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Sustaining productivity of a Vertosol at Warra, Queensland, with fertilisers, no-tillage or legumes. 7. Yield, nitrogen and disease-break benefits from lucerne in a two-year lucerne–wheat rotation

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Abstract. Continuous cultivation and cereal cropping of southern Queensland soils previously supporting native vegetation have resulted in reduced soil nitrogen supply, and consequently decreased cereal grain yields and low grain protein. To enhance yields and protein concentrations of wheat, management practices involving N fertiliser application, with no-tillage and stubble retention, grain legumes, and legume leys were evaluated from 1987 to 1998 on a fertility-depleted Vertosol at Warra, southern Queensland. The objective of this study was to examine the effect of lucerne in a 2-year lucerne–wheat rotation for its nitrogen and disease-break benefits to subsequent grain yield and protein content of wheat as compared with continuous wheat cropping.

Dry matter production and nitrogen yields of lucerne were closely correlated with the total rainfall for October–September as well as March–September rainfall. Each 100 mm of total rainfall resulted in 0.97 t/ha of dry matter and 26 kg/ha of nitrogen yield. For the March–September rainfall, the corresponding values were 1.26 t/ha of dry matter and 36 kg/ha of nitrogen yield. The latter values were 10% lower than those produced by annual medics during a similar period. Compared with wheat–wheat cropping, significant increases in total soil nitrogen were observed only in 1990, 1992 and 1994 but increases in soil mineralisable nitrogen were observed in most years following lucerne. Similarly, pre-plant nitrate nitrogen in the soil profile following lucerne was higher by 74 kg/ha (9–167 kg N/ha) than that of wheat–wheat without N fertiliser in all years except 1996. Consequently, higher wheat grain protein (7 out of 9 seasons) and grain yield (4 out of 9 seasons) were produced compared with continuous wheat. There was significant depression in grain yield in 2 (1993 and 1995) out of 9 seasons attributed to soil moisture depletion and/or low growing season rainfall. Consequently, the overall responses in yield were lower than those of 50 kg/ha of fertiliser nitrogen applied to wheat–wheat crops, 2-year medic–wheat or chickpea–wheat rotation, although grain protein concentrations were higher following lucerne.

The incidence and severity of the soilborne disease, common root rot of wheat caused by *Bipolaris sorokiniana,* was generally higher in lucerne–wheat than in continuous wheat with no nitrogen fertiliser applications, since its severity was significantly correlated with plant available water at sowing. No significant incidence of crown rot or root lesion nematode was observed. Thus, productivity, which was mainly due to nitrogen accretion in this experiment, can be maintained where short duration lucerne leys are grown in rotations with wheat.

Introduction

The cereal growing areas of southern Queensland and northern New South Wales (NSW) have largely relied on native soil nitrogen (N) fertility, which has been declining since cropping started almost 100 years ago (Hallsworth *et al*. 1954; Dalal and Mayer 1986*a*; Martin *et al*. 1988; Dalal and Probert 1997), resulting in static or declining crop yields and grain protein concentrations (Dalal *et al*. 1991). Wheat grain yield and grain protein could be improved by either N fertiliser applications in a continuous cereal cropping (Holford and Doyle 1992; Strong *et al*. 1996) or inclusion of a legume such as lucerne in rotation with wheat (Holford 1980; Littler 1984; Whitehouse and Littler 1984; Hossain *et al*. 1996*b*; Holford and Crocker 1997; Holford *et al*. 1998; Armstrong *et al*. 1999).

In southern Queensland and northern NSW, it has been shown that even a temperate annual pasture legume such as annual medics, significantly increases mineral N (mostly nitrate-N since ammonium-N concentrations are very small), grain yields and protein concentrations of subsequent wheat

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crops (Dalal *et al.* 1991; Hossain *et al.* 1996*b*; Holford *et al.* 1998; Weston *et al.* 2002). Therefore, it is expected that perennial legumes such as lucerne may perform better than winter growing annual medics in this region due to summer-dominant rainfall (Holford 1980; Littler 1984; Hossain *et al.* 1996*b*; Holford and Crocker 1997; Weston *et al.* 2000).

The N benefits of lucerne to the following wheat crop depends on its productivity during the ley period since the amount of N fixed by lucerne is closely associated with the total amount of dry matter (DM) produced; on average, 20–25 kg of shoot N is fixed for each tonne of legume herbage DM produced (Peoples and Baldock 2001). Hossain *et al.* (1995) found that 60 kg/ha of N_2 was fixed (estimated by δ^{15}N natural abundance technique) by lucerne in its aboveground DM at Warra, southern Queensland, in 1988. Another 50% of the legume N may have been present in its root biomass (Peoples and Baldock 2001; Peoples *et al.* 2001). Hossain *et al.* (1995) also found that ~70% of lucerne N yield was derived from atmosphere. Although the proportion of N fixed by legumes is affected by initial soil N fertility (Doughton *et al.* 1993; Holford *et al.* 1998; Armstrong *et al.* 1999) and seasonal growing conditions, lucerne appears to fix more N than either annual medics or chickpeas in northern NSW and southern Queensland (Dalal *et al.* 1991; Hossain *et al.* 1995; Holford *et al.* 1998).

