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Legume and opportunity cropping systems in central Queensland. 1. Legume growth, nitrogen fixation, and water use

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Abstract. An experiment, established on a cracking clay (Vertisol) at Emerald, central Queensland, studied the dry matter (DM) production, nitrogen (N) fixation, and water use of several potential ley-legume species over 4 seasons (1994–1997). Four ley legumes (siratro, *Macroptilium atropurpureum* cv. Siratro; lucerne, *Medicago sativa* cv. Trifecta; lablab, *Lablab purpureus* cv. Highworth; and desmanthus, *Desmanthus virgatus* cv. Marc) were compared with a pulse (mungbean, *Vigna radiata* cv. Satin), and grain sorghum (*Sorghum bicolor*) was included as a non-legume control.

Overall, the annual legumes lablab (17.5 t/ha) and mungbean (13.4 t/ha) and the perennial siratro (16.2 t/ha) accumulated more DM than the perennials lucerne (9.6 t/ha) and desmanthus (7.1 t/ha). Lucerne produced little DM in its first year, but in later years had similar production to siratro and lablab. Desmanthus produced >4 t/ha of DM in the first year but barely survived during later seasons.

Annual legumes grew faster and exhausted soil water more rapidly than the perennials. The perennials were able to extract more water from the soil than the annual legumes and sorghum, but were inefficient at converting small to moderate rainfall events (25–50 mm) into DM production. During the fallow following the growth of lablab and mungbean, nitrate-N in soil increased and was always greater at the time of re-sowing than for the perennial legumes and sorghum.

Initially, the 2 annual legumes derived a high proportion (50% to >70%) of their above-ground N from fixation (%Ndfa) but this declined as the experiment progressed to low values (<13%) in the third and fourth years, reflecting increased supply of nitrate from the soil. In contrast, %Ndfa peaked at 72% for siratro and >90% for lucerne, and remained high (25–50%) throughout the experiment. N fixation rates were strongly negatively correlated with soil nitrate. Over the 4 years, siratro fixed 161 kg N/ha, lucerne 120, lablab 119, mungbean 78, and desmanthus 19 based on above-ground biomass. Mungbean had a net negative N balance (–80 kg N/ha) due to N exported in grain.

Additional keywords: lucerne, siratro, lablab, desmanthus, mungbean.

Introduction

Low and unreliable rainfall and accelerated rates of soil erosion resulting from high intensity rainfall have traditionally been considered the major constraints to the development of sustainable farming systems in central Queensland (CQ). Recently, declining soil fertility, especially nitrogen (N), has been affecting yields and grain protein (Spackman and Garside 1995) and is a major threat to both the immediate economic returns and the long-term viability of cereal production in the region.

Declining N fertility of the once highly fertile Vertisols used for grain production in CQ has resulted from continuous cropping with cereals with no strategy to replace the N removed. There are a number of potential options to improve soil N supply, including use of N fertilisers and rotations with legumes (as pulses, pasture-leys, or green manures). Farmers are reluctant to use N fertilisers in CQ as unreliable rainfall reduces the probability of obtaining economic responses, although recent studies indicate the importance of considering the residual effects of unused N fertilisers to subsequent

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crops (Armstrong *et al.* 1996; Strong *et al*. 1996). Pulse crops have been shown to significantly improve the yield of subsequent cereal crops in northern NSW and southern Queensland (Doughton and Mackenzie 1984; Marcellos 1984; Dalal *et al.* 1998) but doubt exists about their ability to improve soil N in the medium to long term (Dalal *et al*. 1994, 1997). Green manures are regarded as unattractive for marginal dryland farming areas such as CQ due to their opportunity costs and requirements for good rainfall to fully realise their potential benefits (Garside *et al*. 1992). Legume-ley pastures using predominantly annual pastures are widely used in southern regions of Australia (Donald 1965). Research in northern NSW (e.g. Holford 1980; Holford and Crocker 1997) and southern Queensland (e.g. Dalal *et al*. 1991), using temperate legumes such as perennial lucerne and annual medics, has demonstrated the ability of ley pastures to improve cereal yields and grain protein and to provide a cash return through grazing.

However, the ability of legumes to maintain yields and quality of cereal grain in CQ is unknown. In CQ most farms have both grain and beef enterprises, so there is a potential role for both pulses and ley legumes. A research program was commenced in the early 1990s to identify suitable legumes (both pasture-ley and pulses) for this region, and to examine their ability to improve the growth of cereals in the system. Clem and Hall (1994) identified a range of tropical legumes considered to have promise for introduction into perennial grass pastures on cracking clay soils in CQ. Subsequently, Armstrong *et al*. (1997) screened a selection of these legumes in a short-term (one season) study where water was generally non-limiting and found that several had the potential to significantly improve cereal production.

The next phase of this research has been to examine in more detail the performance over several seasons of selected legumes that showed potential in the earlier, one-season, study (Armstrong *et al.* 1997). In this paper we report on the dry matter production, N_2 fixation, and water use of 4 ley legumes and compare their performance with that of a pulse (mungbean) or cereal crop over 4 years. A subsequent paper (see Armstrong *et al*. 1999) examines the effect of these legumes on following cereal crops, especially in relation to the duration of the legume phase.

Materials and methods

Site characteristics

The experiment was conducted on a deep (depth to decomposing basalt 90 to >140 cm) open downs cracking clay (Haplic, self mulching, Black Vertosol; Isbell 1996) at the Queensland Department of Primary Industries Emerald Research Station in CQ (23º29′S, 148º09′E, alt. 190 m). General characteristics of the soil (0–10 cm depth) were: pH (1 : 5 water) 7.6, bulk density 1.05 g/cm^3, total N 0.051%, and organic carbon 0.64%. This soil was typical of many on the central Highlands of Queensland, having been continuously cropped for at least 30 years. The site had previously grown an irrigated wheat crop which was harvested in October 1993. A basal application of 12 kg/ha of phosphorus and 15 kg/ha of sulfur (as superphosphate 8.8% P, 11.0% S) and 2 kg/ha of zinc (as $ZnSO_4.H_2O$, 34.5% Zn) was applied in December 1993. A further 16 kg/ha of phosphorus and 20 kg/ha of sulfur (as superphosphate) were applied in July 1995.

Experimental design

The trial was a randomised complete block design replicated 3 times. Six treatments comprising 2 cropping systems and 4 pasture-ley legumes were planted: (*i*) opportunity cropping (sorghum only), (*ii*) pulse crop, (*iii*) siratro (*Macroptilium atropurpureum*, a summer-growing perennial), (*iv*) lucerne (*Medicago sativa*, a winter perennial), (*v*) lablab (*Lablab purpureus*, a summer annual forage crop), and (*vi*) desmanthus (*Desmanthus virgatus*, a summer perennial). During the trial, the summer-dominated rainfall patterns dictated that grain sorghum (*Sorghum bicolor*) was used for the opportunity cropping (cereal) and mungbean (*Vigna radiata*) for the pulse crop. Mungbeans were planted on a continuous basis rather than as a pulse–cereal rotation as they provided a balanced design with the continuous sorghum and legume treatments. Furthermore, the consecutive pulse plantings permitted an opportunity to examine the effect of increasing soil N status on N_2 fixation. Although pulses are rarely planted on a consecutive basis in farming systems of southern Australia due to disease problems, this can and does occur in northern Australia if relative commodity prices and planting opportunities are appropriate (A. Garside, pers. comm.). Each plot consisted of five 1.8-m planter widths, except for the opportunity cropping (cereals) which had 6 planter widths. Each block was 91 m long. Each year the datum plot (9 m wide by 13 m long) was progressively moved 13 m along each block to allow a grain sorghum test crop (results presented in Armstrong *et al*. 1999) to be planted across all treatments.

Crop and pasture management

In December 1993, desmanthus seed was applied to the surface of appropriate plots and incorporated with diamond harrows. All treatments except desmanthus were flood irrigated commencing on 14 January 1994 to enable plant establishment. Because the desmanthus seed was located in the top 5 mm of soil (short coleoptile prevents germination if soil is placed deeper into soil), this treatment was irrigated with trickle tape to ensure that the surface remained wet for several days.

On 23 January 1994 the entire site (except desmanthus plots) was sprayed with Roundup (glyphosate) and Starane (fluroxypyr) to control widespread germination of broadleaf and grass weeds. Sorghum and lablab were planted the next day using a cone seeder with parallelogram planting units on 60-cm row spacing; mungbean and siratro were planted on a 27-cm row spacing the following day. All seed was placed at approximately 5 cm depth except for the siratro which was sown at approximately 1 cm. Due to poor sorghum establishment, the sorghum was sprayed with glyphosate and fresh seed resown on 31 January 1994; 75 mm of rain over the next 3 days ensured germination. After heavy autumn rain (Fig. 1), lucerne was sown on 17 March 1994 with a cone seeder followed by a light harrow. Due to continuing drought, the entire trial site was again flood irrigated on 1 February 1995 to permit planting of annual crops on 13 February 1995. No further irrigation was applied during the trial until late January 1997 when approximately 35 mm was applied as spray irrigation across the entire trial to ensure grain fill of the sorghum crop.

