

## Nitrogen cycling in degraded *Leucaena leucocephala*-*Brachiaria decumbens* pastures on an acid infertile soil in south-east Queensland, Australia

S.T.M. BURLE<sup>1</sup>, H.M. SHELTON<sup>2</sup> AND S.A. DALZELL<sup>2</sup>

<sup>1</sup> Rua Major Codeceira, Boa Vista, Recife, Brazil

<sup>2</sup> School of Land and Food Sciences, The University of Queensland, Brisbane, Queensland, Australia

### Abstract

A grazing trial was conducted to quantify N cycling in degraded *Leucaena leucocephala* (leucaena)-*Brachiaria decumbens* (signal grass) pastures grown on an acid, infertile, podzolic soil in south-east Queensland.

Nitrogen accumulation and cycling in leucaena-signal grass pastures were evaluated for 9 weeks until all of the leucaena on offer (mean 600 kg edible dry matter (EDM)/ha, 28% of total pasture EDM) was consumed. Nitrogen pools in the grass, leucaena, soil, cattle liveweight, faeces and urine were estimated.

The podzolic soil (pH 4.8–5.9) was found to be deficient in P, Ca and K. Leucaena leaf tissues contained deficient levels of N, P and Ca. Grass tissues were deficient in N and P.

Grazing was found to cycle 65% of N on offer in pasture herbage. However, due to the effect of the plant nutrient imbalances described above, biological N fixation by leucaena contributed only 15 kg/ha N to the pasture system over the 9-month regrowth period, of which 13 kg/ha N was cycled. Cattle retained 1.8 kg/ha N (8% of total N consumed) in body tissue and the remainder was excreted in dung and urine in approximately equal proportions. Mineral soil N concentrations did not change significantly (–3.5 kg/ha N) over the trial period. The ramifications of grazing and fertiliser management strategies, and implications

for pasture rundown and sustainability are discussed.

### Introduction

Nitrogen cycling affects the productivity and sustainability of grazed tropical pastures. Both the size of nutrient pools and transfer between pools are influential, with grazing accelerating the rate of nutrient cycling (Boddey *et al.* 1997). Mature tropical grass pastures are frequently limited by N deficiency and augmentation with legumes is recommended to promote grass growth and grazing animal production. Among tropical legumes, *Leucaena leucocephala* (leucaena) is known to efficiently fix and accumulate N (Ferraris 1979; Jayasundara *et al.* 1997) and is reported to contribute significant amounts of the dry matter in leucaena-grass pastures (Galgal 2002). Therefore, animals grazing leucaena have the potential to cycle considerable amounts of N to the companion grass. Contrary to these expectations, some graziers in northern Australia have reported reduced productivity of leucaena-grass pastures 2–3 years after establishment (G. Brown and P.H. Larsen, personal communication). This may be due to low rates of N fixation and/or inefficient nutrient cycling.

To test this possibility, N fixation and N cycling in leucaena-signal grass (*Brachiaria decumbens*) pastures on an acid, infertile soil were investigated at the University of Queensland Research Facility at Mt Cotton, south-east Queensland. The pastures were initially productive [941 kg leucaena and 4837 kg signal grass edible dry matter (EDM)/ha] and delivered moderate cattle liveweight gains (LWG) (0.65 kg/hd/d) in the first year after establishment in 2000 (Galgal 2002). However, during the 2001 growing season, the pastures were observed to degrade with the appearance of irregular patches of unthrifty and chlorotic regrowth of both legume and grass.

Correspondence: A/Prof. Max Shelton, School of Land and Food Sciences, The University of Queensland, Qld 4072, Australia. Email: m.shelton@uq.edu.au

Although the podzolic soil at Mt Cotton was poorer both physically and chemically than soils where the majority of leucaena is commercially planted, the accentuated symptoms of pasture run-down presented an excellent opportunity to study the parameters of this practical field problem.