A significant benefit of lucerne ley is in its contribution to the soil total N and nitrate-N supply to subsequent wheat crops. A substantial increase in nitrate-N has been observed following lucerne ley (Whitehouse and Littler 1984; Hossain *et al.* 1996*a*) and this is reflected in increased N uptake (Holford 1980) and increased wheat grain yield and protein (Holford 1980; Whitehouse and Littler 1984; Hossain *et al.* 1996*b*). Provided plant available water is not limiting, N uptake by wheat following lucerne was found to be closely related to the nitrate-N present in soil (Holford 1980; Holford *et al.* 1998).

Besides N accretion, legumes in rotation may control or reduce the incidence and severity of soilborne cereal diseases. For example, take-all in wheat (*Gaeumannomyces graminis*) was negligible following a lupin (*Lupinus augustifolius*) crop compared with 36% incidence in wheat–wheat rotation (Reeves *et al.* 1984). Also, the incidence and severity of crown rot of wheat, caused by *Fusarium graminearum*, was reduced by rotation with chickpea in southern Queensland (Wildermuth *et al.* 1992). The incidence and severity of common root rot of wheat caused by *Bipolaris sorokiniana* following chickpea was associated with the plant available water at sowing; the percentage of wheat plants affected increased as plant available water at sowing decreased (Dalal *et al.* 1998). Therefore, the effect of lucerne as a disease-break crop for wheat may be tempered by its capacity to extract more water and thus leave behind larger moisture deficit than continuous wheat cropping.

Plant available water deficit could be greater as well as more frequent following lucerne ley than continuous wheat cropping (Holford and Doyle 1978), annual medics or chickpea (Holford *et al.* 1998), thus adversely affecting wheat yields in the north-eastern subtropical Australia. Consequently, significant amounts of mineral N following the longer duration lucerne ley may remain unutilised by wheat, to be subjected to leaching and denitrification losses. Also, disease-break impact of lucerne on the following wheat may be uncertain.

Since seasonal variability is a strong feature of the subtropical environment, it is necessary to measure lucerne production, fertility restoration and wheat crop yields over a longer term (>1–2 seasons) for assessing the sustainability of lucerne–wheat rotation in this region. This study aims to measure the effects of lucerne in a 2-year lucerne–wheat rotation on yields, N, and disease-break benefits to the following wheat crop. These effects will then be compared with wheat–wheat rotations on a fertility-depleted Vertosol (Isbell 1996) [0.06% total N compared with 0.13% total N for Holford (1980) and Littler (1984) lucerne trial sites on Vertosols] in 4 cycles of the rotation from 1987 to 1996.

Materials and methods

Site details

A long-term field experiment was conducted at Warra (26°47′S, 150°53′E) in southern Queensland on a soil that had been cultivated for cereal cropping since 1935. The soil is a Vertosol (Typic Chromustert) that has lost 70% of organic C (from 2.23 to 0.68%) and total N (from 0.20 to 0.06%) from the 0–0.1 m layer after 50 years (Dalal and Mayer 1986*b*, 1986*c*). Detailed description of the soil, as well as mean monthly maximum and minimum temperatures, mean monthly rainfall, and growing season rainfall at the field site (1987–98) are described in earlier papers of this series (Dalal *et al.*1995; Strong *et al.* 1996; Weston *et al.* 2002). Briefly, the soil contains 56% clay, 17% silt and 27% sand. It is alkaline at the surface (pH 8.6) trending to strongly acidic (pH 4.9) at 1.2 m depth. Annual rainfall varied from 396 mm in 1986 to 800 mm in 1998, and March–September rainfall varied from 74 mm in 1991 to 492 mm in 1998.

Experimental design

The experimental design and treatments of this experiment are described by Dalal *et al.* (1995). The earlier reports from this experiment contain results on the effects of fertiliser N (Strong *et al.* 1996), chickpea–wheat rotation (Dalal *et al.* 1998), and annual medic–wheat rotation (Weston *et al.* 2002) on wheat yield and protein. Briefly, a 2-year rotation of lucerne (*Medicago sativa* L. cv. Trifecta) and wheat (*Triticum aestivum* L. cv. Hartog) is described below. Lucerne was established in a randomised block design with 4 replications (plot size, 6.75 by 25 m) in a core experiment (Table 1), which was not grazed. Pasture treatments were repeated as duplicate plots in an adjacent area where they were grazed by sheep. The lucerne leys in treatment 4 were grown in 1988, 1990, 1992 and 1994, and subsequent wheat crops were grown in 1989, 1993 and 1995. Drought in 1991 precluded the sowing of wheat following lucerne ley. In treatment 5, the lucerne leys were grown in 1989, 1991, 1993 and 1995, and subsequent wheat crops were grown in 1990, 1992, 1994 and 1996. Treatment 5 plots were sown to wheat (wheat bioassay) in 1996–98 and treatment 4 in 1997–98.

Pasture management

Wheat was undersown with lucerne (2 kg/ha) in 1987 to provide a lucerne ley in 1988 (treatment 4), which was followed by a wheat crop in 1989. For the second lucerne ley (treatment 5), wheat was undersown with lucerne in 1988 to provide a lucerne sward in 1989, which was followed by wheat in 1990 (Table 1). Wheat and undersown lucerne was generally sown in May or June, depending on sowing rains.