All legumes were inoculated with appropriate commercially available rhizobium prior to sowing. Because of the poor growth in desmanthus plots from the beginning of 1995, these plots were re-inoculated with rhizobia (using watering cans) on 12 December 1995 following 67 mm of rain the previous night. Although the remainder of the day was overcast and comparatively cool, there was no further follow up rain to ensure that inoculum was washed into the soil.

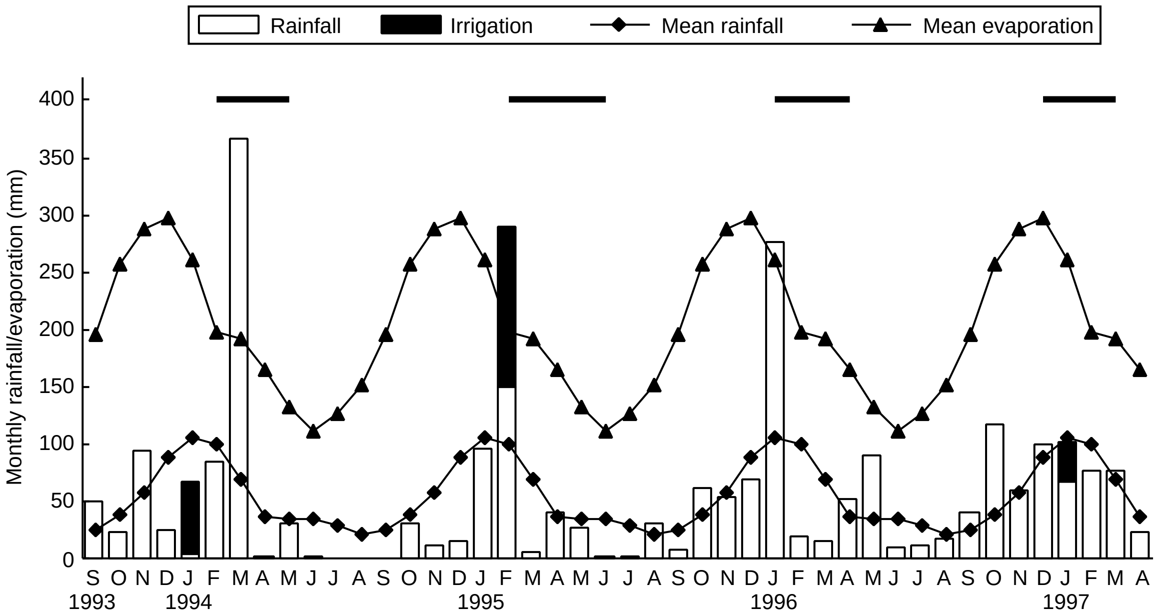

Fig. 1. Monthly rainfall and irrigation events before and during the experiment (September 1993–April 1997). The long-term average rainfall and evaporation for Emerald Research Station has been superimposed. The horizontal bars denote the months when the annual crops were growing.

Table 1. Details of sowing rates, cultivars used, and grain harvest for 1994 to 1997

Species	Cultivar	Sowing rate (kg/ha)	Sowing date	Grain maturity[C]
		1994		
Sorghum	Tulloch	65 000[A]	31.i.94	16.v.94
Mungbean	Satin	25	25.i.94	18.iv.94
Siratro	Siratro	6	25.i.94	
Lucerne	Trifecta	6	17.iii.94	
Lablab	Highworth	25	24.i.94	
Desmanthus	Marc	8	17.i.94[B]	
		1995		
Sorghum	Barrier	100 000[A]	20.ii.95	13.vi.95
Mungbean	Satin	25	18.ii.95	5.v.95
Lablab	Highworth	25	20.ii.95	
		1996		
Sorghum	Bronco	90 000[A]	19.i.96	22.iv.96
Mungbean	Satin	25	19.i.96	26.iii.96
Lablab	Highworth	25	19.i.96	
		1996–97		
Sorghum	MR31	75 000[A]	14.xii.96	19.iii.97
Mungbean	Satin	25	14.xii.96	20.ii.97
Lablab	Highworth	25	14.xii.96	

[A]Established seedlings per ha in 1994, 1995; targetted in 1996, 1997.
[B]Desmanthus was originally sown on 8.xii.93. However, no germination occurred until plots were irrigated on 17.i.94.
[C]These dates correspond to physiological grain maturity, when dry matter cuts and soil sampling were performed. Harvesting of remainder of treatment with a header was often 10–20 days later.

Details of cultivars used, seeding rates, and planting and harvest dates (for annual crops) are listed in Table 1.

Weed control

Regular hand weeding was employed in an attempt to maintain all legume treatments as pure stands. This resulted in good weed control, especially for the annuals in the first 2 years of the trial. The exception was in desmanthus plots where the poor growth recorded from 1995 onwards resulted in persistent weed infestion (particularly of native jute *Corchorus trilocularis*). From 1995 onwards infestations of grass weeds, particularly summer grass (*Brachiaria eruciformis*), which were difficult to control by hand weeding, were sprayed with Verdict 104 (haloxyfop-R) which resulted in generally good control. Despite regular hand weeding, it was also necessary to spot-spray broadleaf weeds with glyphosate, although this was less successful. The growth of weeds and regrowth of legumes in plots sown to annual species were controlled by spraying with glyphosate and fluroxypyr and mechanical cultivation using chisel plough and harrows. Lablab was sprayed out in late July–early August each year and plots were fallowed until planting the following season.

Pasture legumes were not grazed but were slashed with a sickle-bar slasher in 1994 and in later years with a rotary mulcher at approximately 7.5 cm height when it was judged necessary for a particular treatment. This varied with growth rates but usually corresponded to appearance of flowering buds, especially in lablab, lucerne, and siratro plots. Cut plant material was left on the plots as it was felt that it was more appropriate to simulate a green manure system rather than a hay system as used in some other studies (e.g. Dalal *et al*. 1994).

Insect control

In siratro plots a marked decline in plant growth from mid-1996 corresponded to a severe infestation of roots with rough brown weevil (*Baryopadus corrugatus* Pascoe). Siratro plots were subsequently sprayed with Supracide 400EC (methidathion), which appeared to result in good control of the weevil infestation. There were major infestations of *Heliothus* spp. in mungbean and sorghum treatments and these plots were treated with Larvin (thiodicarb), Rogor (dimethoate), and Dipel (*Bacillus thuringiensis* var. Kurstaki) as required. In 1996 and 1997 the trial was sprayed several times with Fenitrogard (fenitrothion) and Dominex (cypermethrin) to limit damage caused by spur-throated locusts (*Austracris guttulosa* Walker).

Data collection

Pasture dry matter (DM) was estimated by harvesting 3 randomly placed 0.5 m^2 quadrats in each plot. The crops sown annually (sorghum, lablab, and mungbean) were sampled by cutting 3 rows of 1.5 m length in the centre rows of each plot. Dry matter sampling varied during the trial but generally coincided with flowering and grain maturity in the grain crops and immediately prior to slashing of the forage species. Because treaments were slashed (except sorghum and mungbean), only regrowth material was included. On some occasions after long periods without rain, several DM determinations were made without slashing. This procedure occasionally recorded negative changes in cumulative dry matter, e.g. siratro in 1997. This apparent decrease was due to leaf drop.

Harvested plant material was dried at 70°C for 48 h, ground to <2 mm, and retained for chemical analysis. At physiological maturity, grain from sorghum and mungbean crops was separated from the stover after drying and both components were weighed, ground (<2 mm), and retained for N analysis.

Soil analyses

Water and nitrate (NO_3) contents of the soil were determined for all treatments at sowing of the annual species and again at grain maturity of the cereal crop. Four 3.5-cm-diameter soil cores were taken from each plot (2 for water, 2 for soil NO_3). Cores for water were divided into 10-cm increments to 30 cm then 15-cm increments to decomposing basalt or 120 cm (whichever was encountered first); soil NO_3 cores were divided into 10-cm increments to 30 cm then 30-cm increments to 120 cm. Soil NO_3 samples were dried at 40ºC before grinding (<2 mm), whereas soil water samples were dried at 105ºC. Plant-available water content of the soil was determined by converting gravimetric soil water concentrations to volumetric by adjusting for bulk density at the upper storage limit and using a lower storage limit for each treatment determined by measurements made during the trial. The lower storage limit for sorghum was based on measurements of gravimetric water when N was non-limiting. Measurements of bulk density were made using 100-mm-diameter cores at the end of 1994 in microplots watered to the upper storage limit (D. Yule, pers. comm.). Estimates of lower storage limits ignored soil in the surface 0–30 cm, which was affected by air drying. Lower storage limits were found to be generally uniform throughout the profile between 30 and 105 cm depth for each species.

