Nitrogen inputs from pasture and patterns of release for crops

Mark Peoples, Bob Gault and John Angus, CSIRO Plant Industry, Canberra, ACT

Overview:

We are seeing an increased demand for nitrogen, especially for crops and livestock. Nitrogen fixed by pastures seems to be a steady 20-25 kg per tonne of dry matter produced. Nitrogen release for annuals is generally in the next spring, whereas for perennials it is generally over a number of years. Establishing and maintaining productive legume dominant pastures is important.

Key findings:

Nitrogen contributions by pastures in Ley Farming Systems are a renewable resource for Central West farmers.

Inputs of fixed N by pastures:

- The amounts of N fixed by pastures are reg ulated by legume content and herbage yield;

  As a general rule-of-thumb 20 to 25 kg of shoot N can be expected to be fixed on average for every tonne of legume foliage dry matter produced;

- Management options can be used to manipu late N fixation through factors which influence:

  The capacity to fix N (e.g. the presence of appropriate strains of rhizobia in soil)

  - Legume growth potential (e.g. removing nutritional constraints to pasture growth, winter-cleaning);

  High levels of N fixation can be achieved in annual pastures, but there can be considerable year-to-year variability due to extreme shifts in the incidence of clover or medic present in pastures; and

  Growing lucerne can provide larger, more consistent inputs of fixed N than annual legumes.

The release of pasture N for crops:

For annual pastures:

  The flush of mineral-N detected in autumn following annual pastures is commonly related to the amount of legume N grown the previous spring;

- Winter-cleaning of annual pastures gives rapid mineralisation and can lead to substan tial increases in soil nitrate and yield by a following crop; and

  The N benefits from subclover or annual medics rarely last beyond 1-2 years.

For perennial pastures:

  Concentrations of soil mineral-N are low levels under pastures containing lucerne;

- Since the majority of the N fixed by lucerne is tied up in organic reserves at the end of a pasture phase, time must be allowed for mineralisation to occur. There will be a delay after a lucerne pasture before N is present in a plant-available form; and
- The flow-on N benefits from perennial pastures to crops generally persist for several years.

Introduction: A role for pastures in cropping systems?

Although the use of pastures containing subterranean clover (subclover) or annual medics has long been considered to be essential for maintaining soil fertility in ley-farming systems, there has been a trend towards shorter pasture phases in pasture-crop rotations and continuous cropping. This in part reflects the relative economic returns from livestock enterprises and crop production and the perceived shortcomings in the ley system associated with problems of pasture decline and soil acidification. The consequences of a shortened pasture phase and more intensive cropping in the southern cereal-livestock belt are a general neglect of pastures, increased grazing pressure, a depletion of legume seed reserves, with difficulties for pasture regeneration. Residual effects of crop herbicides on pasture legumes, particularly sulfonyl ureas on medics have also accelerated pasture decline. Many pastures are now poorly productive and dominated by weedy annual species, with little clover or medic. The net result has been suboptimal inputs of fixed nitrogen (N) and a gradual decline in the organic fertility of cropping soils.

This reduction in the major supply of N from pastures has occurred during a period of increasing yield potential of dryland wheat through the introduction of semi-dwarf varieties, better weed control with selective herbicides, and wider use of break crops such as canola. The increased yield has lead to a greater demand for N than in older fanning systems. Examples of the N requirements of high yielding crops are shown in Table 1. Considering that the efficiency of utilisation of mineral N (nitrate and ammonium) is commonly only 30-50%, the challenge that faces growers is to ensure that the soil has the capacity to provide sufficient available N to satisfy their crops' demand for N. Using the examples presented in Table 1, this implies that for every tonne of grain harvested, the soil might need to supply 75-110 kg N/ha for wheat or 150-225 kg N/ha for canola just to satisfy the N requirements of that tonne of grain and its associated stubble. This must be achieved either via (a) mineral-N accumulated prior to sowing, (b) within-crop mineralisation and/or (c) applications fertiliser N. Given that both (a) and (b) will be related to the organic fertility of the soil, it is perhaps timely to reassess what inputs of N pastures could provide in ley-farming systems.

This paper provides an overview of levels of N fixed by annual pasture legumes and lucerne during a pasture phase, examines the potential for management to improve the contributions of fixed N, and compares the different patterns of N release from annual and perennial pastures to following crops.