A grazing experiment was conducted to study N pools and N cycling in the leucaena-signal grass pastures. It was hypothesised that the poor pasture productivity at Mt Cotton was due to acid-soil infertility factors suppressing leucaena N fixation inducing a N deficit in the pasture. It was further hypothesised that inefficient N cycling via the grazing animals limited the productivity of the companion signal grass.

## Materials and methods

### Site description and preparation

Two 1 ha paddocks of *L. leucocephala* ssp. *glabrata* cv. Tarramba (K636) (leucaena) were planted between December 1998 and February 1999 at the University of Queensland Mt Cotton Research Facility (27° 53' S, 153° 14' E), south-east Queensland, Australia. The soil was a variable acid, infertile, red-yellow podzolic and was fertilised (80 kg P, 60 kg K, 116 kg S, 180 kg Ca, 12 kg Mg, 1 kg Cu, 9 kg Zn and 0.1 kg Mo/ha) prior to establishment (Galgal 2002). Leucaena was established in hedgerows 4 m apart on raised beds to improve drainage. Seed was inoculated with the commercial *Rhizobium* strain CB3060. The inter-row was sown with signal grass (*B. decumbens*) cv. Basilisk and fertilised with 80 kg/ha diammonium phosphate in November 1999 to promote establishment.

In 2000, the paddocks were heavily grazed from 27 March–22 July as part of a grazing animal behaviour-productivity study (Galgal 2002). After grazing, the leucaena stems were slashed to a height of 20 cm in December 2000 and residual woody material was removed from the site.

Maintenance fertiliser of 1.5 t/ha lime and 500 kg/ha single superphosphate (88 kg P, 110 kg S and 200 kg Ca/ha) was applied and incorporated into the top 15 cm of the soil in a 60-cm band either side of the leucaena rows by rotary-hoe to amend soil nutrient deficiencies and paddocks were re-inoculated with the commercial *Rhizobium* strain CB3060 in February–March 2001.

### Grazing management

In order to study N cycling, the aim of grazing management was to ensure that all leucaena EDM on offer was consumed and the undigested portion transferred to the ground via the dung and urine of grazing animals. This is a common management practice for leucaena pastures in Australia. Brahman × Charolais yearling steers, averaging 235 kg liveweight, continuously grazed each paddock for 9 weeks from May 24, 2001. Three steers were allocated to each paddock for the first 7 weeks. To ensure grazing pressure for each paddock was similar and 100% of the leucaena EDM was utilised, an additional 6 and 9 steers were allocated to Paddocks 1 and 2, respectively, for the final 2-week period.

### Measurements

Nitrogen pools and fluxes were estimated from pasture and soil samples, animal LWG, faecal and urine samples and extrapolation from other studies on similar pasture types. Nitrogen cycling from litter deposition and decomposition was ignored in this experiment, since all leucaena and most of the grass was consumed minimising litter production. Subsoil N cycling was not measured.

A soil and plant sampling strategy was adopted to uniformly cover each paddock. Alternate rows of leucaena and signal grass were sampled at 30-m intervals, giving a total of 30 estimations of EDM of leucaena and grass, and 30 paired plucked samples of leucaena and grass EDM, and soil (0–10 cm) per paddock before and after grazing.

### Pasture yield, herbage allowance and intake

Edible DM yield of the leucaena and signal grass was estimated at Weeks 0, 7 and 9 using a calibrated visual ranking method described by Galgal (2002). Pasture growth during the study was considered to be negligible, as low ambient temperatures and dry conditions were assumed to inhibit the growth of signal grass and leucaena.

Pasture intake of the steers was estimated using the equation developed by Minson and McDonald (1987) that predicts forage intake of beef cattle from their liveweight and rate of growth.