Chemical analysis

Soil NO_3 concentrations were determined by automated colorimetric analysis (Best 1976) following extraction in 2 M KCl at a soil extractant ratio of 1:10 (Bremner 1965*a*). Total amounts of NO_3 were calculated on an area basis (kg/ha) by correcting concentrations for bulk density. Total N in plant material was determined by automated colorimetric analysis (Crooke and Simpson 1971) after Kjeldahl digestion (Bremner 1965*b*).

Determination of nitrogen fixation

The ^{15}N natural abundance technique was used to estimate the amount of atmospheric N_2 fixed by the legumes. Five paired shoots of the legume and reference (non-legume) plant were cut at ground level following the general sampling protocol of Unkovich *et al*. (1994). Because of the wide range of growth habits of the different legumes used in this study, viz. winter and summer active/perennial and annual growth, native jute (*Corchorus trilocularis*), a biennial broadleaf weed native that occurred in high numbers at the trial site, was selected as the reference species. Pate *et al*. (1994) have recommended broadleaf weeds as the best reference (non-fixing) species as they have a root distribution pattern more comparable to legumes than grasses. In addition, grain sorghum plants were also sampled at anthesis in 1994 and again in 1997 in sorghum buffer plots and sorghum treatment plots (i.e. in areas not previously sown to legumes) to compare ^{15}N abundance of the cereal with native jute and ^{15}N natural abundance across the site. Plant material was dried at 70ºC for 48 h and ground (<0.12 mm), before conducting ^{15}N analyses on a Europa Tracermass continuous flow isotope ratio mass spectrometer.

The ^{15}N abundance, $\delta^{15}N$, was estimated from the ratio of the signal from ions of mass 28 and 29, relative to that of atmospheric N_2 (i.e. $\delta^{15}N$ of atmospheric $N_2 = 0$). The percentage of nitrogen derived from the atmosphere (%Ndfa) was calculated as:

$$\%\text{Ndfa} = (\delta^{15}\text{N}_{\text{reference}} - \delta^{15}\text{N}_{\text{legume}}) \times 100/(\delta^{15}\text{N}_{\text{reference}} - \beta)$$

where $\delta^{15}N_{legume}$ and $\delta^{15}N_{reference}$ are the ^{15}N natural abundance of nitrogen in the shoots of the legume and reference species, respectively, and β is the $\delta^{15}N$ value of nitrogen in shoots of the legume when effectively nodulated and grown in N-free media. β values were determined using plants grown in a perlite-sand medium free of nitrogen in a glasshouse in Rockhampton. These plants were derived from the same seed batch as used in field planting in 1994, inoculated with the same rhizobium strain as used in the field trial, and were harvested at flowering, at which stage total plant N greatly exceeded original seed N. $\delta^{15}N$ values of 4 replicate plants were averaged to give the β values used (mungbean –2.30, siratro –2.13, lucerne +0.19, lablab –2.78, and desmanthus –1.78).

%Ndfa can only vary between 0 and 100%. Negative values of %Ndfa can be calculated when there are differences in either temporal or spatial nitrogen assimilation between the legume and reference species which interact with changes in the ^{15}N natural abundance of the soil mineral nitrogen due to denitrification (Witty 1983). When this occurred (several times in 1996 and 1997 for the annual legumes), values were rounded up to zero %Ndfa. When calculating the amount of N fixed (kg/ha), %N values from the DM determinations were used rather than %N obtained from the mass spectrometer as the larger sample size was considered to be more representative. Calculations of the total N fixed were based on above-ground data only. Recent studies (Russell and Fillery 1996; McNeill *et al*. 1998; Rochester *et al*. 1998) using ^{15}N labelling techniques suggest that a significant proportion of legume N of annual species is located below-ground and that this proportion is specific to species. However, as no data are currently available for the species used in this study, especially the perennial legumes, it was considered inappropriate to attempt to extrapolate data from southern Australia to this tropical farming system.

Results

Seasonal conditions

The trial period (December 1993–April 1997) was characterised by drought throughout the region lasting until spring 1996. Total rainfall was 85% of the long-term average (639 mm) in both 1994 and 1995, but was characterised by large episodic rainfall events (e.g. >350 mm fell over 7 days in March 1994) and many events of <10 mm per day, which were less than daily evaporation (Fig. 1). This limited the opportunities when crops/pasture could be established. During the trial, irrigation was used on 3 occasions: in January 1994, *c*. 62 mm of water was applied to allow the trial to commence; in February 1995, *c*. 150 mm was applied to enable the annual crops to be planted; and in late January 1997, *c*. 35 mm was applied to enable grain fill of sorghum so that the N effects of the preceding crops would be fully expressed. Significant rainfall fell soon after the first 2 irrigations, 75 mm of rain in 1994 and 93 mm in 1995. In the context of the very high variability of rainfall in this environment, the irrigation used did not result in the total water received being markedly different to the long-term average rainfall (Fig. 1). Consequently, it is unlikely that the findings have been biased by this judicious use of irrigation.

Dry matter production

Cumulative above-ground DM yields for 1994–1997 are presented in Fig. 2*a*–*d*. Lablab (17 510 kg/ha) and siratro (16 170) accumulated the most above-ground DM between 1994 and 1997, followed by mungbean (13 440), lucerne (9590), and desmanthus (7080). Sorghum produced a total of 13 460 kg DM/ha.

However, distinct patterns in DM production emerged between species during this period. All the annual species (sorghum, mungbean, and lablab) accumulated DM rapidily following planting in 1994 (Fig. 2*a*). This high rate of DM production was maintained following a large rainfall event in late March 1994 (Fig. 1), although at a slower rate until mid-year. The growth of the perennial legumes siratro and desmanthus was initially slower than the annuals, but by mid 1994 there was no significant difference ($P > 0.05$) in the total cumulative DM production between species (with the exception of lucerne). No species made any significant growth from June to the end of the year, a pattern repeated each year. Desmanthus produced over 4 t/ha DM in the first year but following slashing in late 1994 subsequently produced little further growth during the trial. Lucerne produced little growth in 1994 but then increased its DM production in the following 2 seasons.

Siratro, lablab, and mungbean maintained their good growth rates in 1995 and produced significantly more ($P < 0.05$) DM than the other legumes in that year (Fig. 2*b*). In 1996, however, the growth of all species was restricted by poor rainfall and there was no significant difference between the species except for desmanthus (Fig. 2*c*). In 1997 (the fourth year of trial), DM production of the annual legumes and sorghum rapidly increased, whereas that of the perennials was significantly ($P < 0.05$) poorer (Fig. 2*d*) when the trial terminated.

N uptake

Patterns of N uptake by the legumes and sorghum (Fig. 3) generally paralleled that of DM production. However, some distinct differences were obvious. Tissue N concentrations of sorghum and desmanthus were markedly lower than those of the other species throughout the trial, resulting in very low amounts of cumulative N uptake. In the annual legumes

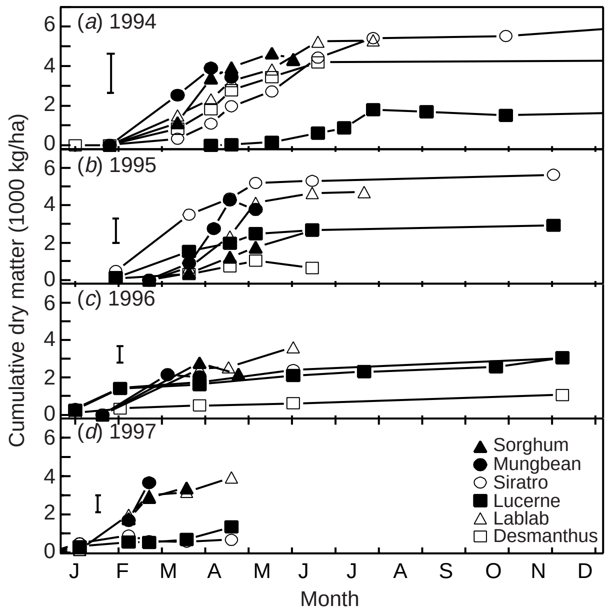

Fig. 2. Cumulative above-ground dry matter production by 4 pasture legumes, mungbean, and grain sorghum for 1994, 1995, 1996, and 1997 at Emerald. Values were re-set each year. Vertical bar represents l.s.d. ($P = 0.05$) for maximum cumulative dry matter for each year.