In the core experiment, ungrazed lucerne leys were harvested ('cut and remove') to a height of 0.1 m at 3-monthly sampling intervals (December, March, June and September); while in the adjacent experiment, lucerne was grazed by sheep to a similar height during the 4 weeks before sampling. Dry matter yield in the grazed lucerne was assessed by harvesting lucerne from movable exclosures at 3-monthly intervals. In both experiments, from each replicate plot, 5 quadrats of 1 × 1 m were used for sampling for lucerne DM yield. At the termination of the lucerne ley in October, an additional DM measurement was made. Plant material was dried at 75°C, weighed and ground to pass through a 1 mm sieve and DM %N determined by Kjeldahl analysis (Crooke and Simpson 1971).

To coincide with the maturity and removal of annual legumes (annual medics, chickpea) (Dalal *et al.* 1995) and allow sufficient time for soil profile water recharge, lucerne leys were terminated in early October by blade ploughing to 0.10–0.15 m depth. Weed growth was controlled during the fallow period by 2–3 ploughings to ~0.1 m depth.

Crop and soil management

After fallow, wheat was sown at 0.25 m spacing at a rate of 40 kg/ha in May or June; or 50 kg/ha when sown in July (1990, 1993). Little weed control was required during wheat cropping, and undersown lucerne contributed only a small amount of DM and N to the overall rotation. Weed growth after wheat harvest during the fallow period was controlled by 2–3 ploughings (Strong *et al.* 1996); similar to that after the termination of the leys. Wheat crop received annually a basal rate of 10 kg of phosphorus as superphosphate, fortified with copper and zinc at sowing. Lucerne leys were topdressed with the same fertiliser at the same rate annually.

Just before harvest, aboveground DM yields of wheat were estimated by harvesting 1 m lengths of 2 adjacent plant rows, and then drying at 75°C. Grain and straw were separated, and from their mass, harvest index was calculated. Wheat grain yields were measured from machine harvesting 1.75 by about 23 m of the central area of each plot. Grain yields were adjusted to 12% moisture content and grain and straw %N determined by Kjeldahl digestion followed by automated ammonium analysis (Crooke and Simpson 1971).

Nitrogen fixation by lucerne was estimated in 1988 and 1992 (2 contrasting seasons) using the ^{15}N natural abundance (Ledgard and Peoples 1988) technique. Milk thistle (*Sonchus oleraceus* L.) was used as a reference plant (Hossain *et al.* 1995; Dalal *et al.* 1997*a*).

Soil sampling and analysis

In May (presowing) and November (after harvest) each year, soil was sampled to a depth of 1.5 m for soil water and nitrate contents using a 50-mm diameter tube hydraulic sampler. Two soil cores taken from each plot were bulked by 0.1-m layers to a depth of 0.3 m and by 0.3-m layers below to a depth of 0.3 m. Soil samples were stored in airtight bags at 4°C until analysis. Soil moisture content was determined gravimetrically by drying soil samples at 105°C for 48 h and converted to volumetric soil moisture content (mm/layer) using a bulk density adjusted for the soil moisture content for the layer (Strong *et al.* 1996). For nitrate analysis, soil was dried at 35°C under draught, and ground to <2 mm for colorimetric determination of nitrate (Best 1976) after extraction of 10 g of soil in 100 mL of 2 mol/L KCl.

Ten cores were collected annually in May from 0 to 0.1 m depth from each plot, bulked together, air-dried and then analysed for mineralisable-N (<2 mm size). This was done using the waterlogged procedure of Waring and Bremner (1964), and total-N (<0.25 mm size) by modified Kjeldahl method (Dalal *et al.* 1984).

Disease assessment

The incidence and severity of common root rot and crown rot of wheat were assessed from 50 randomly collected wheat plants with their roots from each plot at anthesis. The subcrown internode of each plant was examined for the extent of lesions due to common root rot. Based on subcrown internode surface covered by lesions, the wheat plants were segregated into 6 disease categories: (i) no lesion; (ii) 1 and 2 lesions covering <10%; (iii) lesions covering 10–25%; (iv) lesions covering 25–50%; (v) lesions covering 50–99%; and (vi) lesions covering 100%. Then disease severity was calculated from the following formula:

$$\text{Disease severity (\%)} = [(2\,N_1 + 5\,N_2 + 10\,N_3) \times 100]/(10 \times \text{total number of plants}),$$

where N_1 is the number of plants in categories (ii) and (iii), N_2 is the number of plants in category (iv), and N_3 is the number of plants in categories (v) and (vi) (Wildermuth *et al.* 1992).

Table 1. Sequence of lucerne and wheat in a 2-year lucerne–wheat rotation commencing in 1988 (treatment 4) and 1989 (treatment 5), compared with wheat–wheat rotation without fertiliser application

W_l, undersown lucerne; L, lucerne ley; W, wheat; Drought, wheat not sown due to drought
In 1997 and 1998, wheat was sown to assay residual nitrate-N

Year	Treatment 4 Lucerne–wheat rotation (0 kg N/ha)	Treatment 5 Lucerne–wheat rotation (0 kg N/ha)	Treatment 10 Wheat–wheat rotation (0 kg N/ha)
1987	W_l	W	W
1988	L	W_l	W
1989	W_l	L	W
1990	L	W_l	W
1991	Drought	L	Drought
1992	L	W_l	W
1993	W_l	L	W
1994	L	W_l	W
1995	W_l	L	W
1996	L	W	W
1997	W	W	W
1998	W	W	W

Incidence of crown rot was assessed by examining the first internode of tillers for honey brown to dark brown discoloration. Root lesion nematode effects were assessed from root lesion nematodes (*Pratylenchus thornei*) present in soil in May in 1988 (Wildermuth *et al.* 1997). None were found and hence no further assessments were made in subsequent years.