Table 1 Yield and N uptake by crops grown near Cootamundra, NSW [a].

Crop	Crop N uptake (kg N/ha)	Grain yield (t/ha)	N removed in grain (kg N/ha)	kg N requirement per t grain harvest	
				in grain	in stubble
Wheat	200	5.6	130	23	13
Oats	175	4.7	75	16	21
Canola	170	2.3	85	37	37

[a] Grown during 1993 following a lucerne-based pasture. April-October rainfall = 363mm. Data courtesy of J Kirkegaard, CSIRO Plant Industry.

What levels of N are fixed by legumes in pasture leys?

A survey of N fixation achieved by subclover and lucerne in dryland pastures was undertaken over 5 growing seasons (1992-1996) in north-eastern Victoria and southern New South Wales. The amounts of fixed N present in legume herbage were calculated to range from less than 10 kg N/ha to over 200 kg N/ha. Since there is evidence that N associated with the nodulated roots of pasture legumes may represent 40-70% of the total plant N, total inputs of fixed N may be double these amounts.

In all pastures examined, the amounts of N fixed were closely related to legume shoot dry matter production (Fig. 1) and were primarily regulated by pasture legume content (or plant population) and productivity.

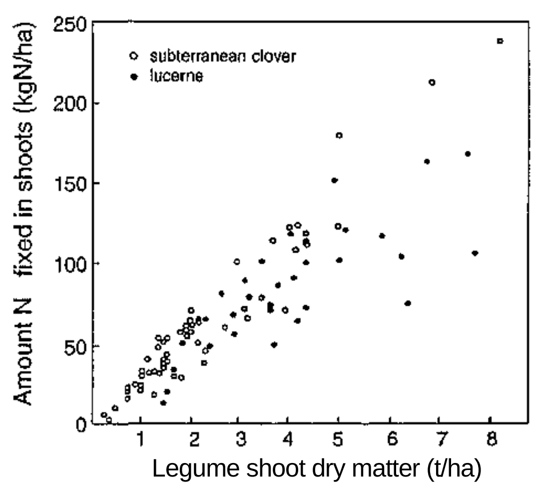

Figure 1 Relationships between the amounts of N fixed in annual and perennial pastures and legume herbage dry matter. Subterranean clover (○) and lucerne (●) data were collated from experimental and on-farm pasture sites in north-eastern Victoria and southern NSW (Peoples *et al.* 1998).

Examples of the average annual inputs of N fixed by pastures growing in a range of environments in eastern Australia are presented in Table 2. Regional limits to N fixation are primarily regulated by climatic limitations to pasture growth imposed by total rainfall, rainfall distribution and temperature, but management practices can also play an important role.

Table 2 Comparison of average amounts of shoot N fixed by pasture leys or pulses growing in different environments.

Location	Pasture type	Annual amount fixed [a] (kgN/ha)	Crop legume	Annual amount fixed [a] (kgN/ha)	Residual fixed N[b] (kgN/ha)
Victoria	**Dryland**				
Horsham [c]	Lucerne-medic	62	Field pea	148	+15
Rutherglen	Subclover	160	-		
NSW					
Wagga/Junee	Subclover	55	Lupin [d]	285	+73
	Lucerne	130	Field pea	135	-15
			Chickpea	105	+10
Trangie [e]	Lucerne-based	45	-		
Queensland					
Warra [f]	Lucerne	88	Chickpea	72	nd
	Medic	42			
ACT	**Irrigated**				
Canberra	Lucerne	325	-		

[a] Calculated from shoot-based measures. Inclusion of an estimate of below-ground N may almost double the total amount of N fixed.

b Fixed N calculated to remain after removal of grain at harvest.

[c] Data from M McCallum, VIDA. [d] Adapted from Armstrong *et al* (1997).

[e] Data from A Bowman, NSW Agriculture. [f] Adapted from Hossain *et al* (1995) nd = not determined.

Effect of management

Management can influence N fixation either through the legume's capacity to fix N, or via changes in legume growth potential within a pasture.