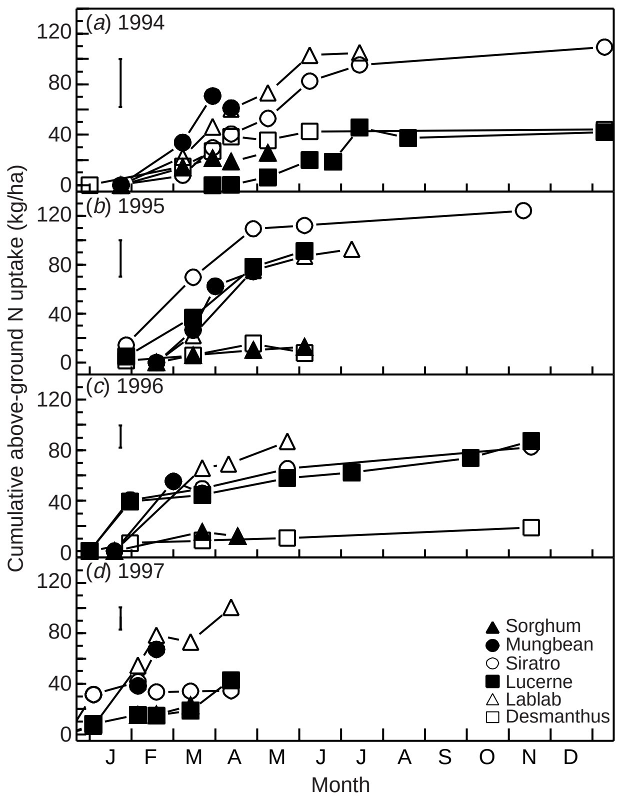

Fig. 3. Cumulative nitrogen uptake of above-ground dry matter by 4 pasture legumes, mungbean, and grain sorghum for 1994, 1995, 1996, and 1997 at Emerald. Values were re-set each year. Vertical bar represents l.s.d. ($P = 0.05$) for maximum cumulative nitrogen content for each year.

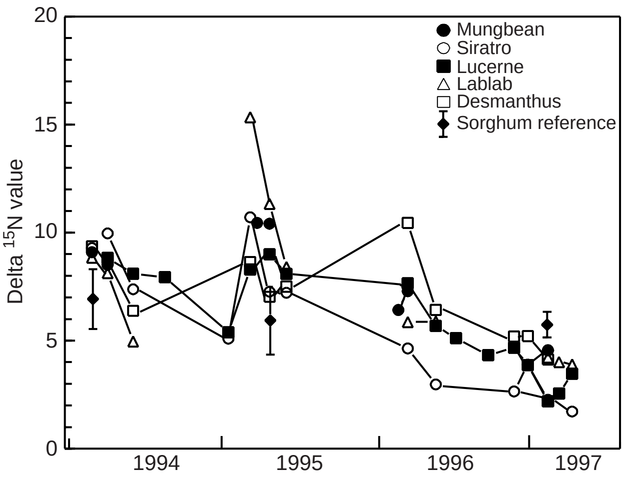

Fig. 4. ^{15}N natural abundance value for reference species (native jute) used to calculate N fixation (%Ndfa) by each legume between 1994 and 1997. ^{15}N natural abundance value (± 2 s.e.m.) for grain sorghum at anthesis in 1994, 1995, and 1997 is also presented.

(lablab and mungbean), tissue N concentrations were very high early in each season but then declined rapidly as DM increased. This pattern was occasionally reversed when autumn rainfall, e.g. April 1994 and March 1996, resulted in renewed growth in lablab and rapid increases in the tissue N concentrations associated with new growth. In contrast, tissue N concentrations in siratro and lucerne tended to fluctuate little throughout the year, so that cumulative N uptake directly paralleled changes in DM production.

Lablab and siratro generally had the highest N uptake in above-ground DM throughout the trial period (Fig. 3*a*–*d*). The exception was 1997 when siratro produced little growth despite an early summer break in late 1996. Lucerne took up little above-ground N in the first year of growth (1994), but in contrast to DM production, there was no significant difference (P > 0.05) in above-ground N uptake between lucerne, lablab, and siratro in 1995 and 1996. Although lucerne took up little N over the 1996–97 summer, there was a steady increase prior to trial termination in early autumn 1997. Mungbean rapidly accumulated N but its short growth

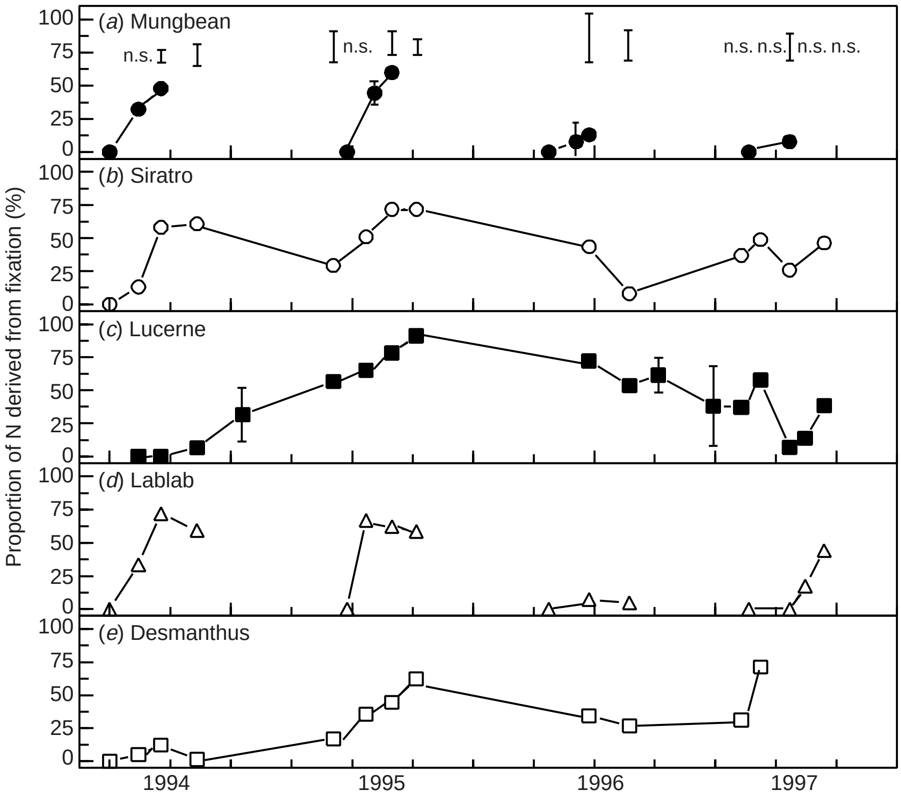

Fig. 5. Changes in the proportion of plant nitrogen derived from fixation (%Ndfa) for (*a*) mungbean, (*b*) siratro, (*c*) lucerne, (*d*) lablab, and (*e*) desmanthus between January 1994 and April 1997 at Emerald. Estimates are based on use of native jute as a reference plant.Vertical bars represent l.s.d. (P = 0.05) for comparison between species measured at that date. n.s., not significant. Individual bar for a particular data point is the 2 × standard error of the mean for individual legume at that date.

season (11–14 weeks) limited its ability to accumulate large quantities of N. Desmanthus consistently contained the lowest amount of N of any of the legumes studied and generally differed little from the N uptake of grain sorghum.

Nitrogen fixation

Changes in $\delta^{15}N$ values of reference species

Estimates of N_2 fixation by the legumes used native jute as the non-fixing reference species. In the first season (1994), $\delta^{15}N$ values of native jute were 9.15 ± 0.14 (s.e.m.) compared with that of grain sorghum measured at anthesis of 6.90 ± 0.46 (Fig. 4). Although there were pronounced fluctuations within a season, $\delta^{15}N$ values of native jute declined in all the legume plots as the trial progressed, especially in plots sown to siratro and lucerne, to average 3.47 ± 0.51 in February 1997. In contrast, $\delta^{15}N$ values of sorghum remained relatively constant from 1995 onwards and averaged 5.79 ± 0.27 in February 1997.

%Ndfa

A clear distinction in the proportion of legume N derived from fixation (%Ndfa) between annual and perennial legumes emerged as the trial progressed between 1994 and 1997 (Fig. 5*a*–*e*). %Ndfa in the annuals lablab and mungbean peaked at moderately high levels (50–72%) during 1994 and 1995 but then declined to very low levels (<13%) in subsequent years of the trial. In siratro, %Ndfa increased rapidly in 1994 before peaking at 72% in mid 1995, and then gradually declined to fluctuate between 25 and 50%. In contrast, %Ndfa for lucerne and desmanthus remained low in 1994 before peaking at 92% in lucerne and 70% in desmanthus in 1995. The %Ndfa of these perennials then generally declined slowly as the trial progressed.