Results

Above ground dry matter production and nitrogen yield

Dry matter and N yields between the ungrazed (core experiment) and the grazed lucerne leys were not significantly different (data not shown). Hossain *et al.* (1995, 1996*a*, 1996*b*) also found no difference in lucerne DM and N yields between the ungrazed and grazed lucerne leys in the first 2 rotation cycles. Therefore, only the results for the ungrazed lucerne leys are presented.

Annual DM yields of lucerne ley ranged from 0.65 t/ha in 1991 to 5.79 t/ha in 1988 (Table 2). Similarly, total N yield varied from 18 kg N/ha in 1991 to 152 kg N/ha in 1988. Undersown lucerne made only a small contribution to DM yield in the cropping years, with N yields less than 8 kg N/ha.year (data not shown).

For October–September rainfall, lucerne DM and N yields increased by 9.7 kg DM/ha.mm rainfall (r^2 = 0.76) and 0.26 kg N/ha.mm rainfall (r^2 = 0.86). September lucerne harvest provided the highest DM yield in most years.

The amount of DM removed from the lucerne plots from lucerne cut and remove treatment varied from 0.18 t/ha in 1991 to 2.5 t/ha in 1988. On average, 25 kg N/ha.year (0–58 kg N/ha) was removed in lucerne harvest (‘cut and remove’) during 1988–95 (Table 2).

Total soil nitrogen and mineralisable-nitrogen

For treatment 4 (commenced in 1998), the amounts of soil total N were significantly higher after the lucerne ley than the wheat–wheat rotation (Fig. 1*a*) in 1990, 1992 and 1994, with the increase in soil total N varying from 109 kg/ha to 123 kg/ha. Following lucerne ley in treatment 5 however, no significant increase in soil total N was observed, mainly due to low rainfall seasons. Using ^{15}N natural abundance technique for 2 contrasting seasons in treatment 4, the amount of N derived from atmosphere (Ndfa) by lucerne was 103 kg N/ha (68% Ndfa) in 1988 and 14 kg N/ha (26% Ndfa) in 1992. The latter lucerne ley followed a no-wheat crop season (drought) in 1991 when mineral-N accumulated in the soil, and that reduced N_2 fixation (Doughton *et al.* 1993). Also, there was lower lucerne DM yield in 1992 than in 1988 (Table 2).

Table 2. Total aboveground dry matter (DM) and nitrogen yields (kg/ha) of lucerne in lucerne–wheat rotations

Year	DM yield (t/ha)	DM N yield (kg N/ha)	Cut and remove N (kg N/ha)
1988	5.79	152	57.9
1989	3.57	114	36.3
1990	2.81	94	50.0
1991	0.65	18	4.7
1992	1.46	57	14.4
1993	1.35	45	8.4
1994	2.28	62	28.2
1995	0.81	24	0
Mean	2.34	71	25.0
l.s.d. (P = 0.05)	0.36	12	21.6

Mineralisable-N was also significantly higher after the lucerne ley than the wheat–wheat rotations (Fig. 1*b*) in all years except in 1992 and 1994. Mineralisable-N increases ranged from 15 to 34 kg/ha. Mineralisable-N, therefore, was a more sensitive indicator than soil total N, thus demonstrating the ability of lucerne to increase the supply of potentially available N in soil.

Nitrate-nitrogen

The amount of nitrate-N (0–1.2 m depth) accumulated at the end of the fallow period in May ranged from 35 to 89 kg N/ha in the wheat–wheat rotations compared with 40 to 202 kg N/ha following the lucerne leys (Table 3). Differences between the 2 treatments ranged from nil in 1996 to 167 kg N/ha in 1993. On average, nitrate-N after the lucerne ley was 74 kg/ha greater than in the wheat–wheat rotations over the 8-year period (1989–96). In the initial years of this experiment, nitrate-N accumulated to very high levels following good lucerne growth during 1988–90, but in the later drier years, it was due to low N removal associated with poorer wheat growing seasons during 1993–95. Increases in

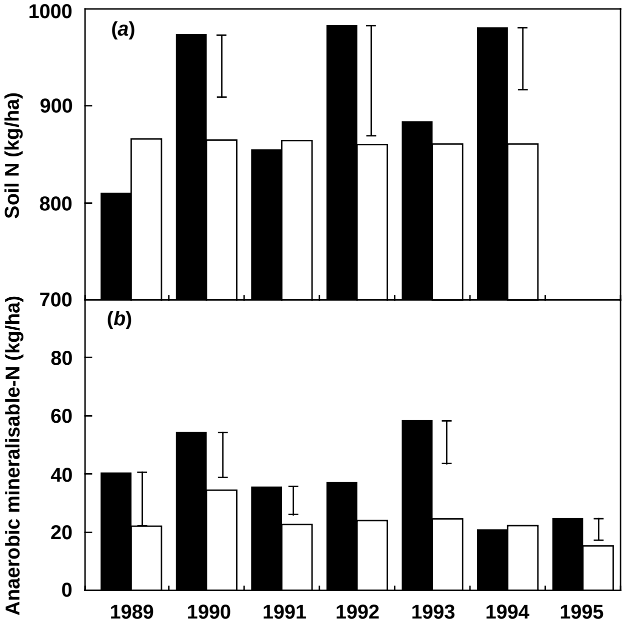

Figure 1. (*a*) Total soil nitrogen (*b*) and mineralisable-nitrogen after lucerne (solid bars) in lucerne–wheat rotations and wheat–wheat rotation (open bars) with 0 kg N/ha fertiliser application. The bar heights represent the l.s.d. at P = 0.05 between treatments.

soil nitrate-N were observed down to 0.9 m depth early in the rotation years (Fig. 2). When wheat crops were grown in better seasons and produced higher grain yields, they extracted more plant available N; thus, generally resulting in lower nitrate-N accumulation.

