Comparisons of the efficiency of nitrogen fixation in pastures

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Abstract

Levels of N_2 fixation were quantified for 540 pastures containing subterranean clover, annual medic, lucerne or white clover growing in different farming systems over a wide range of rainfall zones in Victoria and New South Wales. It was found that the efficiency with which N was fixed was generally similar regardless of the legume species or the environment in which they were grown. On average 20 to 25 kg shoot N was fixed for every tonne of legume shoot dry matter produced. It is proposed that these values may provide useful, predictive guides to the likely inputs of fixed N through pasture herbage.

Key words: Pastures, nitrogen fixation, lucerne, subterranean clover, white clover, annual medic

Introduction

The use of pasture legume species such as subterranean clover (*Trifolium subterraneum*), annual medics (*Medicago* spp.), lucerne (*Medicago sativa*), and white clover (*T. repens*) has long been considered to be a sustainable and profitable means of maintaining soil nitrogen (N) fertility, forage quality and productivity in both permanently grazed pastures and ley-farming systems. However, over the past two decades there has been a decline in the level of management inputs (eg. applications of superphosphate) routinely supplied to pastures for wool and meat production, and a trend towards shorter pasture phases in pasture-crop rotations in the southern cereal-livestock belt of Australia. This general neglect of pastures and increased grazing pressure in phase-farming systems has resulted in difficulties for pasture regeneration, and pastures are often characterised by poorly productive swards containing little legume. It is assumed that suboptimal amounts of N are being fixed in many pastures; however, there is no simple way to assess what levels of N_2 fixation occur.

This paper examines the efficiency with which N_2 is fixed by the legume components of annual and perennial pastures growing in different environments of New South Wales and Victoria using the ^{15}N natural abundance technique (6), with the aim of developing 'rules-of-thumb' which might allow the prediction of N_2 fixation inputs by pastures. Much of the information presented is derived from the results of collaborative experiments funded by Grains Research & Development Corporation (GRDC), some of which have been published already (5, 6, 7).

Materials and methods

In experimental trials, pasture growth was estimated either using 4 relocatable exclusion cages which were moved to a fresh area of grazed pasture every 3-4 weeks, or from measures (5 x 1 m^2) of shoot regrowth just prior to grazing. Annual measures of pasture productivity were determined from sequential measures of grazed and ungrazed herbage (6). At on-farm survey sites pastures were sampled by cutting 4 replicate quadrat areas (30 cm by 30 cm) of standing feed towards the end of spring to obtain 'point-in-time' measures of N_2 fixation efficiency.

Legume material in pasture samples were separated from other plant material (grass and broad-leaf weeds). Both the legume and non-legume fractions were dried at 70oC for 48 h and weighed. These samples were subsequently ground analysed for total N and 15N composition by combustion in an automatic nitrogen and carbon analyser (ANCA-SL) interfaced to a 20-20 stable isotope mass spectrometer (Europa Scientific, Crewe, UK). The amounts of N_2 fixed were calculated from the 15N natural abundance-based estimates of the proportion of the legume N derived from N_2 fixation (determined from the 15N-content of legume and non-legume reference plants), and measures of legume shoot N as previously described (6, 8).

Since there is evidence that N associated with the nodulated roots of crop and pasture legumes may represent 28-40% and 40-70% of the total plant N, respectively (4, 8, 9,10), it is clear that N_2 fixation calculated solely from measures of legume shoot N will underestimate the total amounts of N_2 fixed. To adjust the annual measures of N_2 fixation presented in Table 1 to include estimates of the contributions of below-ground legume N (ie. to calculate amounts fixed on a whole plant basis), the shoot-based determinations were multiplied by a factor of 1.5 (ie. assumed 33% of total legume N below-ground) or 2.0 (ie. 50% below-ground) for crop and pasture legumes, respectively.

The relative efficiency with which N_2 was fixed was calculated as kg shoot N fixed/t legume shoot dry matter (DM) accumulated. Expression of the data in this way allowed comparisons of N_2 fixation across legume species, management treatments, locations, and growing seasons. It also enabled the inclusion of estimates of N_2 fixation derived from material collected directly from farmers' pastures where the only dry matter information available were measures of standing feed remaining in the presence of grazing animals.

Results

Experimental estimates of the total annual inputs of fixed N by grazed lucerne-based pastures range from 80-190 kgN/ha/yr (combined lucerne and annual medic contributions) in a Mediterranean-type climate (Horsham, Victoria, Table 1), 22-200 kgN/ha/yr in the summer-dominant rainfall environment of Trangie in central western New South Wales (Table 1), and 206-334 kgN/ha/yr during the first 3 years after lucerne establishment at Junee in the Riverina of southern New South Wales (6). The symbiotic performance of differently aged pastures at Horsham were compared to N_2 fixation by field pea (*Pisum sativum*) growing in neighbouring paddocks over each of the 2 years of investigation (Table 1). Although significantly more N was estimated to be fixed by pea in 1995 (Table 1), substantial amounts of N were also removed with the grain (151 kgN/ha in 1995 and 115 kgN/ha in 1996), so that the amounts of fixed N calculated to remain vegetative residues and roots after harvest (111 and 66 kgN/ha, respectively) were generally lower than the derived inputs by many of the adjacent pastures. In all cases, the amounts of N_2 fixed were closely regulated by legume shoot biomass accumulated during growth (Table 1). Similar findings were also obtained from a survey of N_2 fixation undertaken for subterranean clover and lucerne sampled from farmers' pastures and research trials over 5 growing seasons (1992-1996) in north-eastern Victoria and southern New South Wales (Fig. 1).