%Ndfa was strongly negatively correlated (r^2 = – 0.54, n = 30) with the amount of soil nitrate in the profile for all legumes except desmanthus, which was omitted from the analysis (Fig. 6). N fixation contributed <20% of plant N when soil NO_3 levels were >40 kg N/ha.

Amount of N fixed

The annual amount of N fixed by legumes declined as the trial progressed (Fig. 7). Lablab and siratro fixed 60 kg N/ha, mungbean 29 kg N/ha, and lucerne 11 kg N/ha in 1994. All legumes (except desmanthus) fixed similar amounts of N in 1995 (40–70 kg N/ha), but in 1996 the annual legumes fixed significantly less than the perennials (5 *v*. 33–56 kg N/ha). In 1997 there were no significant differences between the legumes. Desmanthus fixed only small amounts of N during the trial. By mid 1997, siratro had fixed a cumulative total of 161, lucerne 120, lablab 119, mungbean 78, and desmanthus 19 kg N/ha.

N balance

A summary of the N balance (defined as the N input via N_2 fixation, minus that taken off in grain) of all legume systems is presented in Table 2. The greatest contribution of N from fixation occurred in the first year of the trial (1994). In subsequent years, more plant N was acquired from the soil than from N_2 fixation by all legumes (Table 2). Mungbean had a negative N balance (ranging from 16 kg N/ha in 1994

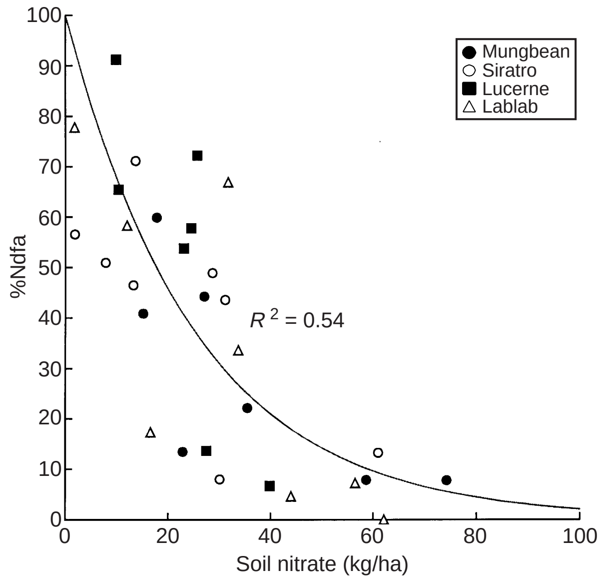

Fig. 6. Relationship between %Ndfa and soil nitrate-N for mungbean, siratro, lucerne, and lablab. Individual points are mean of 3 replicates. Data represent amount of soil nitrate-N in the profile (0–120 cm) taken at planting and grain maturity of annual crops (see Fig. 8) and the next measurement of %Ndfa (after planting) or closest measurement (at maturity). No value is presented for lucerne at the planting NO_3-N made in January 1994 (n = 30).

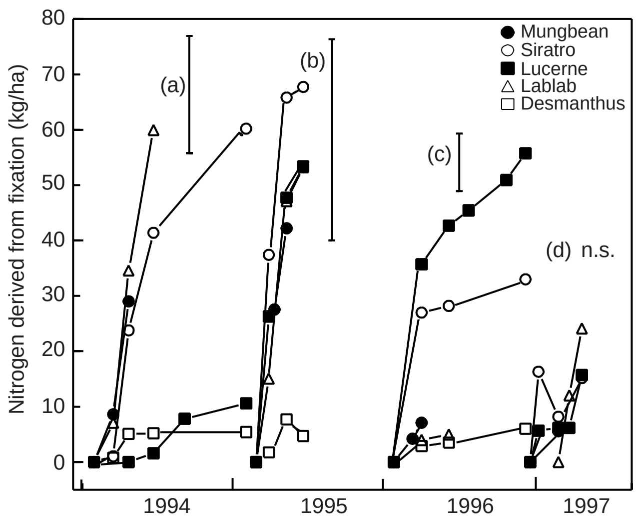

Fig. 7. The amount of nitrogen (kg/ha) derived from fixation for each legume. Estimates are based on use of native jute as a reference plant. Vertical bars represent l.s.d. (P = 0.05) for (*a*) 1994, (*b*) 1995, (*c*) 1996, and (*d*) 1997 for the comparison of maximum cummulative nitrogen fixed for each year between species. (n.s., not significant).

Table 2. Amounts of above-ground plant nitrogen (kg/ha) derived from N_2 fixation and soil, and the nitrogen balance of legume systems

Data presented correspond to the maximum above-ground cumulative value for the treatment within a year

	Mungbean Total[A]	Mungbean Grain	Siratro	Lucerne	Lablab	Desmanthus	l.s.d.[B] (P = 0.05)
			1994				
Plant N	70.6	44.9	109.4	45.5	104.8	44.1	41.4
N fixed	29.0	—	60.2	10.6	60.0	5.4	21.2
Soil N	41.6	—	49.2	34.9	44.9	38.7	27.4
N balance[C]	–15.9	—	60.2	10.6	60.0	5.4	
			1995				
Plant N	74.5	58.9	112.1[D]	70.0[D]	86.8[D]	15.4	29.6
N fixed	42.2	—	67.7	53.4	53.9	7.7	36.2
Soil N	32.3	—	44.4	16.5	32.9	7.7	29.0
N balance[C]	–16.7	—	67.7	53.4	53.9	7.7	
			1996				
Plant N	45.8	24.4	82.6	87.4	87.0	18.5	19.5
N fixed	7.1	—	33.0	55.7	5.0	6.0	48.2
Soil N	37.7	—	49.6	31.6	82.0	12.5	18.3
N balance[C]	–16.3	—	33.0	55.7	5.0	6.0	
			1997				
Plant N	67.2	35.9	34.6[B]	42.9	100.4	n.d.	20.8
N fixed	5.6	—	15.2	15.7	24.1	n.d.	n.s.
Soil N	61.6	—	19.4	27.3	76.3	n.d.	24.7
N balance[C]	–30.3	—	15.2	15.7	24.1	n.d.	
			Total (*1994–1997*)				
Plant N	258	164	339	246	379	78	82.3
Fixed N	84	—	176	135	143	19	59.8
Soil N	173	—	163	110	236	59	54.6
N balance	–80	—	176	125	143	19	

n. d., not determined; n.s, not significant (P > 0.05).

[A]N contained in grain + stover.

[B]Comparison between species.

[C]N balance for the pulse (mungbean) takes account of the N removed in grain. For the other species the N balance corresponds to that attributed to N derived from fixation.

[D]There were no corresponding Nfix data collected for the sampling date corresponding to maximum plant N uptake. Consequently, data presented are from the date that was next highest.

to >30 kg N/ha in 1997, and totalling 80 kg N/ha between 1994 and 1997) as more N was removed as grain than was acquired from N_2 fixation in all years. This reflected both the large proportion of N exported as grain by mungbean and the small amounts of N fixed, especially in 1996 and 1997. Sorghum had a net cumulative N balance of –48 kg N/ha. It should be noted that these calculations ignore the contribution of N located below ground.

Soil nitrate

The amount of nitrate in the soil profile to 120 cm under the various legumes and sorghum crops at the time of planting and grain maturity of the sorghum each year is presented in Fig. 8*a–h*.

Plots sown to annual legumes (lablab and mungbean) always had significantly more (P < 0.05) NO_3 at the time of re-sowing compared with the perennial legumes and grain sorghum. There was a general progressive increase in the total amount of NO_3 present at planting for all legume species as the trial progressed, especially in the annual legume plots. In contrast, the amount of NO_3 remaining in the profile at sorghum grain maturity varied with season. At sorghum maturity in 1994 there was an average of <8 kg NO_3-N/ha (ignoring lucerne which had been fallowed until 7 weeks previously). At the same growth stage in 1995 this had increased to only 12 kg NO_3-N/ha but in 1996 it had risen to an average of 24 kg/ha (with 44 kg/ha in lablab plots) before decreasing to 14 kg NO_3-N/ha at sorghum maturity in 1997. The amount of soil NO_3 remaining in the profile at the time corresponding to sorghum maturity tended to be lowest in sorghum and desmanthus plots (the exception was 1994).