Plant available soil water

At wheat sowing in May, available soil water (0–1.2 m depth) in lucerne–wheat rotations was significantly lower in 1989, 1993, 1995 and 1996 than in wheat–wheat rotations (Table 3). Even in seasons when total plant available water was similar in both rotations, its distribution within the soil profile differed (Fig. 2). For example, in 1990, 1991, 1992 and 1994, significantly lower soil water contents were observed in deeper layers, usually at 0.9–1.2 m and 1.2–1.5 m depths (Fig. 2). This is consistent with greater water removal by lucerne, especially from deeper layers, and then followed by higher grain yields. On average, 27 mm less water was present in the lucerne–wheat rotations than in the wheat–wheat rotations, usually in layers below 0.6 m depth.

Wheat grain yields and grain protein concentrations

Wheat grain yield increased significantly following lucerne in 1990, 1994, 1996 and 1998 compared with the wheat–wheat rotations with no N fertiliser (Table 4). However, lower grain yields were obtained in 1993 and 1995 compared with the wheat–wheat rotations with no N fertiliser. In these 2 cropping seasons, plant available water at sowing was less than 80 mm (Table 3).

Wheat grain protein concentrations in lucerne–wheat rotation were significantly higher than those from the wheat–wheat rotation without N fertiliser in all years except in 1992 and 1996 (Table 5). Increases in grain protein concentration following lucerne ley ranged from 4 to 96% (Table 5).

Incidence and severity of common root rot and crown rot

Although common root rot occurred in all years in both lucerne–wheat and wheat–wheat rotations, its incidence and severity varied (Table 6). The lowest incidence of common root rot (23%) occurred in the wheat–wheat rotation in 1992 and the highest incidence of common root rot (93%) was observed in lucerne–wheat rotation in 1993. However, significant differences in the incidence of common root rot were found only in 1990 and 1993; in both of these years, the incidence was higher in lucerne–wheat rotation than that in wheat–wheat rotation. The lucerne–wheat rotation also recorded the lowest (10% in 1989) and the highest (68% in 1993) severity of common root rot of wheat. However, the severity of common root rot was similar in both rotations in all years except in 1990, when it was significantly higher in lucerne–wheat rotation compared with wheat–wheat rotation.

Crown rot of wheat was not detected in this experiment until 1995; even then the incidence and severity of crown rot were negligible in this and subsequent years. Root lesion nematodes were not observed at this site.

Discussion

Lucerne yield and soil nitrogen

Dry matter yield response to similar rainfall during the lucerne ley season (October–September) of 9.7 kg/mm of lucerne DM in this study compares favourably with that observed by Lloyd and Hilder (1978) at Kingsthorpe (5.5–11.9 kg/mm of lucerne DM). Significant increase in total N (109–123 kg N/ha) was found following lucerne. Holford (1981) also found an estimated increase of 140 kg N/ha.year, even though initial soil N levels were high in this study (0.13% *v.* 0.06%). Whitehouse and Littler (1984) measured similar increases in soil N, that is, ~130 kg N/ha.year in the first 2 years but no further increases after 2 years of lucerne ley. Similarly in Central Queensland, soil total N did not increase after 2 years although soil N increases were only 120 kg N/ha (Armstrong *et al.* 1999). These values were measured in the top 0.1 or 0.15 m layer. Significant increases in total N may also be found below these depths (Holford *et al.* 1998) although Whitehouse and Littler (1984), Hossain *et al.* (1996*a*) and Dalal *et al.* (1995) did not find a significant increase in total N below 0.1 m depth following lucerne as compared to wheat–wheat rotation.

Table 3. Soil nitrate-nitrogen (0–1.2 m) and plant available water (0–1.2 m) in May (pre-sowing time) following 6 months of fallow after lucerne in lucerne–wheat rotation and wheat–wheat rotation without fertiliser N

Year	Nitrate-N (kg/ha)			Plant available water (mm)		
	Lucerne–wheat	Wheat–wheat	l.s.d. ($P = 0.05$)	Lucerne–wheat	Wheat–wheat	l.s.d. ($P = 0.05$)
1989	116	35	15	150	195	35
1990	142	38	22	143	165	n.s.
1991	123	38	36	81	95	n.s.
1992	98	89	n.s.	127	151	n.s.
1993	202	35	55	58	85	25
1994	85	47	30	167	176	n.s.
1995	169	62	53	76	124	26
1996	40	40	n.s.	144	168	23
Mean	122	48	32	118	145	23

Significant increases in mineralisable-N following lucerne (15–35 kg N/ha) showed that 1 year of lucerne ley provides significant N benefits although these may not be evident in total N values in some years. These increases in mineralisable-N were similar to those reported by Hossain *et al.* (1996*a*). Dalal and Mayer (1987) also observed that mineralisable-N was a sensitive indicator of changes in soil N fertility.

