants of *M. bracteatum* failed to survive to Year 3 at all sites (Figure 6), seedling recruitment of up to 73 plants/m² ensured the survival and continued productivity of this species. Grazing management practices that allow some flowering and seed set will need to be adopted by graziers if the aim is to have a longer-term pasture. The environmental conditions that facilitated significant germination of *M. bracteatum* seeds between spring Year 2 and spring Year 3 (Table 2) may indicate that frequent replenishment of the soil seed reserves might be necessary to overcome a rapid decline in seed reserves when environmental conditions favour germination. Little is known at this stage about the seed-dormancy mechanisms of this species. Due to the low plant survival of *M. bracteatum* cv. Juanita, the commercial release of ‘Burgundy bean’ included cv. Cadarga (CPI68892), which displays stronger perenniality than cv. Juanita, but less seedling recruitment. In the highly variable rainfall environments of Queensland, a mixture of both cultivars is the best strategy for ensuring persistence and production.

While *C. ternatea* produced the least biomass of the 3 species tested at Downfall Creek in Year 1, biomass increased progressively over time. We hypothesise that this legume directs resources initially into developing a taproot system rather than into above-ground production. Both *L. purpureus* and *M. bracteatum* have rooting systems that are more susceptible to death by overgrazing and herbicide application (field observations by the authors). In addition to the high survival of the original *C. ternatea* plants at all sites, seed set and seedling recruitment resulted in increasing plant population density during the experimental period. Bowen (2003) collected extrusa, digesta and faecal samples from cattle grazing *C. ternatea*-grass pastures and found that *C. ternatea* seed was ingested in large quantities. While no associated quantitative measurements were made on pod consumption or pod digestibility, appearance of seedlings in dung in adjacent fields indicates that at least some of this seed remains viable after passage through the digestive tract.

Low production at Condamine for all species was related to the lower rainfall received at this site and the shallow soil profile (~1.20 m) restricting rooting depth and consequently PAWC. Trampling and soil puddling damage occurred in the *C. ternatea* and *M. bracteatum* treatments in Year 2 during a period when cattle were grazing the plots and a heavy rainfall event occurred (January 7–12, 2000). While this event may have further depressed yields in Year 3, the biomass figures reported for Year 3 are from 1 sampling event in early summer and underestimate potential production for the whole season.

*Cereal production following the legume leys*

*Soil water management.* Under dryland farming systems where adequate rainfall and soil water frequently limit crop production, the transition from pasture to cropping can be difficult to manage. After a legume pasture, stored soil water is usually low and, depending on the rainfall received after the pasture phase is terminated, a long fallow period may be required to recharge soil water before planting a cereal crop. The negative effect of low soil water on grain yield was demonstrated at the Brigalow site, where sorghum, planted 9 months after the legume phase, produced significantly less grain than the continuous-cereal treatment. Inadequate rain had fallen prior to and during the sorghum phase to even up the treatment differences in stored soil water or produce good sorghum growth. The *C. ternatea* treatment at Downfall Creek also showed that a deep-rooted legume, producing
high biomass, will deplete the soil profile of moisture resulting in poor grain yield of a subsequent cereal phase where starting soil water and in-crop rainfall are low. Holford (1992) found that 12 months of lucerne growth caused drying of the soil to 2 m, resulting in depressed wheat yields. He concluded that adequate rainfall between the lucerne crop and the next cereal crop was needed to rewet the soil to exploit the benefit of the lucerne phase. Therefore, timing the removal of the pasture phase is vital. McCallum et al. (1996) also reported declines in wheat yield of up to 827 kg/ha following a lucerne phase, which were attributed to low soil water. Despite differences in nitrate-N in the different treatments, available water was the primary limiting factor. The higher sorghum yields in 2001 (Table 3) on the continuous-wheat treatment were a function of higher soil water on this treatment. In the 2002 wheat crop, soil water was again the primary limiting factor. The extra 13–37 mm of soil water contained in the continuous-wheat treatment, relative to the legume treatments, could account for an extra 260–740 kg/ha wheat grain using a water–use efficiency of 20 kg grain/ha/mm of stored water.

Nitrogen dynamics. No direct measurements of N-fixation were made during these experiments. It could be assumed, however, that, due to the low soil organic matter and nitrate-N measured at Downfall Creek and Condamine at the commencement of these trials, legumes would be mainly dependent on biological N-fixation for supply of N to the vigorously growing plant. Armstrong et al. (1997) showed that, in central Queensland, under a relatively high soil nitrate-N content of 65 kg/ha N (0–120 cm) and over a 4-month growth period, *L. purpureus* cv. Highworth, *M. bracteatum* (CPI 27404) and *C. ternatea* cv. Milgarra derived 34, 40 and 45%, respectively, of the nitrogen in above-ground biomass from the atmosphere. N-fixation is most efficient early in a pasture rotation, and Armstrong et al. (1999a) showed that, in tropical legume pastures grown in central Queensland, 50–70% of N in the legume tops was derived from fixation in Years 1 and 2. This decreased to <13% in Years 3 and 4 of the rotation. A large amount of data also exists on the N benefits of pasture systems in southern Australian farming systems. Peoples and Herridge (1990) reported that N-fixation ranged from 20–25 kg N/t dry matter regardless of species, soil type and environment in southern Australian systems.

