Nitrogen fixation and cycling of pasture legumes – a review

D. F. Herridge

NSW Agriculture, Tamworth Agricultural Institute, RMB 944, Calala Lane, Tamworth NSW 2340

Pasture legumes provide high-quality feed for animals in grazing systems. They also fix nitrogen (N) and add organic N to the soils in which they grow, thereby restoring the chemical and physical quality of the soil. In the Australian grains belt, pasture legumes are rotated with cereal and other grain crops, with the pasture phase countering the degradation of the cropping phase (Reeves 1991; Peoples and Baldock 2001).

Pasture legume N_2 fixation in Australia

Pasture legumes in Australia are estimated to fix 1.3-5 million tonnes of N annually (Angus 2001; Unkovich 2002). Reported pasture areas in which legumes are a significant component range between 16 and 35 million hectares (Angus 2001; Peoples and Baldock 2001; Unkovich 2002). With large differences in the reported areas of pasture legumes, it is little wonder that the N_2 fixation estimates vary so greatly.

At the paddock level, calculating N_2 fixation is more straightforward. A substantial body of work has shown that, on average, 25 kg N is fixed in the shoots of pasture legumes for every tonne of shoot biomass produced (Peoples and Baldock 2001). It should be noted that the authors reported wide variations for this value, ranging 8-53 kg shoot N fixed/t shoot biomass. Such variation would have been caused by differences in soil nitrate levels and pasture vigour, as well as experimental treatment and experimental error. Assuming 50% of pasture legume N is below-ground (McNeill et al. 1997; Peoples and Baldock 2001), then the overall average for N_2 fixation by

Table 1. Nitrogen fixation of pasture legumes in Australia. Values summarise a large number of Australian studies in which N_2 fixation by pasture legumes was quantified (Peoples and Baldock 2001). %Ndfa is the percentage of legume N derived from N_2 fixation

Species/group	%Ndfa		Shoot N fixed (kg/ha)		Total N fixed (kg/ha)	
	Mean	Range	Mean	Range	Mean	Range
Subterranean clover	82	50-100	92	2-238	184	4-476
Annual medics	67	18-99	82	2-220	164	4-440
Lucerne	62	23-93	67	4-167	134	8-334
Tropical legumes	70	6-95	65	2-240	130	4-480
Overall	70	6-99	75	2-240	150	4-480

pasture legumes is 50 kg N fixed/t shoot biomass.

Within the Australian grains belt, the average percentage of pasture legume N derived from N_2 fixation (%Ndfa) is 70% (Table 1, Peoples and Baldock 2001). The average shoot N fixed is 75 kg N/ha and total N fixed is 150 kg/ha. These values varied enormously with site and season, and with experimental treatment. The latter would have provided much of the variation because experimental treatments are often designed to provide differences and extremes. It would be reasonable to assume, however, that the average values for species, as well as the overall average values, are representative of well-managed pasture legumes in the Australian grains belt in an average rainfall season.

Nitrogen cycling in pasture legume systems

The fate of the fixed N is just as important, and has as much relevance to productivity issues for grazing and cropping systems, as the amount fixed. What happens to the fixed N? How much stays in the plant-soil system and how much is exported and lost from the system as harvested product and through the various loss mechanisms? Below are 2 diagrams describing N flows for a hypothetical, average pasture legume in the Australian grains belt. Figure 1 shows the N flow during a 12-month period of active growth, i.e. the second or third year of the pasture. The second N-flow diagram (Fig. 2) covers the final year of the pasture before the land is returned to cropping. Data to construct the N budgets were taken largely from the review articles of Peoples and Baldock (2001) and Fillery (2001).

It should be noted that the hypothetical pasture is intensively grazed, i.e. heavily stocked with animals for short periods. Such management means that more of the N is cycled through the animal. Pastures that are not heavily stocked, but grazed for longer periods may have more of the N cycle through plant residues. The uneven distribution of dung and urine patches in a paddock creates a problem with large gains in soil N in small areas of the paddock and losses from the remainder (Fillery 2001). I have assumed spatial uniformity of N cycling.

