Estimated symbiotic N₂ fixation by annual legume and lucerne pastures on 2 Vertosols with and without applied gypsum.

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Key words

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Abstract

The amount of symbiotic dinitrogen (N_2) fixed by an annual legume pasture (subterranean clover + balansa clover) and a lucerne-annual legume pasture growing on vertosol soils was estimated at two sites (Grogan and Morangarell) over 3 years in southern NSW following treatment with 3 rates of gypsum. Based on shoot growth only, the annual legume pasture was estimated to fix between 91 and 146 kg N_2 /ha/yr at Grogan and 86-214 kg N_2 /ha/yr at the less sodic Morangarell site. When roots were also included these values increased to 156-254 kg N_2 /ha at Grogan and 148-370 kg N_2 /ha/yr at Morangarell. Estimates of N_2 fixed by the lucerne-annual legume mixed sward at Grogan were similar to the annual legume sward, but at Morangarell estimates of N_2 fixed by lucerne were both higher and lower depending on seasonal conditions. Gypsum increased estimated total N_2 fixed by the annual and lucerne pastures by up to 16% and 37% respectively at Grogan, but had no effect at Morangarell.

Introduction

Legume-based pastures play an important role in the cropping zone of southern Australia by increasing soil nitrogen (N), acting as a disease break and providing income diversification. Placing a value on the N₂ fixed by pastures has become increasingly important as farmers question the future role of pastures in the system given perceived potentially higher returns from cropping and the increased work load associated with running livestock. Most measures of N₂ fixation by pasture legumes undertaken in Australia (e.g. see Peoples and Baldock 2001; Unkovich et al. 2010) and elsewhere in the world (Carlsson and Huss-Danell 2003) have generally indicated that the amounts of N₂ fixed were related to legume dry matter (DM) production. However, many of these previous estimates of N_2 fixation have focussed on measuring the N contained in the herbage (Peoples and Baldock 2001) and have ignored the below-ground contributions of N associated with root exudates (rhizodeposition; Wichern et al. 2008) and present in, or derived from, roots and nodules (Peoples et al. 2001). An improved understanding of the relationship between the N contained in the roots relative to top growth in both annual and perennial pasture legumes has allowed more realistic estimates of the total N₂ fixed by legume pastures to be derived. The following study sought to quantify the likely N contribution of annual legume and lucerne pastures growing on heavy clay sodic Vertisols in southern New South Wales (NSW) over a three year period following amelioration with gypsum.

Materials and methods

Two pasture types (annual legume pasture and a lucerne (*Medicago sativa* L.) -annual legume mixture) were established on 2 sodic Vertosol soils at Grogan and Morangarell in southern NSW in autumn 1999. The annual pasture treatment was a mixture of 2 cultivars of subterranean clover (*Trifolium subterraneaum* L.) (cvs Riverina and Clare) and balansa clover (*T. michelianum*)(cv. Paradana). The

lucerne treatment consisted of cv Aquarius, sown with the same annual legumes at half the rate as the annual only treatment. Three rates of gypsum were applied prior to sowing and incorporated by rotary hoeing, the rates varied to account for the different levels of sodicity at the two sites. The more sodic Grogan site received 0, 5, or 10 t gypsum/ha and the Morangarell site 0, 2.5 and 5 t/ha. The experimental design at both sites was a fully randomised split plot design with 4 replications, pasture type were main plots and gypsum rate sub plots within each main plot. Main plots were 4 m wide by 54 m long and subplots 4 m by 18 m.

Soil cores were taken at both sites to a depth of 1.5 m to characterise each site and analysed for pH, exchangeable cations and electrical conductivity. A detailed description of the analysis performed and the techniques used are given in Dear et al. (2010). The change in soil pH, exchangeable sodium and electrical conductivity down the profile at the two sites is given in Figure 1.



Soil pH (CaCl₂) and electrical conductivity (EC_e) dSm⁻¹

Figure 1. Change in soil pH, exchangeable sodium percentage (ESP) and electrical conductivity (EC) down the profile to 1.5 m at (a) Grogan and (b) Morangarell experimental sites.

Herbage dry matter (DM) yields were measured at intervals throughout the growing season and partitioned into annual legume and lucerne components. Direct measurement of symbiotic N_2 fixation is problematic as available methods are not always reliable and can be expensive to apply (Unkovich et al. 2008). Although the amounts of N_2 fixed by the lucerne and annual legume swards were not measured in the current experiment likely inputs of fixed N were approximated using relationships between legume herbage DM and N_2 fixation derived from a large number of prior studies of subterranean clover and lucerne; respectively Unkovich *et al.* 2010), including studies previously conducted at the Grogan and Morangarell sites (Dear et al. 2003). Total amounts of N_2 fixed (shoots + roots) were subsequently calculated by multiplying the estimated N_2 fixed in shoots by a 'root N factor' (1.72 for subterranean clover and 2.0 for lucerne; Unkovich *et al.* 2010).

The data were statistically analysed by fitting linear mixed models using the Asreml package (Butler et al. 2007) in the R environment (R Development Core Team 2008). Least significant differences (l.s.ds) to determine statistical differences were calculated at P = 0.05.

Results

The application of gypsum increased herbage yields at the Grogan site on 10 of the 16 occasions pasture yield was measured over the 3 year period. Seasonal pasture responses to gypsum at the less sodic

Morangarell site were few and statistically unimportant. A more detailed description of the seasonal and total productivity of the lucerne and annual swards is presented in Dear et al. (2010).