Very large amounts of soil nitrate-N were measured in the legume treatments at Brigalow and Downfall Creek after the 3-year legume leys were terminated (Tables 4, 5 and 6). In comparison with continuous-wheat at Brigalow, soil nitrate-N remained high even after the sorghum and wheat crops had been harvested. This N cannot be utilised until another crop is sown, by which time it may be transformed back to the organic phase or lost through leaching and denitrification processes (Pu et al. 2001). The use of a ‘mop-up’ crop, such as forage sorghum, has been suggested as a method of utilising available mineral N present after a legume ley (Weston et al. 2000). Doughton et al. (1996) showed that a forage sorghum crop, which contained 116 kg/ha N in the plant tops, reduced the available soil nitrate-N to less than 40 kg/ha N compared with almost 200 kg/ha N on a treatment which was cultivated and had no crop grown. In a normal farming system, these tops would be grazed and, excluding some N removal in livestock, most of the N would be returned to the soil in predominantly organic forms. While a ‘mop-up’ crop may prevent soil mineral N losses, this system is unlikely to fit into such water-constrained environments in south-east and central Queensland.

Residual value. Maximising the residual effect of the legume ley on subsequent cereal crops is desirable for profitability. This effect may be direct through the supply of additional soil N or indirect, e.g. improvements in soil physical conditions that may increase crop germination and water infiltration (Whitbread et al. 2000a; 2000b). The cereal assay phase reported in this paper did not continue for long enough to measure residual effects; however, other similar studies have drawn conclusions. Holford (1992) reported beneficial effects on wheat lasting for at least 9 years following a lucerne phase of 2.5–5.5 years on a calcic vertosol (black earth). Marcellos and Felton (1992) investigated the effect of one season of chickpea, wheat or long fallow on the grain yield of 2 subsequent wheat crops. The increase in yield of the first wheat crop following both a chickpea phase and long fallow ranged from 0.41 to 2.11 t/ha. They also found that the level of soil nitrate-N at sowing of the wheat crop strongly influenced wheat yields, but there were no benefits to subsequent wheat
crops. Armstrong et al. (1999b) showed that legume leys consistently resulted in large increases in grain yield (188–272%) and grain protein (0.2–7.0%) in sorghum test crops compared with continuous sorghum. These effects persisted for up to 3 cereal crops and Vigna radiata cv. Satin and L. purpureus cv. Highworth produced the best responses in sorghum yield in the first season after the legume pastures.

This paper describes a pure legume pasture system where a residual herbicide (Spinnaker®) was used to prevent grass species from becoming established. Under farmer-managed conditions, where expensive herbicides are unlikely to be used past the initial establishment phase, various grass species would become established as the competition from legumes declined and as soil nitrate-N concentrations increased due to BNF. We consider that managing the establishment and persistence of both the legume and grass species is desirable to maximise pasture production, forage quality, biological N-fixation and ultimately soil organic matter dynamics. Dalal et al. (1995), reporting on the Warra trial in south-east Queensland, showed that 2, 3 and 4-year grass-legume leys effectively increased organic carbon content while short-term lucerne and annual medic leys, chickpeas and N fertiliser did not.

Conclusions

Mixed crop-livestock systems require well adapted legume species to produce high quality forage and improve soil fertility. The 3 new legumes (M. bracteatum and C. ternatea and the perennial form of L. purpureus, cv. Endurance) can contribute successfully in various situations.

M. bracteatum cv. Juanita can produce large amounts of seed and can rely on seedling recruitment to maintain plant populations. The commercial release of Burgundy bean in 2002 included the M. bracteatum cv. Juanita described in this paper and the strongly perennial form of cv. Cadarga (CPI68892).

C. ternatea cv. Milgarra can also produce large amounts of seed and can rely on plant survival and seedling recruitment to maintain and increase the plant population. While biomass production in the first season might be low, production will increase in subsequent seasons.

These legumes are therefore suitable for leys of varying length, which can be influenced by the grazing pressure imposed. The growth of all the legumes will result in large amounts of soil nitrate-N build-up, presumably through BNF. This N could be utilised by a subsequent cereal crop with a marked increase in grain protein concentration. The recharge of soil water following a legume ley is essential to capitalise on the high soil nitrate-N content, so the timing of removal of the ley is vital.

Further work on the adaptation of M. bracteatum to the northern NSW region is suggested. Future work should aim at a better understanding of the agronomy and management of these species and their effective integration into farming systems including grass-legume mixed pastures. Maximising the residual value of soil organic matter and nitrogen from grass-legume pastures also requires further investigation.

Acknowledgements

Financial support was provided by the Grain Research Development Corporation-funded CSA3 National Annual Pasture Improvement Program (NAPILP) and the Australian Centre for International Agricultural Research (ACIAR) AS2/96/149 forage legume program in southern Africa. The skilled technical assistance of Mrs Cristine Hall and Mr John Donnelly is gratefully acknowledged. Dale and Lyn Stiller of ‘Lyndale’ at Downfall Creek, Neil and Kathy Wegener of ‘Karingal’ at Brigelow and Paul Keys of ‘Toston’ at Condamine are thanked for providing land and animals and for assisting in the planning and management of these on-farm experiments.

References


(Received for publication January 13, 2004; accepted May 22, 2004)