Percentage of leucaena in the diet was calculated using the data of Galgal (2002) who estimated the dietary proportions of leucaena (C3)

and grass (C4) by the faecal carbon isotope ratio technique (Jones *et al.* 1979), and who showed that the proportion of leucaena in the diet of cattle was closely related to the relative time spent grazing leucaena compared with signal grass. The time steers spent grazing leucaena and grass was measured in a concurrent grazing behaviour study (D. Jones, personal communication) and the percentage leucaena in the diet of steers was estimated using this relationship. Estimation of leucaena and grass DM intake was necessary in order to calculate N intake, faecal output and N excretion via faeces. Faecal output was estimated using the *in vitro* DM digestibility values measured by Galgal (2002) multiplied by the pasture intake estimated from the growth of the grazing animals (Minson and McDonald 1987).

#### *Pasture, faecal and urinary nitrogen*

Thirty samples of leucaena and grass EDM from each paddock were dried for 48 h at 65°C, finely ground and analysed for total N by combustion analysis (LECO® CNS 2000, LECO Corporation, St Joseph, MI, USA). Eight sub-samples of leucaena were measured to determine the percentage of N derived from biological N fixation (Ndfa) using the natural <sup>15</sup>N abundance technique (Peoples *et al.* 1989). Signal grass was used as a reference to measure the proportion of <sup>14</sup>N:<sup>15</sup>N in a companion non-N fixing plant.

Faecal grab-samples were taken from the rectum of individual steers fortnightly between 07.00 and 09.00 h from the initial 6 steers from Weeks 0–9, starting from Week 3 of grazing until the end of the grazing period. Samples were dried for 48 h at 65°C, finely ground and analysed for total N (LECO® CNS 2000). These data were then used to estimate the amount of N excreted via faeces.

Urine was sampled fortnightly in the morning and afternoon from the initial 6 steers, and bulked for individual animals. At each collection, 100 ml of urine was sampled and immediately adjusted to pH 3 (30% aqueous H<sub>2</sub>SO<sub>4</sub>) to avoid N losses. Total N (LECO® CNS 2000) and creatinine (Balcells *et al.* 1992) concentrations were analysed. Urinary N excretion/animal/d was derived from the N:creatinine ratio using a formula developed by Bolam (1998). This ratio is a relatively constant value/kg of liveweight.

#### *Liveweight gain (LWG)*

Steers were fasted and weighed at the beginning of the trial and every 2 weeks thereafter. The amount of N retained in body tissue was estimated by multiplying the total LWG/ha over the trial period by a standard value of 2.4% N for animal body tissue (Whitehead 1995).

#### *Soil chemical and physical analysis*

Prior to the application of maintenance fertiliser in February 2001, soil was collected from sites where plant nutrient deficiency symptoms were particularly severe. Soil pH (1:5 H<sub>2</sub>O), mineral N concentration (Bremner and Keeney 1965), bicarbonate-extractable P (Colwell 1963), extractable S (Rayment and Higginson 1992) and exchangeable bases (K, Na, Ca and Mg) (Gillman and Sumpter 1986) were measured.

Soil mineral N concentration (Bremner and Keeney 1965) was measured in 30 soil samples from each paddock before and after grazing. Samples comprised a mixed sub-sample from 3 cores of 5.5 cm diameter to a depth of 10 cm taken from each sampling position. The volume of fresh soil was weighed, broken up and oven-dried for 60 h at 55°C. The moisture content was recorded and bulk density calculated.

#### *Statistical analysis*

Intensive sampling procedures were employed to account for variability across paddocks. Means and standard errors of means are presented for all measured and estimated parameters.

## **Results**

#### *Climate*

Rainfall recorded during the experimental period (171 mm) was 37% below average. Maximum and minimum temperatures ranged from 18–22°C and 6–10°C, respectively, and relative humidity at 09.00 h was 30–40%.

#### *Soil chemical analysis*

The chemical composition of the soil, sampled prior to the application of fertiliser, indicated that it contained low concentrations of N, P, K, Ca, Mg and S, and had a pH of 4.9 (Table 1).