Inoculation - Prior to European settlement, Australian soils contained no root-nodule bacteria (rhizobia) for the majority of agriculturally useful legumes. Since then a great many strains of nodule bacteria have been introduced accidentally or deliberately. Today, the numbers of naturalised rhizobia in most soils are usually adequate to induce nodulation and N fixation by most common pasture legumes. Nevertheless, there are a number of conditions, such as the first time a new legume species is sown in a pasture, under which soils may be devoid of effective rhizobia and require inoculation. However, hostile soil conditions such as acidity can effect rhizobia survival and inoculation of seed when undersowing pasture legumes in the final year of cropping is useful "insurance". There is no nodulation or capacity for N fixation in the absence of appropriate rhizobia.

Removing constraints - Productivity and amounts of N fixed can be increased if constraints to legume growth are removed. In Table 2 for example, the growth potential of lucerne and the amount of N fixed was raised by supply of irrigation water. In other situations, improvements from 2- to 10-fold have been observed in pasture productivity, legume content and N fixation by alleviating nutritional constraints by liming acid soils or by applying superphosphate to P-deficient soils.

Manipulating the legume content of pastures - Nitrogen fixation can be improved by increasing the pasture's legume content. This might be achieved in perennial pastures by establishing a dense lucerne stand by using a high sowing rate, or through the application of herbicides to remove grasses from annual pastures. Pasture plants exposed to a herbicide such as Paraquat as part of a 'winter-cleaning' treatment to remove grasses become desiccated following treatment. Subterranean clover and medics can subsequently regenerate from the crown; grasses do not. Thus, grass removal treatments can increase legume content provided the herbicide treatment is applied early enough to allow recovery. The aim is to produce an almost pure legume sward. As well as having a big impact on the carry-over of cereal root disease into a cropping phase, grass control can also significantly improve amounts of N2 fixed during spring, despite a general decrease in total pasture production (Fig. 2).

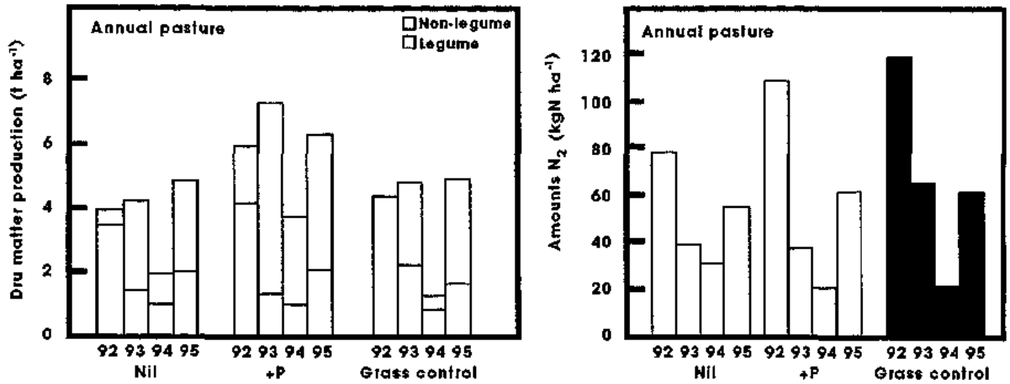

Figure 2 Comparisons of the effect of winter-cleaning to remove grasses on: (a) shoot dry matter production by subterranean clover (black bars) and non-legume components of grazed pasture, and (b) amounts of N fixed in legume herbage at Rutherglen, Victoria, between 1992 and 1995. The + and - symbols indicate treatments with and without herbicide applications. Adapted from Peoples *et al.* (1998).

Comparison of N fixation by pastures with pulse crops

The N fixation of pastures has been compared with that of legume crops either growing in neighbouring paddocks or under similar rainfall conditions (Table 2). Although significantly more shoot N may be fixed by pulses than in pastures, much more N is harvested in grain at the end of the growing season (95-212 kgN/ha in the examples shown in Table 2) than either removed from grazed pastures in animal products (generally less than 10 kg N/ha), or lost from urine patches. Therefore, the residual amounts of fixed N in vegetative residues remaining after harvest of pulses are generally lower than estimates of N contributed by pasture legumes.