Wheat yield and protein benefits following lucerne ley

The overall yield benefits of lucerne were only marginally better (8%) in lucerne–wheat rotation than wheat–wheat rotations without N fertiliser during 1989–98. However, this included both good and poor cropping seasons; the best yield increase (>50%) was obtained in 1990, and the worst yield decrease (<50%) was obtained in 1995. Similar results were obtained by Holford and Doyle (1978) for 1970 and 1971 on a Vertosol in northern NSW, irrespective of the duration of lucerne ley. Thus, the lucerne–wheat rotations in this study exacerbated the grain yield variability, from 0.5 to 3.4 t/ha. In comparison, the wheat–wheat rotations without fertiliser N varied from 1 to 3.5 t/ha; and wheat–wheat rotations with 50 kg N/ha fertiliser application, from 0.8 to 3.7 t/ha (Table 4). Compared to the lucerne–wheat rotation, the average benefits in wheat yield in annual medics–wheat rotation, chickpea–wheat rotation, and wheat–wheat rotation

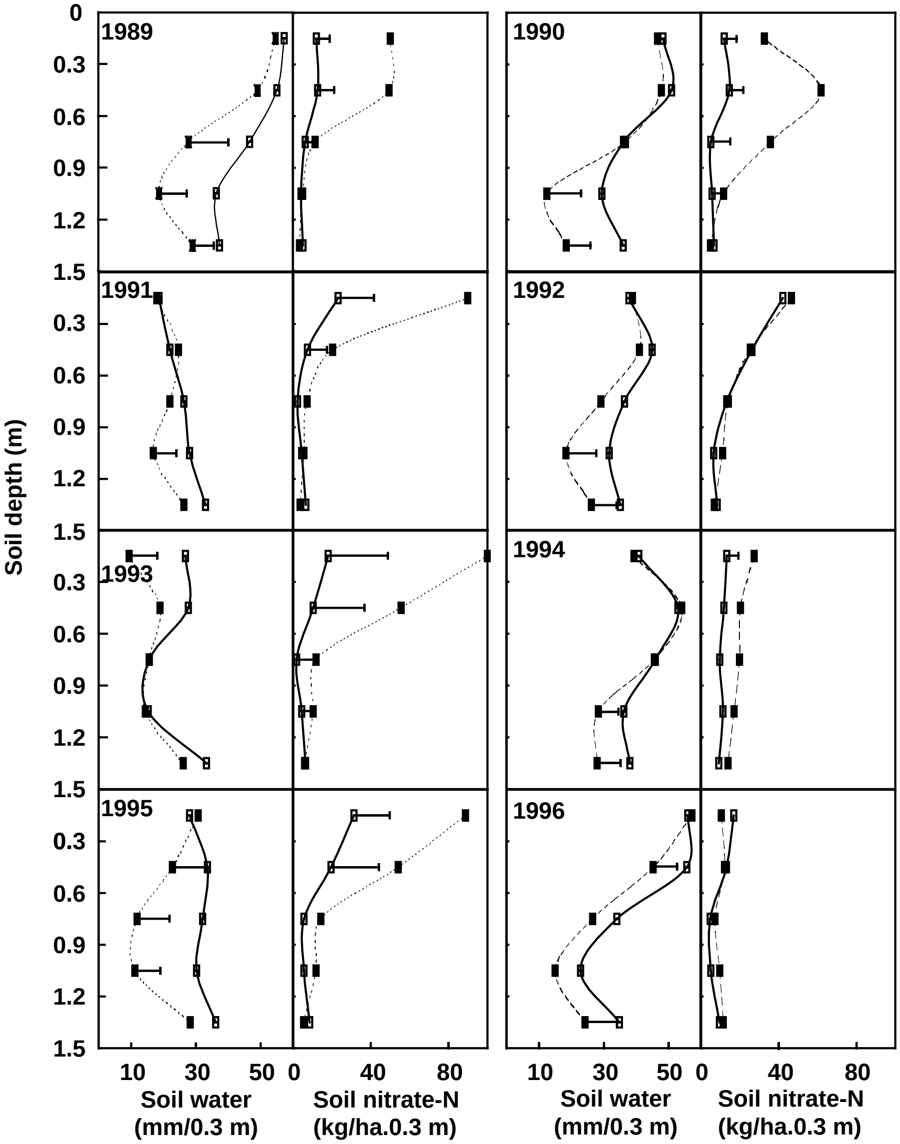

Figure 2. Depth-distribution of plant available water and nitrate-nitrogen in the soil in May (pre-sowing for wheat), measured after 6 months summer fallow following lucerne leys in lucerne–wheat rotation (■) and wheat–wheat rotation with 0 kg N/ha fertiliser application (☐). Horizontal bars represent l.s.d. at $P = 0.05$.