Nitrogen availability in the surface 10 cm of soil was variable, ranging from 54–360 kg/ha of mineral N equivalent. Before grazing, Paddock 1 averaged 227±14 kg/ha N and Paddock 2 averaged 177±9 kg/ha N. After grazing, soil mineral N was 212±10 kg/ha N and 185±10 kg/ha N in Paddocks 1 and 2, respectively. Using average figures, there was no appreciable change in soil mineral N concentration.

#### Pasture yield and intake

Paddock 1 had a lower amount of forage on offer at the beginning of the trial (1676±22 kg/ha EDM) than Paddock 2 (2616±40 kg/ha EDM) (Table 2). Leucaena EDM on offer represented 23 and 31% of the total EDM for Paddocks 1 and 2, respectively. At the end of the trial, leucaena was totally consumed, and only 416±4 kg/ha and 575±4 kg/ha EDM of signal grass remained in Paddocks 1 and 2, respectively.

Estimated pasture EDM intakes averaged 4.9 kg/hd/d for Paddock 1, and 5.2 kg/hd/d for Paddock 2. The diet composition data estimated from Galgal (2002) indicated an overall average percentage of leucaena in the diet of 29 and 38% for Paddocks 1 and 2, respectively.

#### Pasture, faecal and urinary nitrogen

Mean N concentrations (% DM) of forage components, total N on offer and biologically fixed N on offer in each paddock are presented in Table 2. The average N concentration of leucaena EDM was only 2.71 and 3.50% for Paddocks 1 and 2, respectively, and 1.21 and 0.95% for signal grass EDM.

Estimated cycled N was calculated as the difference between N on offer before and after grazing, and included N consumed and N transferred by other ways not measured in this experiment (*e.g.* trampling and senescence). The proportion of the leucaena N regarded as biologically fixed ( $\delta^{15}\text{N}$  technique) averaged 75% (range 65–80%) in both paddocks. Paddock 2 had a higher biological N fixation (BNF) input associated with higher leucaena yield and higher N concentration in leucaena tissues.

The mean N output via urine and faeces for each paddock showed that the proportion of urinary N was higher in Paddock 2 (mean 47% of total N excreted) than Paddock 1 (40%) (Table 3). Faecal N was less variable, averaging 45 g N/hd/d for both paddocks. Urinary excretion of N increased towards the end of the experiment.

**Table 1.** Chemical and physical properties of the Mt Cotton podzolic soil (0–10 cm) prior to the application of maintenance fertiliser, averaged across both paddocks.

Mineral N	Extractable P	K	Ca	Mg	S	pH	Bulk density <sup>1</sup>
(mg/kg)	(mg/kg)	(meqv)	(meqv)	(meqv)	(mg/kg)	(1:5 H <sub>2</sub> O)	(g/cm <sup>3</sup> )
23.2±2.8	3.9±0.4	0.15±0.09	1.57±0.45	2.64±0.62	6	4.9±0.1	2.18±0.02

<sup>1</sup> Soil bulk density measured post grazing.

**Table 2.** Presentation yields of forage and estimated biologically fixed N and N cycled by grazing cattle in leucaena-signal grass pastures at Mt Cotton, Queensland.

Pasture component		EDM <sup>1</sup>	N	Total N on offer	Estimated cycled N	Ndfa <sup>2</sup>	BNF <sup>3</sup> input
		(kg/ha)	(% DM)	(kg/ha)	(kg/ha)	(%)	(kg/ha)
<b>Paddock 1</b>							
Week 0	Leucaena	385±20	2.71±0.07	10.4			
	Grass	1291±11	1.21±0.05	15.6			
Week 9	Leucaena	0	—	—	22.5	75	7.8
	Grass	416±4	0.84±0.03	3.5			
<b>Paddock 2</b>							
Week 0	Leucaena	816±39	3.50±0.10	28.6			
	Grass	1800±17	0.95±0.03	17.1			
Week 9	Leucaena	0	—	—	41.8	75	21.4
	Grass	575±4	0.67±0.02	3.9			

<sup>1</sup> EDM = edible dry matter.