Comparison of annual pastures with lucerne-based systems

Productivity and N fixation by annual pastures were compared with the performance of lucerne over several growing seasons at Junee Reefs, in southern New South Wales (Fig. 3). A striking observation was the dramatic year-to-year shifts between clover dominance and grassy pastures on the amounts of N fixed by subclover in the annual pasture (An, Fig.3). For example about half of the N fixed by subclover over the 4 year period was the result of a single good growing season in 1992. However, the lucerne pasture (Luc, Fig. 3) contained greater amounts of legume dry matter and fixed more N than the annual pasture in each of the 3 years where direct comparisons were made. Most of lucerne's advantage was in late spring and summer when occasional rainfall events gave immediate growth responses. The average annual input of N fixed by lucerne in this environment (130 kg N/ha/yr) was substantially greater than neighbouring annual pastures (55 kg N/ha/yr).This largely reflected the ability of lucerne pastures to maintain a consistently higher legume component, and to continue growing and fixing useful amounts of N during the 1994 drought (Fig. 3).

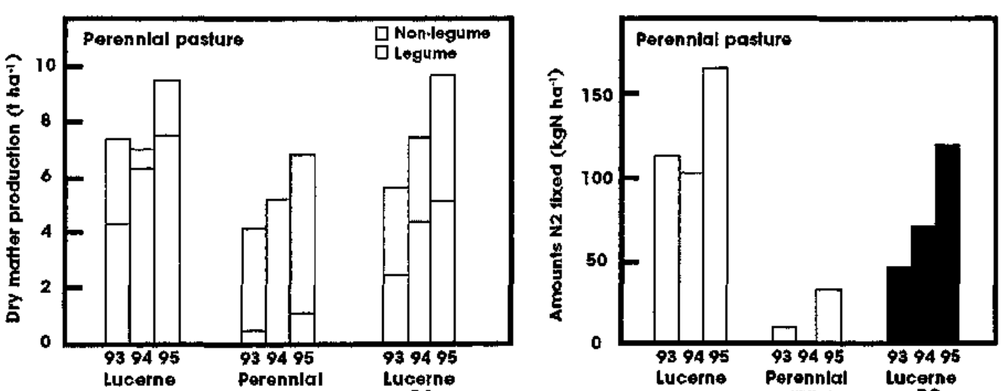

Figure 3 Year-to-year changes in (a) herbage dry matter production and (b) N fixation by either subterranean clover in annual pastures (An), or by neighbouring lucerne-based pastures (Luc) growing at Junee Reefs, NSW. Lucerne was established in August 1992; so no measurements were collected until 1993. Both pastures received lime (1.5 t/ha) and superphosphate (150 kg/ha). Adapted from Peoples *et al.* (1998).

Predicting N fixation in pastures

The efficiency with which N is fixed by pasture legumes can be estimated by expressing the amounts of N fixed per unit of legume shoot dry matter produced. This provides a benchmark by which N fixation can be compared across management treatments, locations, legume species and growing seasons. Table 3 summarises measures of N fixation efficiency for a number of experimental and on-farm pastures at various localities in New South Wales and Victoria. These values came from pastures grown in rotation with crops in which legumes represented from less than 10% to more than 95% of the total pasture dry matter production.

Despite inherent differences in the many pastures examined, there was remarkable uniformity in the average efficiency of N fixation for both annual (subterranean clover or medic) and lucerne-based pastures across most sites (Table 3). On average between 20 and 25 kg N of shoot N was fixed for each tonne of legume herbage dry matter produced. Similar relationships have also been observed for pastures in the cropping zones of South Australia (Butler 1988), Western Australia (Bolger *et al,* 1995) and Queensland (Hossain *et al.* 1995). A simple rule-of-thumb for GRDC-Topcrop groups, individual farmers, consultants or advisers is to use a value of 20 kg shoot N fixed per tonne of legume herbage dry matter produced to predict likely amounts of N fixed during a growing season.

Table 3 Estimates of the amounts of shoot N fixed for each tonne of legume herbage produced by pastures grown in rotation with crops.

Pasture type and localities [a]	Annual rainfall (mm)	Number of pastures	Annual legume [b] Range (kg N-fixed /t)	Annual legume [b] Mean (kg N-fixed /t)	Lucerne Range (kg N-fixed / t)	Lucerne Mean (kg N-fixed / t)
Canberra	631	7 4	13-32	24	13-24	20
Cootamundra	625	1 2	27	27	19-25	22
Rutherglen	608	19 11	18-36	27	19-31	24
Wagga Wagga	560	16 7	9-34	26	13-31	24
Junee	504	26 13	8-34	26	8-33	21
Lockhart	487	6 2	14-32	22	17-36	27
Trangie [b]	479	100			3-35	20
Horsham [c]	423	3 5	24-31	27	19-30	25
Overall		222		25		21

[a] Adapted from Peoples *et al.*(1997, 1998).