A comparative measure of the relative efficiency with which N_2 was fixed in these pastures can be provided if the amounts of fixed N present in herbage are expressed per unit of legume shoot DM. Table 2 summarises measures of N_2 fixation efficiency calculated in this way for 540 experimental and on-farm pastures sampled at various localities around New South Wales and Victoria. Botanical composition varied from <10% to > 95% of total pasture herbage DM as legume and covered a wide range of productivities across different rainfall zones. However, despite the inherent differences in the many different pastures examined there was remarkable uniformity in the average efficiency of N_2 fixation for both annual (subterranean clover or medic) and perennial-based pastures (lucerne in the cropping zone, white clover under permanent grazing) across most sites examined (Table 2). There appeared to be no effect of pasture age on measurements of symbiotic efficiencies for lucerne, and it appeared to make little difference whether pastures were based on annual or perennial legumes, or were under permanent grazing or from ley-farming systems (Table 2). The average determinations generally represented between 20 and 25 kg shoot N fixed for each tonne of legume DM produced (Table 2).

Conclusion

Similar relationships to those reported for the present study between amounts of N_2 fixed and legume shoot dry matter production (Table 2) have also been observed for pastures in the cropping zones of Western Australia (1), South Australia (2), and southern Queensland (3). It may therefore be feasible for GRDC-Topcrop groups, individual farmers, consultants or advisers to use a value of 20 kg fixed N/t legume herbage DM as a conservative rule-of-thumb which could be combined with measures of legume productivity to predict average amounts of N_2 fixed during a growing season. Because of the general relationship between shoot-based measures of N_2 fixation and clover herbage N in spring and the levels of soil mineral-N the following autumn (6, 7), such derived measures of N_2 fixation may also provide a guide to the likely concentrations of soil mineral-N expected following annual pastures in phase-farming systems.

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Table 1 Annual shoot dry matter (DM) production and estimates of the amounts of N_2 fixed by different lucerne-based pastures: Comparison of N_2 fixation potential with field pea.

		1995				1996			
				Amount N-fixed[a]				Amount N-fixed[a]	
Location/ pasture	Species	Pasture content	Shoot DM	Shoot	Whole plant	Pasture content	Shoot DM	Shoot	Whole plant

age	?	(% leg)	(t/ha)	(kg N/ha)	(kg N/ha)	(% leg)	(t/ha)	(kg N/ha)	(kg N/ha)
Horsham	?	?	?	?	?	?	?	?	?
2nd year	lucerne	42	1.47	44	88	-	-	-	?
?	medic	29	1.04	33	66	-	-	-	?
3rd year	lucerne	25	1.11	25	50	26	1.23	38	76
?	medic	14	0.62	15	30	2	0.08	2	4
4th year	lucerne	25	0.91	19	38	79	3.30	90	180
?	medic	58	1.87	56	112	5	0.20	5	10
?	?	?	?	?	?	?	?	?	?
?	field pea	?	7.49	175	262	?	5.21	121	181
?	?	?	?	?	?	?	?	?	?
Trangie	?	?	?	?	?	?	?	?	?
3rd year	lucerne-1	-	-	-	-	(3.6)[b]	2.10	30	60
?	lucerne-2	?	?	?	?	(7.2)	5.64	100	200
4th year	lucerne-1	-	-	-	-	(6.5)	2.63	52	104
?	lucerne-2	?	?	?	?	(9.7)	2.80	32	64
5th year	lucerne-1	-	-	-	-	(1.1)	0.70	11	22
?	lucerne-2	?	?	?	?	(3.5)	1.47	24	48
?	?	?	?	?	?	?	?	?	?

[a] Least significant difference between mean estimates of N2 fixation (P=5%) ranged from ?22 and 21 kg N/ha for the 3 legumes monitored at Horsham in 1995 and 1996, respectively, to ?34 kg N /ha for lucerne at Trangie. Whole plant = shoot+root

[b] Lucerne plant populations (plants/m2) were recorded rather than % legume content. Levels of N_2 fixation were monitored in 2 lucerne paddocks differing in plant population for each age category.

Table 2 Estimates of the amounts of shoot N fixed for each tonne of legume shoot dry matter produced.

Pasture type and localities[a]	Mean annual rainfall (mm)	Number of pastures	Annual legume[b]		Perennial legume[c]	
			Range	Mean	Range	Mean
			(kg N-fixed/t)		(kg N-fixed/t)	
Permanently grazed						
Allansford-Timboon, Vic	620-1940	7	10-40	27		
		257			12-53	27
Braidwood, NSW	1059	13	9-21	17		
Orange, NSW	900	9	22-31	27		
Beechworth, Vic	820	13	20-36	27		
Bungendore, NSW	760	13	20-31	25		
Goulburn-Yass, NSW	631-652	13	13-32	24		
Overall		325		24		27
Rotated with crop						
Canberra, ACT	631	4			13-24	20
Cootamundra, NSW	625	1	27	27		
		2			19-25	22

Rutherglen, Vic	608	19	18-36	27		
		11			19-31	24
Wagga Wagga, NSW	560	16	9-34	26		
		7			13-31	24
Junee, NSW	504-536	26	8-34	26		
		13			8-33	21
Lockhart, NSW	487	6	14-32	22		
		2			17-36	27
Trangie, NSW	479	100			3-35	20
Horsham, Vic	423	3	25-31	27		
		5			21-30	25
Overall		215		26		21

[a] Adapted from data of Peoples et al. (6, 7, 8) and includes unpublished findings of Bowman, Gault, and McCallum.

[b] All data refer to subterranean clover except for Horsham where the pasture contained annual medic.

[c] White clover collected from dairy pastures or lucerne grown in rotation with crop.

Figure 1: Relationships between the amounts of shoot N fixed by subterranean clover (m) and lucerne (l) in pastures and legume shoot dry matter measured. Data collated from experimental and on-farm pasture sites as described by Peoples *et al.* (6).