Estimates of shoot N₂ fixation at the more sodic Grogan site varied with gypsum treatment, species and year (P<0.001). Based on shoot growth only, annual swards fixed on average between 91-146 kgN₂/ha/yr and lucerne 82-138 kgN₂/ha/yr (Table 1). At the Morangarell site there was a significant (P<0.001) species by year effect on estimated shoot N₂ fixation, but it was unaffected by gypsum treatment with annual swards calculated to have fixed on average 86-214 kgN₂/ha/yr, and lucerne pastures 109-147 kgN₂/ha/yr and (Table 1).

Estimates of total N₂ fixation (shoots + roots) at Grogan was influenced by species, gypsum treatment and year and ranged from 156-268 kgN₂/ha/yr in annual swards and 157-267 kgN₂/ha/yr in lucerne swards. Total N₂ fixation estimates at Morangarell varied with species and year, but were unaffected by gypsum treatment. Annual pasture swards were estimated to fix up to 370 kgN₂/ha/yr compared to 279 kgN₂/ha/yr for lucerne.

Increases in herbage DM and amounts of N_2 fixed due to gypsum application at the more sodic Grogan site ranged from 0-16% in annual swards and 0-37% in lucerne.

Table 1. Estimated biological N₂ fixation (kgN₂/ha/yr) in shoots and shoots+roots of annual pasture (AP) and lucerne/annual pasture (L) swards at (a) Grogan and (b) Morangarell in 1999, 2000 and 2001 in response to 3 rates of gypsum (0, 5, 10 t/ha at Grogan and 0, 2.5, 5 t/ha at Morangarell).

Year /plant part		Pasture type and gypsum rate (t/ha)								
	(a) Grogan									
1999	AP0	AP5	AP10	Mean	LO	L5	L10	Mean		
Shoots	91	89	92	91	88	80	77	82		
Shoots+roots	157	155	158	156	167	155	149	157		
2000										
Shoots	133	152	154	146	115	145	155	138		
Shoots+roots	231	264	268	254	220	281	301	267		
2001										
Shoots	93	102	102	99	97	107	110	104		
Shoots+roots	161	176	175	170	183	205	213	200		

I.s.d.(P = 0.05) between shoot N values=12, between total N values = 22

1999	AP0	AP2.5	AP5		L0	L2.5	L5	
Shoots	107	109	114	110	109	111	108	109
Shoots+roots	184	188	196	189	203	208	201	204
2000								
Shoots	213	211	218	214	143	150	149	147
Shoots+roots	368	365	377	370	269	282	285	279
2001								
Shoots	83	87	89	86	111	111	110	111
Shoots+roots	142	149	154	148	219	218	217	218

(b) Morangarell

I.s.d. .(P = 0.05) between shoot N values = 10, between total N values = 19

Discussion

The contributions of N₂ fixation for legume growth varies during the year (Dear et al. 1999) and with levels of available mineral N in the soil (Unkovich et al. 2010) although studies have shown that the proportion of legume N derived by biological fixation in the winter dominant rainfall zone of southern Australia is uniformly high (65-95%)(Peoples et al. 2001). The values used to estimate N₂ fixed in the current study are based on average values derived from data collated from a large number of studies of lucerne and annual legumes in Australia (Unkovich et al. 2010). Given that previous measures of N₂ fixation undertaken elsewhere in southern NSW by Peoples et al. (1998) and Dear et al. (1999) found that subterranean clover fixed between 19-34 kgN/t above-ground DM and lucerne 17-29 kgN/tDM and, the values of 20 and 18kgN/tDM used for subterranean clover and lucerne in the current study could therefore be considered to provide a conservative estimate of realistically achievable targets of total N₂ fixation on these heavy clay sodic soils.

The estimates of yearly total shoot N₂ fixed in the current study were 86-214 kgN/ha/yr for subterranean clover and 82-147 for lucerne/annual swards which were comparable to, or higher than, those observed by Peoples et al. (1998) for pastures in districts around Junee on red-brown earths, but were lower than values previously reported on a red earth at Wagga Wagga in a similar climatic zone (Dear et al. 1999). The values most likely reflect the lower yield potential of pastures on the vertosols compared to red earths and the effects of the drier seasonal conditions.

In the current study lucerne did not produce significantly greater N_2 fixation than the annual pastures as has been reported previously (Peoples et al.1998; Dear et al. 1999), despite a potentially longer growing season. This is undoubtedly related to the generally dry conditions experienced over the summer periods that reduced the competitive advantage of a perennial species such as lucerne which has the capacity to utilise water outside the growing season of the annuals (Peoples and Baldock 2001; Sandral et al. 2006). Had more summer rain occurred generating additional lucerne growth, the resultant annual amounts of N_2 fixed by lucerne would be expected to increase relative to the annual pastures.

Conclusion

Gypsum enhanced the productivity of the pastures at the sodic Grogan site which had high levels of surface sodicity (>10% ESP in top 10cm), and the herbage response was reflected in the increased estimates of N₂ fixation in 2000 and 2001. Although the Morangarell site was sodic at depth, it had relatively low surface sodicity (<5% ESP in top 10cm) and hence herbage yield and N₂ fixation did not respond to gypsum applications. The derived estimates of N₂ fixation presented here were calculated using simple empirical relationships between shoot DM and symbiotic N₂ fixation (Unkovich *et al.* 2010). This approach represents a means of assessing inputs of fixed N to farms where only pasture legume DM production is known. While it is acknowledged that the assumed size of below-ground pools of fixed N in the calculations were far less than those that might be incurred by ignoring N contributed by the nodulated roots. It was clear from comparisons of the estimates of shoot N fixed with total (shoot + roots) inputs of fixed N that any conclusions about the relative role pastures play in building the organic fertility of soils in mixed farming systems could be substantially underestimated if determinations of N₂ fixation were based solely on shoot data.

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