Plant-available water

The perennial legumes consistently extracted water to lower moisture contents than the annual legumes and sorghum (see Fig. 9). However, there was no evidence of dif-

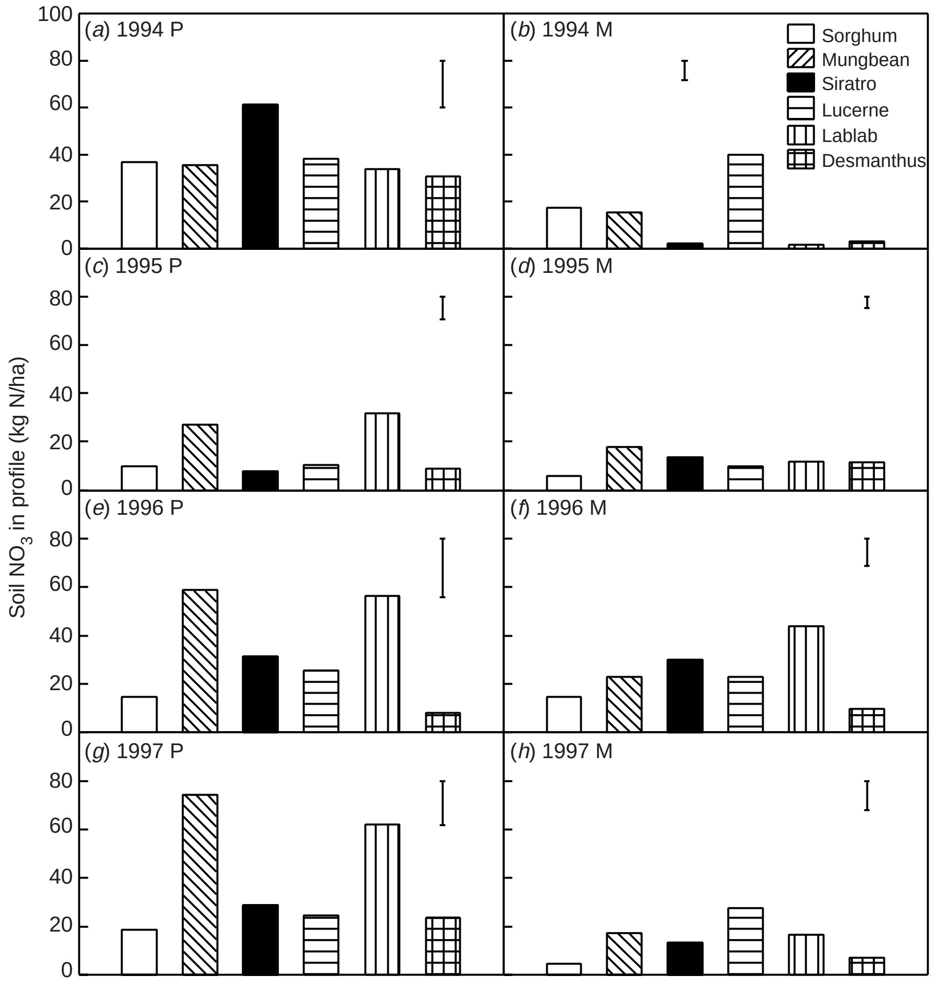

Fig. 8. Total soil NO_3-N in the profile (0–120 cm) under different legumes and sorghum at planting (P) and grain maturity (M) of sorghum crop each year (1994–1997). Vertical bars represent l.s.d. ($P = 0.05$) for comparison between species.

ferences in effective rooting depth between the species as water extraction profiles were generally uniform between 0.3 m (the maximum depth affected by air drying) and 1.2 m (maximum depth sampled).

Changes in plant-available water content (PAWC) of the soil profile (0–120 cm or to decomposing basalt) between 1994 and 1997 are shown in Fig. 10 *a–d.* The annual legumes exhausted PAWC of the soil sooner in the season than the perennials. However, the perennials consistently kept the soil profile much drier throughout the year than the annuals. The shorter growing season of the annuals resulted in a greater opportunity to accumulate soil water during the fallow but fallow storage efficiencies were very poor. For example, when lablab plots were sprayed out in early July 1996, there was 18 mm of PAWC. By early December this had risen to less than 30 mm, despite receiving >225 mm of rain during the fallow.

Discussion

This report describes the growth, N fixation, and water use over several seasons of several potentially useful species for a pasture-ley system in CQ. Assessment of legume performance depends on criteria used. In this study the attributes considered to be desirable were ability to (*i*) establish rapidly and accumulate DM with high N concentrations (to supply cattle with high value feed), (*ii*) efficiently utilise available soil water (including that supplied by small to moderate rainfall events) and convert it to DM, and (*iii*) obtain a high proportion of plant N from fixation so as to improve soil N for

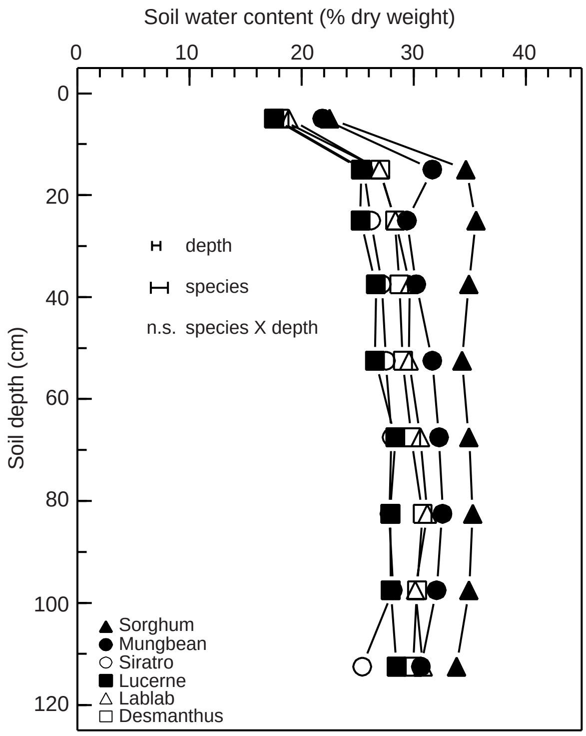

Fig. 9. Gravimetric soil water in the soil profile (0–120 cm) under different legumes and sorghum (without added N) at sorghum grain maturity on 18 March 1997. Bars indicate l.s.d. (P = 0.05) for main effect of species and depth. (n.s., not significant.)

subsequent cereal crops. We found that the performance of individual species varied markedly with time during the trial period (1994–1997) and no one species clearly outperformed the others in all categories.

In this study, legumes were not grazed but slashed and cut material left on the plots. A study in southern Queensland showed little difference in N status between plots that were grazed by sheep and those in which cut DM was removed (Hossain *et al.* 1996), although a proportion of the dry matter was effectively retained on the plots (R. Dalal, W. M. Strong, pers. comm.). Grazing can significantly affect N cycling through return to soil of excreta and losses via volatilisation of N from urine compared with decomposition of plant residues *in situ* (Vallis 1979). Haynes and Williams (1993), for example, note that studies in temperate climates have generally found that grazing increases the availability of plant nutrients such as N. However, a study in CQ (Cowie 1993) found very little change in soil N balance in pastures grazed by beef cattle over several years compared with a cropping system. Consequently, a system where DM is retained, as in our study, may better approximate a grazed pasture in this environment than when pasture is slashed and removed.

Growth performance of the legumes

Large-seeded annual legumes such as lablab and mungbean are generally easier to establish in tropical environments such as CQ compared with smaller seeded species such as desmanthus and lucerne, as they can be sown deep enough to permit germination before the soil surface dries out. In farming systems of southern Australia, annual pulses are rarely planted consecutively due to the build up of pests and diseases. However, in this study, both annual legumes produced consistently large amounts of DM during all 4 seasons studied. This contrasted with the perennials, where disease (e.g. rust in siratro) or pests limited growth as the trial progressed.

Although the annuals generally accumulated DM and nitrogen (above ground) faster than the perennials in the first few months after trial establishment, the perennials soon matched the DM production of the annuals as plant-available soil water was rapidly exhausted by the annuals. The exception was lucerne, which made little growth in the first year after establishment, reflecting its need for autumn establishment, and lack of significant follow-up rain until the following year (Figs 2 and 3). In contrast to lucerne, both siratro and desmanthus initially had high growth rates after establishment. However, whereas the perennial legumes (except desmanthus) were able to maintain higher N fixation rates longer than the annuals, they tended to reach peak DM performance after 2–3 years and then subsequently declined. This decline appeared to be caused by a number of factors, including insect attack (siratro) and competition with weeds (lucerne). Consequently, this may limit the value of these perennial legumes for those farmers in CQ who are chiefly beef producers and crop on an occasional basis, as they would prefer a perennial legume that could persist for several years.