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

[c] Data from A Bowman, NSW Agriuclture. [d] Data from M McCallum, VIDA.

The release of pasture N for crops

Annual pastures

Soils in subclover-based pastures are characterised by cyclic changes in levels of soil mineral-N (nitrate and ammonium). There is usually a flush of mineral N in autumn (largely) released from the previous year's dead clover material, and a depletion in concentrations of available N during periods of rapid growth in spring. Studies in the NSW Riverina suggests that concentrations of soil mineral N in autumn and winter is often related to the amounts of clover N grown the previous spring (Table 4). However, this is not always the case (e.g. annual pasture sites 3 and 4, Table 4) - qualitatively this seems to be dependent upon adequate rainfall to stimulate mineralisation over summer and early autumn (usually rainfall between November and April is 40% or more of the total annual in the Riverina), and/or the presence of summer weeds which take up the mineral N before it can accumulate in soil.

Table 4 Seasonal changes in soil mineral-N (to 60cm) and estimates of the amounts of N in legume herbage grown by annual pastures from different on-farm sites in the Junee, Wagga Wagga and Lockhart districts of southern NSW.

On-farm site and pasture type	Autumn Mineral-N (kg N/ha)	Spring		Autumn Mineral-N (kg N/ha)
		Mineral-N (kg N/ha)	Clover N grown (kg N/ha)	
Annual				
Subclover-based				
1	nd[a]	28	16	47
2	nd[a]	55	135	205
3	90	12	56	26
4	28	14	145	25
5	174	34	73	80
6	140	50	72	136
Perennial				
Lucerne	45	51	150	41
Phalaris-subclover	42	34	40	54

not determined.

The variation in legume content of pastures and summer mineralisation is so great that the only reliable way of estimating levels of soil mineral N at sowing is to measure it directly. A 'deep soil nitrate test' (lab analyses of concentrations of soil mineral N to 60cm) would be most appropriate. Nonetheless, the general relationship that is emerging in southern NSW suggests that the greater the legume growth during spring, the higher the concentrations of mineral N that can be expected the following autumn (eg Tables 4 and 5).

Table 5 The amounts of N accumulated by different pasture treatments near Junee, NSW during 1992, and the levels of soil mineral N detected the following autumn (April 1993) [a]

Treatment applied (1992)	Clover herbage N grown (1992) (kg N/ha)	Soil mineral N to 200cm (1993) (kg N/ha)	Difference in mineral N from fallow (kg N/ha)
Nil	104	179	+104
Superphosphate	135	205	+130
Winter cleaned	152	283	+208
Chemical fallow [b]	0	75	-

[a] Adapted from Peoples *et al.* (1998).

[b] Included to determine the direct contribution to subsequent mineralisation from clover grown during the spring

Previous research suggested that mineralisation during growth in a continuous cropping system in this region follows a fairly predictable pattern:

- 60 kg N/ha mineralised in low fertility soils (less than 0.08% topsoil total N)
- 80 kg N/ha mineralised by a medium fertility soil (0.08-0.12%N)
- 100 kg N/ha mineralised by high fertility soils (greater than 0.12%N).

However, studies of the crop cycle following a legume-dominant annual pasture have shown mineralisation about 30% greater than expected on the basis of soil total N%, suggesting that fresh legume residues break down much faster than the soil organic matter. This conclusion is based on only a few observations and needs to be confirmed (Angus *et al.* 1998a).

Results from Junee indicate that a single good clover year can result in high concentrations of mineral N the following autumn (Table 3). The use of herbicides to remove annual grasses and improve pasture clover content ('winter-cleaning') was capable of elevating levels of available soil N by a further 70-100 kg N/ha over and above other management treatments (Table 5).

Some of the best documented increases in soil available N and improvements in crop yield in response to winter-cleaning come from research trials based at Rutherglen, Victoria (Table 6). Greater than 50 kg mineral N/ha difference was generated between winter-cleaned and untreated pastures in the top 20 cm of soil after only 2 years of pasture ley, and a difference of more than 100 kg mineral N/ha was detected down to 110 cm (approximate rooting depth of most crops) after 4 years of pasture. In both years of cropping (crops failed in 1994 because of drought) there were impressive improvements in wheat yield and quality. Canola gave a proportionally larger response than wheat in 1993, suggesting that in this case the majority of the yield benefit of the winter-cleaning was due to the additional N rather than breaking the life-cycle of soil-borne diseases. In other circumstances the disease break may be more important.