Table 4. Wheat grain yield (t/ha) in lucerne–wheat rotations, compared with medic–wheat, with and without N-fertilised wheat–wheat rotations

Year	Lucerne–wheat (0 kg N/ha)	Wheat–wheat (0 kg N/ha)	Medic–wheat[A] (0 kg N/ha)	Wheat–wheat[B] (50 kg N/ha)	l.s.d. ($P = 0.05$)
1989	1.86	2.07	2.70	2.82	0.27
1990	3.38	2.23	3.59	3.14	0.27
1991	Drought year with no wheat crop sown				
1992	3.40	3.48	3.85	3.72	n.s.
1993	1.28	1.88	1.33	1.88	0.20
1994	1.70	1.02	1.34	1.58	0.20
1995	0.50	1.20	0.49	0.80	0.20
1996	2.62	2.27	4.17	3.79	0.34
1997	2.44	2.11	2.79	2.21	0.37
1998	1.93	1.40	2.18	1.71	0.38
Mean	2.12	1.96	2.63	2.41	0.35

[A] Weston *et al*. (2002). [B] Strong *et al*. (1996).

with 50 kg N/ha.year fertiliser applications were 40% (Dalal *et al*. 1998), 25% (Weston *et al*. 2002), and 10% (Table 4), respectively. Holford and Crocker (1997), however, recorded higher wheat yields following lucerne (average = 3.5 t/ha) than annual medics (2.87 t/ha) or chickpea (2.59 t/ha); possibly in good wheat cropping seasons.

In spite of the grain yield differences, water use efficiency {kg grain/ha.mm = grain yield in kg/ha/[(soil water at sowing – soil water at harvest in 0–1.2 m depth) + in-crop rainfall]} was essentially similar in lucerne–wheat (9.9 ± 4.9), annual medic–wheat (9.8 ± 4.9) (Weston *et al*. 2002), chickpea–wheat (11.3 ± 3.2) (Dalal *et al*. 1998) and wheat–wheat rotations with 50 kg N/ha.year fertiliser application (10.6 ± 4.4) but tended to be higher than wheat–wheat rotation without fertiliser application (8.4 ± 4.0) during 1989–96 (data not shown). Thus, plant available water was used as efficiently in lucerne–wheat rotation as, for example, in annual medics–wheat rotation.

In spite of the large wheat yield variability in lucerne–wheat rotations, grain protein concentrations were always higher (average protein = 13.1%) than in wheat–wheat rotations without fertiliser N application (9.7%). They were also higher than those obtained in wheat–wheat rotations with 50 kg N/ha.year of fertiliser (12.1%) (Table 5), annual medics–wheat rotation (12.9%) (Weston *et al*. 2002) or chickpea–wheat rotation (10.7%) (Dalal *et al*. 1998). In 1989, 1993 and 1995, wheat grain proteins exceeded 15%, with the consequence of low grain size (high screening leading to downgrading of grain). For example, in 1995, wheat grain of 16% protein concentration weighed 23 mg/seed from lucerne–wheat rotations compared with 36 mg/seed in wheat–wheat rotations without N fertiliser. However, high protein and low grain weight wheat could be blended with low protein/high grain weight on-farm to maximise economic returns from high protein wheat.

Table 5. Wheat grain protein (%) in lucerne–wheat rotations, compared with medic–wheat, with and without N-fertilised wheat–wheat rotations

Year	Lucerne–wheat (0 kg N/ha)	Wheat–wheat (0 kg N/ha)	Medic–wheat[A] (0 kg N/ha)	Wheat–wheat[B] (50 kg N/ha)	l.s.d. ($P = 0.05$)
1989	15.7	8.0	13.2	10.7	0.8
1990	13.0	8.3	12.1	10.0	0.8
1991	Drought year with no wheat crop sown.				
1992	11.6	10.8	12.7	12.7	1.0
1993	16.1	9.6	16.3	15.1	0.6
1994	11.4	8.7	12.1	11.2	1.0
1995	16.0	11.8	15.6	14.4	0.6
1996	10.6	10.2	12.6	12.2	0.9
1997	11.7	9.0	11.8	11.0	1.1
1998	11.9	10.6	11.9	11.5	0.6
Mean	13.1	9.7	12.9	12.1	0.8

[A] Weston *et al*. (2002). [B] Strong *et al*. (1996).

Table 6. Incidence and severity of common root rot in wheat crop in lucerne–wheat rotation and wheat–wheat rotation at anthesis

Year	Incidence (%)			Severity (%)		
	Lucerne–wheat	Wheat–wheat	l.s.d. ($P = 0.05$)	Lucerne–wheat	Wheat–wheat	l.s.d. ($P = 0.05$)
1989	30.6	26.6	n.s.	10.0	11.9	n.s.
1990	46.2	24.6	11.1	32.5	14.8	10.8
1992	35.1	23.1	n.s.	22.8	13.5	n.s.
1993	92.7	80.8	11.6	68.4	61.8	n.s.
1994	55.5	41.1	n.s.	19.0	11.7	n.s.
1995	23.7	34.1	n.s.	13.8	22.9	n.s.
1996	47.8	46.3	n.s.	13.3	18.2	n.s.
Mean	47.4	40.6	n.s.	25.7	22.1	n.s.

Wheat grain yields for all years were poorly correlated with pre-sowing plant available water or soil nitrate concentrations (Tables 3 and 4), especially following lucerne ley. This was possibly due to water limitations to crop yield in some years. However, wheat grain protein (Table 5) was closely correlated with the ratio of plant available water to nitrate-N ($r^2 = 0.80$) using relationships developed by Dalal *et al.* (1997*b*). Thus, impact of plant available water as well as nitrate-N must be considered following lucerne in lucerne–wheat rotations.