<sup>2</sup> Ndfa = proportion of total N derived from biological N fixation.

<sup>3</sup> BNF = biological N fixation.

**Table 3.** Nitrogen output in excreta of steers grazing leucaena-signal grass pastures at Mt Cotton, Queensland.

	Grazing time	Urinary N <sup>1</sup>	Faecal N <sup>1</sup>	% excreta N cycled in urine <sup>1</sup>
	(weeks)	(g/hd/d)	(g/hd/d)	(%)
<b>Paddock 1</b>	0-3	18±2	39±5	32±1
	4-5	17±2	40±5	30±4
	6-7	46±12	57±6	45±7
	8-9	48±12	43±4	53±5
<b>Mean</b>		<b>32±6</b>	<b>45±3</b>	<b>39±3</b>
<b>Paddock 2</b>	0-3	15±3	38±7	29±6
	4-5	39±12	40±1	49±7
	6-7	69±16	61±11	53±10
	8-9	55±13	42±2	57±7
<b>Mean</b>		<b>45±8</b>	<b>45±4</b>	<b>46±4</b>
<b>Overall mean</b>		<b>38±5</b>	<b>45±2</b>	<b>42±3</b>

<sup>1</sup> Mean±s.e. of three steers per paddock.

#### Liveweight gain

Steers initially lost liveweight but recovered to produce moderate LWGs that peaked between Weeks 6 and 9 at 0.6 kg/hd/d (Table 4). The amount of N retained in animal body tissue was calculated (Whitehead 1995) to be 1.8 kg/ha N.

**Table 4.** Summary of the liveweight changes and total nitrogen retained in animal body tissue during the trial for each leucaena paddock at Mt Cotton, Queensland.

Paddock	Liveweight gains per period				Total liveweight gain	N retained in liveweight gain <sup>1</sup>
	0-3 wk	4-5 wk	6-7 wk	8-9 wk		
	(kg/ha)				(kg/ha)	(kg/ha)
1	-6	13	25	30	62	1.49
2	1	15	25	47	88	2.11
<b>Mean</b>	<b>-2.5</b>	<b>14.0</b>	<b>25.0</b>	<b>38.5</b>	<b>75.0</b>	<b>1.80</b>

<sup>1</sup> 2.4% N in body tissue (Whitehead 1995).

#### Nitrogen fluxes

A summary of the N fluxes is given in Table 5. The stocking rates applied to the pastures were calculated using the number of steers and number of grazing days. Of the total N on offer (35.9 kg/ha), 32.2 kg/ha (90%) was cycled. Of the total N cycled, 72% was cycled by the grazing animals with the remainder (28%) cycled by pathways not measured in this study [*e.g.* treading, senescence (litter) and translocation within plants]. Assuming 90% of BNF input was cycled, only 13 kg/ha N of biologically fixed N was added to the system.

## Discussion

### Soil fertility, pasture yield and biological N fixation

The study confirmed that leucaena-signal grass pastures grown in the acid, infertile podzolic soil at Mt Cotton were declining in productivity after an initial period of good growth during 1999 and 2000. Yields recorded in this study (2001) were 65 and 32% of the leucaena and signal grass EDM yields, respectively, for Paddocks 1 and 2, produced by the same pasture in 2000 (Galgal 2002). The pastures were degrading due to lack of available essential nutrients for leucaena growth and N fixation, and due to limited cycling of symbiotically fixed N to the associated signal grass. This was evidenced by poor pasture growth, visible chlorotic symptoms and declining animal LWG.