Table 6 Examples of the effect of grass removal from pastures and different periods of pasture ley on the **levels of soil mineral N at sowing and the yield of following crops.**[a]

Pasture treatment	2 year pasture ley (1993)			4 year pasture ley (1995)		
	Mineral to 20cm (kg N/ha)	Wheat yield (t/ha)	Canola N yield (t/ha)	Mineral to 110cm (kg N/ha)	Wheat yield (t/ha)	Canola N yield (t/ha)
nil (50% clover)	54	4.0	1.2	237	3.6	1.7
winter-clean (95% clover)	110	6.1	3.0	342	5.3	2.3

[a] Data from G Scammell, Agriculture Victoria.

The extra wheat production at Rutherglen in 1993 after only 2 years of pasture represented an additional gross return of about $240 per ha while the extra canola was worth an additional $420 per ha - both for a cash expenditure of less than $20 per ha on herbicide. There may be indirect costs with winter-clearing in some circumstances associated with the need for supplementary feeding due to lost winter feed, although this was not required in the Rutherglen study. Winter-cleaning may also involve a hidden cost of additional acidification. In this case it probably represented a requirement for an additional 100-200 kg/ha of lime worth $5-10/ha. Other potential problems can be associated with areas of bare soil during the summer period which will allow growth of unpalatable weeds after summer ram, and difficulties with clover seed set which could affect subsequent pasture regeneration, so growers' are best advised to winter-clean pastures only in the year immediately prior to cropping rather than trying to maintain a pure legume sward over a series of years. However, the improvements in crop yield demonstrated at Rutherglen represent at least a 3- to 4- fold return on investment over 18 months. Even in a good season, N fertiliser is unlikely to give such returns. But while the first crop following an clover-dominant pasture may benefit from the rapid mineralisation, the effects of annual pastures generally persist for only one or two seasons.

Perennial pastures

Although there are generally clovers and annual grass growing in perennial pastures, seasonal flushes of mineral N in response to growth-death cycles such as those experienced in annual pastures are not common (e.g. Table 4), unless the perennial component (lucerne and/or perennial grass) is present at a very low density and clover fills the gaps. In the case of lucerne, levels of soil mineral N remain low despite its potential to grow more legume biomass and fix much more N than subclover (Table 4, Fig. 3). Lucerne's perennial nature of growth usually ensures that most of the N mineralised during the pasture phase is reassimilated by the lucerne, and concentrations of soil mineral N are generally maintained uniformly low.

It is common to maintain lucerne pastures until just a few months before cropping to take advantage of lucerne's valuable grazing potential over summer. However, if one of the objectives of including lucerne in a rotation is to make use of its ability to improve soil N fertility, then on-farm experimentation undertaken at Junee during 1996 suggests that this strategy may not fully realise lucerne's N benefits in the first crop following a pasture phase.

Grower experience and some previous experiments had shown there is a risk of low crop yield in the first year after lucerne pastures, particularly in dry years, because of low reserves of soil water and mineral N. This problem was addressed by examining the effect of removing areas of lucerne at monthly intervals (from November 1995 until April 1996) prior to sowing wheat in May 1996 (Angus et al 1998b). Late removal of lucerne (March-April 1996) shortly before land preparation for cropping resulted in relatively low levels of mineral N in the soil profile (around 50 kg N/ha, Fig. 4a). Concentrations of mineral N were increased by almost 200 kg N/ha if lucerne was removed late the previous spring (November 1995). This represented a net mineralisation rate equivalent to 0.75 kg N/ha/day. Wheat yields (Fig. 4b) and grain quality (11.5% and 10% protein for November and April removals, respectively) reflected the levels of mineral N present at sowing. The differences in mineral N between the earliest and latest dates of lucerne removal effectively resulted in loss of 5% grain yield for every month's delay.