Lucerne showed promise as a ley-legume, with DM production ranging from 1800 kg in the first season to approximately 3000 kg/ha in the subsequent 2 years and N fixation peaking at 56 kg N/ha.year. Previous studies with lucerne in the northern cereal belt of Australia have demonstrated its ability to grow, persist, and supply significant quantities of N to subsequent crops (Holford 1980; Dalal *et al*. 1991; Hossain *et al*. 1995; Holford and Crocker 1997). However, lablab and siratro performed significantly better. Lablab produced on average 4400 kg/ha over the 4 years (i.e. 84% greater than lucerne) and siratro averaged 4040 kg/ha (69% greater), despite suffering significantly in the third season from rough brown weevil (*Baryopadus corrugatus* Pascoe). The use of recently released rust resistant siratro cultivars, e.g. Aztec, would have probably increased performance of this species (B. Pengelly, pers. comm.). Even grain sorghum, which was obviously severely N deficient after 4 continuous years of cropping (and prior to that wheat), produced slightly more DM than lucerne. Although lucerne is regarded as a summer-growing legume in temperate regions of Australia, optimum temperatures for this species correspond to winter in CQ. Recent studies (McCallum 1998) have shown that under comparatively high temperatures (>35°C, which is

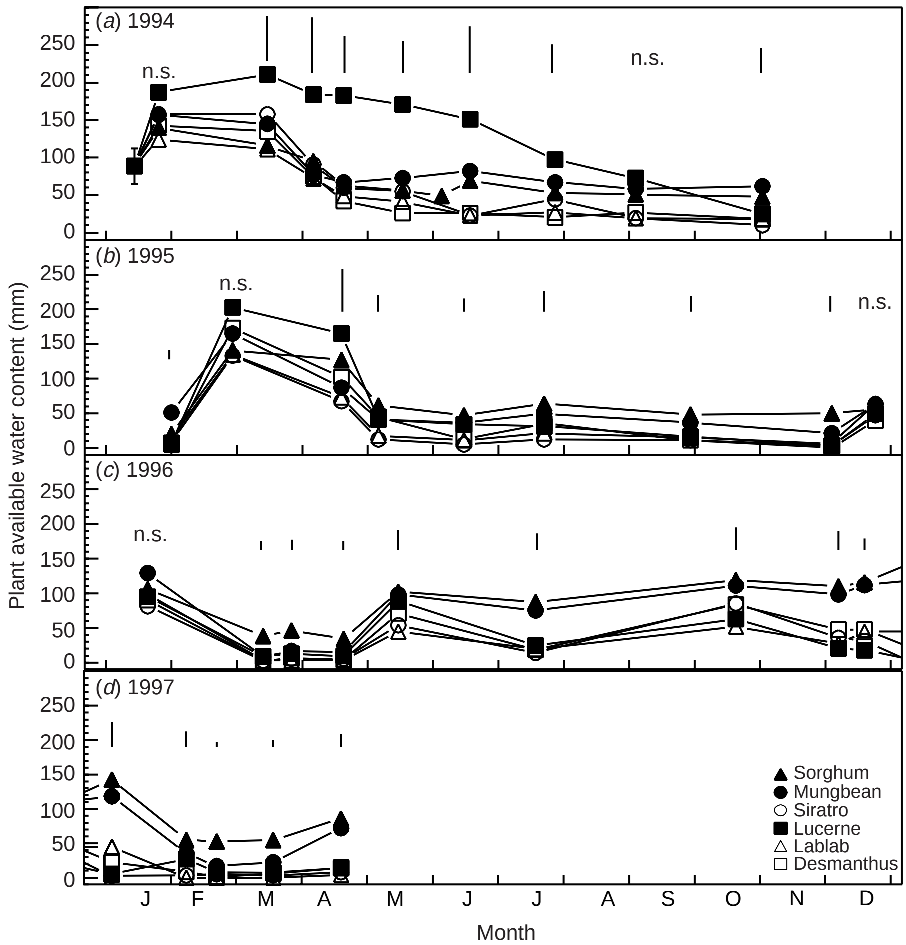

Fig. 10. Changes in plant-available water content of soil (0–120 cm) under different legumes and sorghum between 1994 and 1997 at Emerald. Different lower storage limits were set for each species on the basis of repeated sampling during the trial. Vertical bars represent l.s.d. (P = 0.05) for comparison between species measured at that date. (n.s., not significant.)

regularly experienced throughout summer in CQ) and dryland conditions, lucerne allocates a large proportion of its fixed carbon below ground. Given that maximum temperatures in CQ in early late autumn or early spring average >30ºC, it is highly likely that lucerne is unsuitable for use under dryland conditions in this particular agro-ecological zone.

Desmanthus struggled to survive after slashing at the end of the first season. The poor performance of desmanthus may have resulted from the slashing, although another study (Armstrong *et al.* 1996) found that the species has difficulty fixing nitrogen due to poor nodulation. This latter explanation is supported by the relatively good DM production during the first year (>4300 kg/ha, Fig. 2) but very low %Ndfa (Fig. 5), indicating that growth in the second and subsequent years may have been limited by ability to obtain nitrogen. However, the few desmanthus plants that did survive in subsequent seasons appeared to have an effective symbiosis (Fig. 5). The future of this species as a ley legume in CQ needs to be re-assessed using a newly released commercial strain of rhizobium (N. Brandon, pers. comm.).

The growth performance of all the legumes and sorghum will reflect the seasonal (rainfall) conditions. The first 3 years of the experiment were conducted during drought, whereas rainfall during the final season was close to ‘average’. There is the need to place these experimental data, collected over only 4 years, into the longer term climatic context. Rainfall in CQ is inherently highly variable. Extrapolation of the trial results to the full range of seasonal conditions likely to be encountered will be facilitated through computer simulation models such as APSIM (Probert *et al.* 1998). Data from this study provide the means of verifying the output from these models.

Legume performance and potential use for grazing

In addition to improving soil fertility, a major additional benefit of the ley is its value to animal production (Weston *et* *al*. 1997). This will depend on both the amount of high quality feed produced and also the timing of this feed availability. Graham *et al.* (1986) note that liveweight gains of cattle grazing grass pastures in CQ decline in autumn, reflecting deteriorating pasture quality. Lablab helped delay this trend in 2 of 3 years (Graham *et al.* 1986).

DM production by all the legumes in the current study (including lablab) was generally greatest between January and April. Even in 1996, when there was above-average rainfall in late autumn and early spring, there was little DM produced by the perennial legumes. Tissue N (protein) concentrations of the perennial legumes siratro and lucerne tended to remain consistently higher throughout the year compared with lablab, for which N concentration generally declined markedly within 3 months of sowing. However, the poor growth of the perennials over winter and spring may limit their potential to significantly extend the period of liveweight gain by stock compared with annual forages such as lablab.

N fixation

The estimated shoot β values used to calculate N fixation were similar to reported values. For example, siratro β was estimated at –2.13, whereas Steele *et al.* (1983) reported values of –2.7 and –4.6 and Ladha *et al*. (1996) report a value of –1.26. The β value of lablab was estimated at –2.78, compared with an estimate of –1.36 (Peoples *et al*. 1989). For lucerne there is a wide range of reported values [–3.18 by Hossain *et al*. (1995) to +1.7 by Shearer and Kohl (1989)] that can be compared with the value of 0.19 in this study. Variation in β arises from isotopic fractionation during fixation and the partitioning of N between root and shoot. A variety of factors can influence β values, including differences in inoculum and growth conditions (e.g. Shearer *et al.* 1982; Unkovich *et al*. 1994).

The dependence of legumes on N derived from fixation (%Ndfa) decreased as the trial progressed (Fig. 5). %Ndfa of legumes can be influenced by several environmental factors, especially the inhibitory effect of high soil NO_3 concentrations and soil water deficits (Walsh 1995). %Ndfa was clearly related to the amount of soil NO_3 present (Fig. 6) for all species except desmanthus, which was omitted from this calculation due to the very poor growth experienced by this species after 1994. The low %Ndfa of the 2 annual legumes (mungbean and lablab) in latter years of the trial clearly corresponded to the higher concentrations of soil nitrate present in these plots, particularly at planting.

To maintain high rates of N fixation by pulse crops it is essential that they be grown under conditions of low N supply, and under commercial conditions this is usually achieved when the pulse crop is grown in rotation with a cereal. For example, increasing soil NO_3 from 20 to 40 kg/ha reduced %Ndfa from 50% to 25%. However, in CQ the amount of soil NO_3 can vary significantly over time, regardless of previous rotations, due to N mineralisation in drought-induced long fallows (R. D. Armstrong and G. Millar, unpublished data). This highlights the value to farmers of measuring pre-crop N when considering what crops to plant in the system, especially if their primary goal is minimising the decline in soil N fertility.