Other assumptions are:

- %Ndfa is 70%.
- Shoot biomass is 3 t/ha, with an N concentration of 3.6%.
- Below-ground N is 50% of total plant N.
- About 5% of the above-ground plant material is incorporated into the soil as residues.

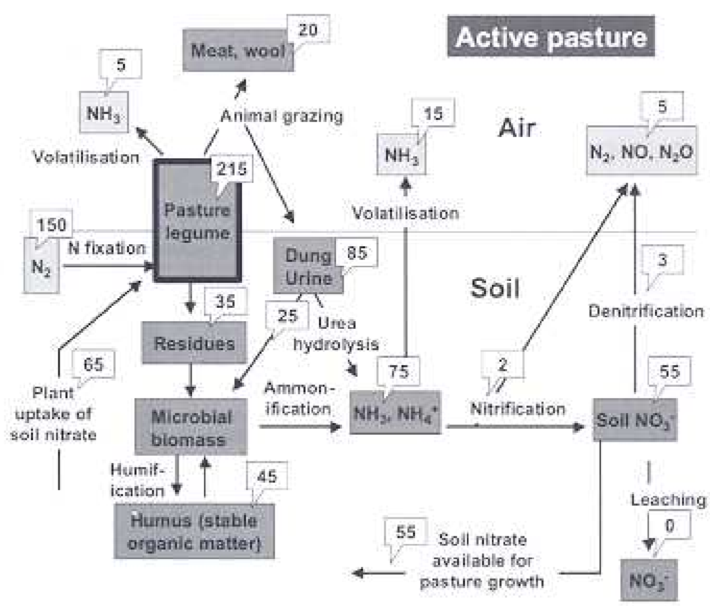

Figure 1. N-flow diagram for the pasture legume component of a well-managed pasture in the Australian grains belt in an average rainfall season. The period covered is 12 months during the active phase of the pasture.

- Annual turnover of below-ground N is 30%.
- Urine constitutes 70% of the dung/urine pool.
- Volatilisation losses of N from urine are 20%, although Fillery (2001) questions whether such rates, determined in enclosed experimental systems, are relevant to large grazed paddocks.
- Annual rate of fresh residue/dung decomposition is 25% (net mineralisation of 20%).

In the 12 month period, the pasture fixes 150 kg N/ha and accumulates a total of 215 kg N/ha in above and below-ground biomass. More than half of the total is returned to the soil as plant residues, dung and urine (120 kg N/ha). Only 20 kg N/ha is removed in animal product. Various loss mechanisms (ammonia volatilisation, nitrification and denitrification) account for about 25 kg N/ha, although these could be partly offset by deposition and re-absorption of N (not shown).

The annual increment of soil N under the pasture would be about 105 kg N/ha, with about 30% added to the humus and nitrate pools and 40% remaining in the soil as living roots and nodules. The contribution to soil nitrate from the mineralisation of native organic matter is not shown, and would be expected to add another 20-30 kg N/ha to the nitrate pool.

Termination of the pasture phase to commence cropping changes the N dynamics (Fig. 2). All living roots and nodules become plant residues, which are subject to mineralisation. This pool includes living roots and nodules that accumulated during the life of the pasture, i.e. at 70 kg N/ha/yr. Thus, for a 2-year old pasture, there would be an extra 70 kg N/ha in the below-ground residues pool. For a 3-year old pasture (the example in Fig. 2), an additional 140 kg N/ha is below-ground. Assuming net mineralisation rates of 20% for a 6-8 month fallow, the 3-year old pasture delivers 95 kg nitrate N/ha at the end of the fallow. Other assumptions are similar to those of the active pasture.

The contribution to soil nitrate from the mineralisation of native humus is again not shown and would add another 20-30 kg N/ha to the nitrate pool. Taking into account all 3 sources of nitrate (current year's residues, previous years' residues and native humus), net nitrate levels at the time of sowing a crop could be as high as 100-150 kg N/ha, depending on the length of the pasture ley (Hossain *et al.* 1996; Fillery 2001).