This experimentation has indicated that the timing of the transition from lucerne ley to the cropping phase could be crucial in determining crop response. Particularly since mineralisation immediately after lucerne is likely to be slower than experienced following annual pastures. This is partly because lucerne is very efficient at extracting water, and the soil will be much drier following lucerne than an annual pasture. However, one of the advantages of lucerne-based phase in a crop rotation is that the flow-on N benefits to crops continue for several years.

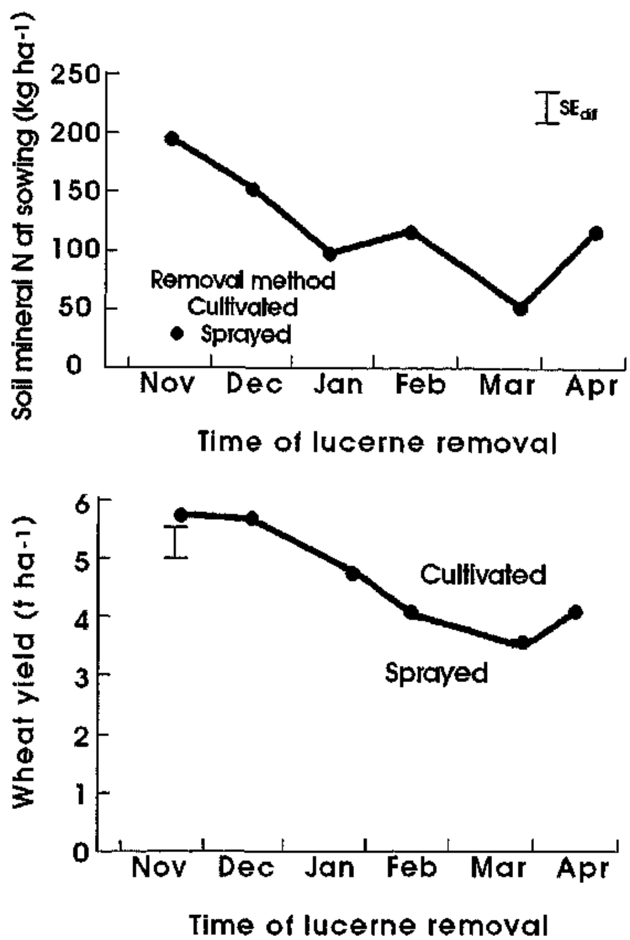

Figure 4 The effect of timing of lucerne removal on (a) soil mineral N (to 1.6m) measured in May 1996, and (b) subsequent wheat yield at Junee Reefs, NSW.

Conclusions

Nitrogen fixation inputs by pastures are closely linked to their legume content and productivity. Management which favour high legume production will also improve potential inputs of fixed N. Approaches which can be used to manipulate and manage N fixation in dryland pastures include:

- Rhizobial inoculation. Particularly the first time **a** new legume species is sown;
- A dense legume stand;
- Removal of growth constraints:
  - applications of superphosphate in P-deficient soils;
  - lime to ameliorate acid soils; and
- Herbicide applications to remove grasses in annual pastures in the year prior to cropping.

Pasture response to these strategies might be further modified by grazing management through livestock effects on nutrient cycling and species composition. Because of the prostrate growth habit of clovers for example, strategic heavy grazing of a grassy pasture in early spring can shift botanical composition toward legume dominance. As a general rule, under-grazing encourages grass growth and results in pastures with depressed legume content.

High levels of N fixation can be achieved in annual pastures, but there can be considerable year-to-year variability due to extreme shifts in the incidence of clover or medic present in pastures. Evidence is mounting that pastures containing lucerne, are the most promising long-term option for managing the N and water balances of pasture-crop rotations. Lucerne pastures maintain a more stable legume content and continue to grow and fix N when seasonal rainfall patterns are unsuitable for growth of annuals. Therefore, pastures based on lucerne may have greater potential for consistent growth and N fixation than annual pastures. However, unlike clover or medic-based pastures where there are regular annual flushes of mineral N each autumn, time must be allowed for N to be released from lucerne organic reserves before **a** following crop can benefit directly from the N fixed.

Key research issues in the Central West

Some key research issues are:

- Management to establish and maintain productive legume dominant pastures.
- The best mix of perennial and annual pasture species that are adapted to the Central West environment.
- Reliable techniques to remove perennial pastures at the end of a pasture phase.
- The optimal timing to remove lucerne pastures prior to cropping to allow mineralisation and partial recharge of soil water reserves.

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