In most years, the plant available water (generally below 0.6 m depth) following lucerne was lower than in wheat–wheat rotations (Fig. 2). On average, it was also lower (118 mm in 0–1.2 m depth of soil) than chickpea–wheat rotation (163 mm) (Dalal *et al.* 1998) or annual medics–wheat rotation (142 mm) (Weston *et al.* 2002). Consequently, in extremely dry years (e.g. 1993 and 1995), wheat yields following lucerne were lower than those in the monoculture wheat without additional N, although grain protein concentrations were 16% and above. The very high levels of accumulated nitrate-N may have been detrimental to wheat yields during low rainfall cropping seasons (van Herwaarden *et al.* 1998). Holford and Doyle (1978) and Holford *et al.* (1998) also observed that a black Vertosol at Tamworth did not wet to field capacity 2.5 years after the termination of lucerne ley. They suggested that lucerne must be ploughed out before January if a severe reduction in grain yield of the following wheat crop is to be minimised. In this experiment, although lucerne ley was terminated in early October, dry seasons during the fallow and cropping in some years still had adverse effects on wheat yields.

Incidence and severity of soilborne diseases

Both incidence and severity of common root rot for all years (1989–96) were inversely related to the amount of available water at sowing (including annual medic–wheat and chickpea–wheat); irrespective of crop rotations (Fig. 3*a*). For example, incidence and severity decreased from 39% at 100 mm to 15% at 200 mm of plant available water (0–1.2 m depth). Pre-sowing nitrate-N in these rotations was not significantly related to the severity of common root rot in wheat (Fig. 3*b*).

Since plant available water at sowing was generally lower in lucerne–wheat rotation than wheat–wheat rotation, common root rot occurrence was usually higher in the former. Other soilborne diseases, crown rot and root lesion nematode, were either absent or very low in this experiment. Reeves *et al.* (1984) and Wildermuth *et al.* (1997) observed the disease-break effects of legumes in rotation with wheat

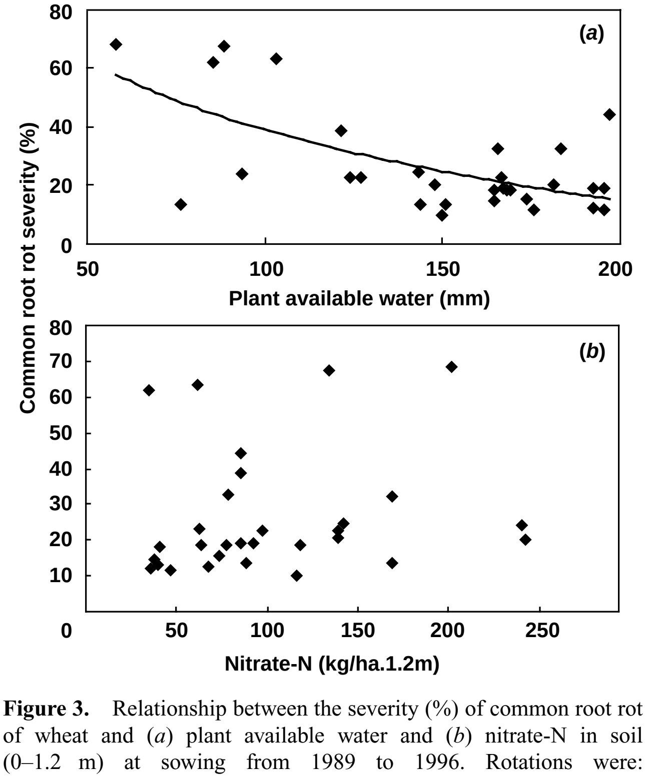

Figure 3. Relationship between the severity (%) of common root rot of wheat and (*a*) plant available water and (*b*) nitrate-N in soil (0–1.2 m) at sowing from 1989 to 1996. Rotations were: lucerne–wheat, annual medics–wheat (Weston *et al.* 2002), chickpea–wheat (Dalal *et al.* 1998), and wheat—wheat with 0 and 50 kg N/ha (1989 and 1996 only) application (Strong *et al.* 1996). The equation of the line in (*a*) is:

$$y = -34.8 \log_e(x) + 199.1 \quad (R^2 = 0.4).$$

when plant available water, including in-crop rainfall, was either similar or higher than wheat–wheat rotations.

In summary, besides wheat yields and protein benefits following lucerne ley, lucerne–wheat rotations maintained similar soil N levels at the end of the experiment (Fig. 1) compared with the decline in soil total N in chickpea–wheat rotation (Dalal *et al*. 1998). Holford *et al*. (1998) also obtained similar results although the periods of lucerne leys in their experiments (Holford and Doyle 1978; Holford 1980; Holford *et al*. 1998) were longer (1.5–6.75 years) than the 4 cycles of 1-year lucerne ley in this study.

Conclusion

The lucerne–wheat rotation provides an attractive option for restoring the fertility of N-depleted soils and sustaining wheat yields in the eastern subtropical region of the Australian cereal belt. The main benefits from lucerne in lucerne–wheat rotations were due to N accretion rather than disease-break; provided good amounts of stored soil water and growing season rainfall occurred. In low rainfall seasons, however, wheat yields in lucerne–wheat rotations are depressed and grain protein levels are elevated (due to higher nitrate-N concentrations). They are often above 15%, resulting in lower wheat yields, higher yield variability, and smaller seed size; as compared with wheat–wheat rotations with moderate and targeted fertiliser N applications. This may have been due to short lucerne ley (1 year) in lucerne–wheat rotation, thus, not allowing a long enough period to recharge the soil water profile to field capacity before wheat sowing in this subtropical environment. We report in a subsequent paper the effect of various durations of lucerne leys (1–4 years) on N benefits and yields of following wheat crops from this experiment (Dalal *et al*. 2004).

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