The capacity of leucaena to fix N was clearly insufficient to maximise pasture growth. In January 2001, prior to the application of maintenance fertiliser, N levels in the youngest fully expanded leaves (YFEL) of severely affected plants were 2.37% in leucaena and 0.38% in signal grass. This compares unfavourably with N levels in YFEL of healthy leucaena, often >4.0% DM (Ruaysoongnern *et al.* 1989; B.F. Mullen, personal communication), and with data of Galgal (2002) who reported that leucaena EDM (leaf and soft stem) contained 3.5% N and signal grass 2.0% N in the same Mt Cotton pastures in 2000. Although nodulation occurred in all leucaena plants and an effective *Rhizobium* strain was present (data not presented), the addition of urea strongly promoted plant growth and significantly increased N concentration in leaf tissue (Burle 2001), confirming N deficiency was the primary limitation.

In work reported elsewhere, nutrient deficiencies (P, Ca, Cu and Zn) and imbalances (a low Ca:Mg ratio and high/toxic concentrations of Mn and Fe), were limiting biological N fixation by leucaena growing on the podzolic soil (Burle 2001). Other workers have shown that Ca and P deficiencies can retard nodulation (nodule number and size), N fixation and growth of leucaena in acid soils (Ruaysoongnern *et al.* 1989; Kerridge 1991). Poor aeration due to compaction (bulk density = 2.2 g/cm<sup>3</sup> at 10 cm depth) and waterlogging of the podzolic soil were evident and may have limited soil exploration and

**Table 5.** Summary of nitrogen flows and fluxes in leucaena-signal grass pastures grazed by steers in the winter of 2001 at Mt Cotton, Queensland.

Parameter	Unit	Paddock 1	Paddock 2	Mean
Stocking rate	(AU <sup>1</sup> /ha)	2.0	2.4	2.2
Total EDM <sup>2</sup> on offer	(kg/ha DM)	1676	2616	2146
% leucaena	(%)	23	31	28
<b>N in pasture</b>				
Total N on offer	(kg/ha)	26.1	45.7	35.9
N remaining in pasture after grazing	(kg/ha)	3.5	3.9	3.7
Total N cycled	(kg/ha)	22.6	41.8	32.2
BNF <sup>3</sup> input	(kg/ha)	7.8	21.4	14.6
<b>N cycled via grazing</b>				
N consumed	(kg/ha)	19.5	27.1	23.3
N retained in LWG <sup>4</sup>	(kg/ha)	1.5	2.1	1.8
N returned via urine	(kg/ha)	7.9	12.4	10.2
N returned via faeces	(kg/ha)	10.1	11.7	10.9
% total N on offer cycled via grazing	(%)	75	58	65
<b>N cycled via other ways</b>				
N cycled via treading, senescence, etc. (by difference)	(kg/ha)	3.1	14.7	8.9
Soil mineral N change (surface 10 cm)	(kg/ha)	-15.0±11.2	8.1±6.0	-3.5±6.5

<sup>1</sup> AU = 450 kg liveweight.<sup>2</sup> EDM = edible dry matter.<sup>3</sup> BNF = biological nitrogen fixation.<sup>4</sup> LWG = liveweight gain.

nutrient uptake by leucaena roots, and impeded N<sub>2</sub> gas exchange at the nodules further restricting N fixation and promoting denitrification of fixed N under anaerobic conditions. This would explain why the application of maintenance fertiliser and *Rhizobium* in February–March 2001 failed to amend the nutrient imbalances of the leucaena plants in the podzolic soil (Burle 2001). It is likely that both fertilisation with the limiting nutrients, and soil physical renovation (deep ripping) to reduce compaction and promote aeration, water infiltration and root extension, will be necessary to ameliorate the deficiency symptoms.