The natural abundance methodology works well when N fixation is measured over a single season. However, its use for studies over several seasons is more problematic. Rather than remaining constant, the $\delta^{15}N$ value of the native jute reference, which grew within the legume plots, declined as the trial progressed, although this was partly obscured by a large variation within any one year (Fig. 4). For example, $\delta^{15}N$ values of jute averaged 9.14 in March 1994 but by February 1997 had decreased to an average of 3.47 in siratro and lucerne plots. This progressive decrease in $\delta^{15}N$ of the native jute is explained by the incorporation of N (presumably via mineralisation) derived from the legume material. Because legume N has a lower $\delta^{15}N$ than the background soil mineral N, soil NO_3 derived from this legume material would also have a lower $\delta^{15}N$ value. Decreases in $\delta^{15}N$ values tended to be largest in plots where most legume fixation occurred, as seen in Fig. 4 by comparing $\delta^{15}N$ values of jute in siratro plots with that in desmanthus plots.

In contrast, the $\delta^{15}N$ of sorghum in the continuous sorghum plots, which was unaffected by recycling of legume N, remained relatively unchanged throughout the trial period. Thus calculated, %Ndfa for siratro in February 1997 was 54.7% with sorghum in adjacent plots used as a reference ($\delta^{15}N = 5.79 \pm 0.27$) but 25.9% if native jute within the legume plot ($\delta^{15}N = 3.47$) was used as a reference. This effect, which had previously been recognised by Gault *et al.* (1995), would presumably increase as the trial progressed, and clearly demonstrates that some of the legume-derived N was effectively being re-cycled in the soil–plant system.

A further problem associated with estimating N fixation in this study may have been the remobilisation of root N following cutting. For lucerne, a $\delta^{15}N$ value of 4.31 was measured in the roots compared with 0.19 for shoots (Johnson 1997). The effect would be to increase legume $\delta^{15}N$ values and decrease the apparent rate of N fixation. The magnitude of this effect would depend on the differences between shoot and root $\delta^{15}N$ values for each species and the frequency of slashing.

Soil mineral N

Soil NO_3 concentrations were higher in annual legume plots at planting compared with perennial legume plots (Fig. 8) but were not directly related to the amount of N fixed, especially in latter stages of the trial. The higher soil NO_3 in the annual legume plots is unlikely to result from higher rates of N mineralisation *per se*, as Armstrong *et al*. (1998) found little difference in N mineralisation rates between these species. Three processes may explain the differential accumulation of NO_3 between annual and perennial legumes during this period. Firstly, the annual species had a fallow period during winter and spring, whereas the perennials continued to grow and fix N (although at very slow rates). Decomposition rates of root and shoot material would be very high once the annuals were harvested or terminated, whereas a large proportion of roots of the perennial legumes would remain alive and thus be less prone to decomposition (and N mineralisation). Secondly, N mineralisation may have been enhanced in annual legumes during the fallow due to better soil moisture conditions, although Myers *et al.* (1982) indicated that N mineralisation in this soil type is not as sensitive to soil moisture levels as many other soils due to its high clay content. Finally, low mineral N concentrations in the perennial plots may indicate that mineralised N derived from the legumes was being concurrently used either by the perennial legume itself, or by broad-leaf and grass weeds. In latter stages of the trial, weed populations were higher in the perennial legume plots than for annual legume plots, which were relatively weed free.

N balances

The nitrogen balance of the legume systems, based on above-ground estimates of N fixation, was negative for the pulse crop (mungbean) and ranged from +19 kg N/ha for desmanthus to 176 kg N/ha for siratro over 4 seasons (Table 2). However, a significant proportion of legume N is contained below-ground, ranging from 27 to 40% for annual pasture legumes and pulse crops in southern Australia, using estimates based on shoot feeding with ^{15}N (Russell and Fillery 1996; McNeill *et al.* 1997, 1998; Rochester *et al.* 1998). No corresponding measurements have been made for either perennial legumes or legumes in tropical areas in Australia. It is possible that perennial legumes have a larger below ground biomass than annual species (e.g. McNeill *et al.* 1997, compared with Zebarth *et al.* 1991).

Assuming a below-ground N distribution of 40% (based on values published for pulses growing in southern Australia), mungbean still produced a net N deficit due to the effect of exporting N as grain. A negative N balance occurred even in the first year of the trial when soil NO_3 levels were lowest and %Ndfa was highest. N fixation rates were clearly related to soil NO_3 (Fig. 6) so that this negative balance would be made worse as soil N increased, such as occurs after any length of drought-induced fallow.

Nitrogen balances for the perennial legumes were largest in the early seasons, except for lucerne which peaked in the second and third seasons. Legume N fixation rates for the perennial legumes may have been increased in the second and subsequent seasons by sowing with a companion grass (to reduce soil NO_3). However, most grass species that are adapted to CQ probably would have out-competed the legume. Furthermore, these grasses have the potential to become a serious weed in the following cereals phase, especially as in-crop weed control is very rarely used in CQ farming systems due to its high comparative costs, which would inhibit farmers adopting this strategy.

Legume use of rainfall

Two factors have a major influence on 'rainfall use efficiency' by crops and pasture in CQ. Firstly, fallow storage efficiencies are poor, even on cracking clays, due to both the significant runoff of rainfall occurring during high intensity storms (Carroll *et al.* 1997) and high evaporation rates. This was confirmed by the small proportion of rainfall occurring during fallow periods after lablab and mungbean crops that was available to the following crop (Fig. 10). Despite the use of zero tillage practices, both annual legumes left little stubble cover even under zero tillage practice and this appeared to reduce the ability of rainfall to infiltrate during storms of moderate intensity.

Farmers in CQ have attempted to overcome poor rainfall use efficiency resulting from high evaporation rates by developing opportunistic cropping systems. In opportunity cropping systems, crops are planted when sufficient soil water is available to reliably establish a crop rather than waiting for further rainfall to fill the soil profile, as more soil water can be lost in this intervening period by evaporation than is replenished by rainfall. High evaporation rates in CQ mean that rainfall <10–20 mm/day, which constitutes the majority (85%) of events, is regarded as 'ineffective' (C. Carroll, pers. comm.). Opportunity cropping effectively maximises the ratio of transpiration to evaporation, although it does increase the risk of crop failure due to drought.

Consequently, a perennial plant such as lucerne, with its longer period of transpiration compared with annual crops (Sheaffer *et al.* 1988), should constitute the ideal opportunity 'crop'. Although the perennial legumes utilised soil water for much longer periods of the year than the annuals (Fig. 10), there was little evidence that they made more effective use (for DM production) of small to moderate rainfall events. This was particularly evident during 1996 when good rainfall fell during late autumn and early spring (Fig. 1). Although siratro's ability to respond to this rainfall would have been limited by low temperatures and root damage caused by root weevil, lucerne also failed to produce significant DM responses during this period

The perennial legumes, however, appeared to obain a greater proportion of water stored in the soil *per se* (Fig. 9). This resulted in the perennial legumes having access to significantly more 'plant-available' water than the annual species. For example, mungbean was able to lower soil water to 32% (oven dry weight) compared with 27% for lucerne (Fig. 9), thus resulting in different lower storage limits for each species. This effect was evident throughout the entire soil profile to 120 cm (with the exception of the top 30 cm, which was subject to air-drying). There was no evidence that the legumes differed in their effective rooting depths. This finding may reflect the ability of the perennials to extract water to a greater matric potential *per se*, although it is possible that the perennials have a greater root density than the annuals. With an upper limit of 47%, the difference in lower storage limit between the legumes effectively provides lucerne with a soil water store that is 50 mm/m profile (33%) higher than mungbean. A major disadvantage of this ability to extract water to lower matrix potential, however, is that more rain is needed to recharge the profile for subsequent crops.

Conclusions

This study has demonstrated the potential of a range of legumes to produce significant quantities of DM and to fix nitrogen over several years. Both annual legumes consistently produced high amounts of DM and fixed large quantities of N when soil NO_3 was low, a situation that can be achieved commercially by the use of legume–cereal rotations. However, the pulse still produced a negative N balance due to the export of N as grain, even when soil NO_3 was low. In contrast, soil NO_3 was lower under perennial legumes and comparatively higher rates of N_2 fixation were maintained. DM production, however, was generally lower in the perennial legumes than the annuals and declined during latter years due to insect and weed problems.

The use of legumes by farmers in CQ is currently based on both relative commodity prices (grain prices for mungbean and beef prices in the case of pasture legumes *v*. price of cereal grain) and planting opportunities rather than the contribution of legumes to soil N fertility. Ley legumes offer a potentialy significant contribution to animal liveweight gains to finish beef cattle (Graham *et al*. 1986), but whether this is enough to offset the loss of cropping opportunities needs to be determined. The return from growing continuous cereals will decrease as soil N fertility continues to decline. Given the current relative commodity prices of grain and beef, the value of legumes in CQ will increasingly depend on their N contribution to subsequent grain crops. This issue is addressed by Armstrong *et al*. (1999).

Acknowledgments

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