Pasture leys in cropping systems – a published example

How well do the N budgets for the hypothetical pasture legume in Figures 1 and 2 above match up with published accounts of N_2 fixation and N inputs of pasture legumes? Holford (1981) reported long-term experiments at Tamworth, NSW that showed well-managed, intensively-grazed lucerne added about 140 kg N/ha/yr on a black earth and 110 kg N/ha/yr on a red earth. Differences in N inputs were related to productivity of the lucerne. The higher soil N levels were maintained at the black-earth site during more than 9 years of wheat cropping (Fig. 3). Data from other field studies, e.g. subterranean clover in wheat cropping at Wagga Wagga (Heenan and Chan 1992), annual medics and lucerne in wheat cropping in south-eastern Queensland (Hossain *et al.* 1996; Weston *et al.* 2002), are also consistent with the constructed budgets above.

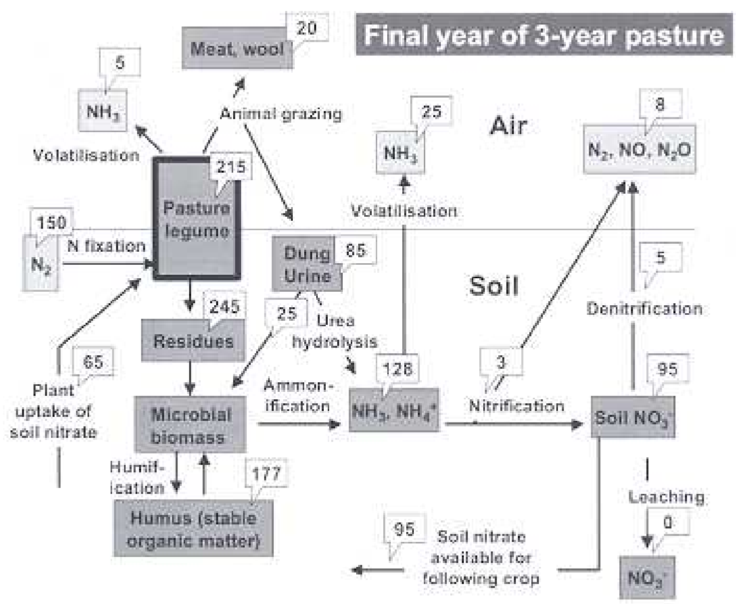

Figure 2. N-flow diagram for the pasture legume component of a well-managed pasture in the Australian grains belt in an average rainfall season. The period covered is 12 months during the final year of the pasture, prior to the land being used for cropping.

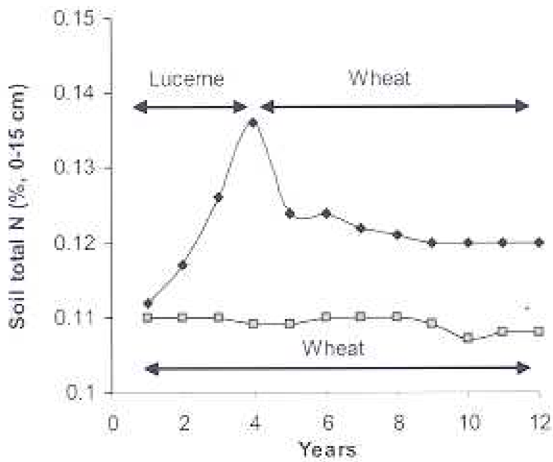

Figure 3. Build-up of soil N under a well-managed, intensively-grazed lucerne pasture on a black earth at Tamworth and the subsequent run-down during the following 9 years of continuous wheat cropping. Soil N levels under the wheat monoculture are also shown. A 0.01% increment in soil N to 15 cm depth is equivalent to 180 kg N/ha, assuming bulk density of 1.2. (Redrawn from Holford 1981)

In conclusion, pasture legumes play a major role in supplying N to Australia's agricultural soils. The legumes fix atmospheric N_2, adding millions of tonnes annually of organic and mineral N to Australia's agricultural soils. Amounts fixed and associated N benefits are strongly linked to pasture productivity with, on average, 50 kg N fixed/ha for each tonne shoot biomass produced.

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