Unthrifty leucaena-signal grass pastures in the current trial fixed only 8 and 21 kg/ha N over the 9-month regrowth period. These rates of biological N fixation were insufficient to sustain pasture productivity. By comparison, Cadisch *et al.* (1994) reported that a mixed signal grass pasture containing 2600–5200 kg/ha DM *Calopogonium mucunoides* fixed 60–117 kg N/ha/yr, sufficient to sustain productivity of the pasture system on a red latosol soil in Brazil. Similar contributions of 128 kg N/ha/yr from *Arachis pintoi*-grass pastures (Ibrahim 1994) and 100 kg N/ha/yr from *Stylosanthes* spp. (Vallis and Gardener 1984) pastures have been reported.

Leucaena can accumulate large quantities of N (410–560 kg N/ha/yr) in standing biomass (19–22t/ha) under ideal growing conditions (Ferraris 1979). High rates of N fixation would be expected from healthy, vigorous leucaena-grass pastures in subhumid Australia. For example, a typical pasture yielding 2500 kg EDM/ha/yr of leucaena at 4% N would contribute approximately 75 kg/ha/yr of biologically fixed N to the system, assuming an average of 75% Ndfa.

The mean proportion Ndfa of 75% measured in this trial was within the range of 63–84% reported for tropical pasture legumes (Peoples and Baldock 2001), and was in agreement with findings of 70–74% Ndfa in monoculture leucaena (Kadiata *et al.* 1996) and 73–83% in mixed leucaena-grass systems (Jayasundara *et al.* 1997). Similar proportions of Ndfa have been reported for other established tree legumes, including *Gliricidia sepium* (with grass) 74–83% (Jayasundara *et al.* 1997) and *Albizia lebbek* in monoculture 79–84% (Kadiata *et al.* 1996). Boddey *et al.* (1997) suggested that tropical forage legumes compete poorly with grasses such as *Brachiaria* spp. for soil mineral N so that the legume must rely almost exclusively on BNF for N supply. Biological N fixation of legumes associated with strongly competitive grasses often provides >80% of legume N

when essential nutrients are in adequate supply (Cadisch *et al.* 1994).

#### Nitrogen cycling

The cycling of nutrient elements, especially N, between soil, plants and animals is vital in grasslands. The presence of a forage legume, such as leucaena, can greatly increase grass herbage yield and N status due to the transfer of fixed N (Fisher *et al.* 1997). Nitrogen can be cycled from legumes to companion grass via exudation of N from roots and nodules, mineralisation of leguminous organic matter (shoots, roots and nodules), and faeces and urine of grazing animals (Mannetje 1997). Efficient N cycling is critical for tropical pasture sustainability and can be manipulated by managing rates of pasture utilisation by grazing animals (Boddey *et al.* 1996).

The amount of N retained in animal body tissue (1.8 kg/ha) in this study was small (<5%) when compared with the total N cycled per year. Vallis and Gardener (1984) and Whitehead (1995) also observed that grazing animals retained <10% of dietary N from leguminous pastures. Therefore, most of the N cycled in the pasture system was retained in labile nutrient pools (urine, faeces and soil) where N losses might occur through volatilisation and leaching, and nutrient immobilisation in poor quality grass litter (Boddey *et al.* 1997).

The Mt Cotton pastures were found to be N-deficient with only small amounts of N being accumulated and cycled. It was estimated that 59% (21 kg/ha N) of the total N on offer (36 kg/ha N of which 15 kg/ha N was fixed) at the beginning of the current trial was cycled via the excreta pathway, a pathway which is susceptible to losses and leads to non-uniform distribution of nutrients in the paddock (Whitehead 2000). Of the N cycled via excreta, the proportion excreted via urine ranged from 29–57% over the experimental period, and although N in this form is more readily available for plant uptake, it is also highly susceptible to volatilisation losses, especially under dry conditions (Whitehead 1995). Vallis and Gardener (1984) reported volatilisation rates of 25–50% of urinary N and 5–20% of faecal N from cattle grazing *Stylosanthes hamata* pastures.

The proportion of N excreted via urine is highly dependent on the N concentration of the diet (Whitehead 2000). In this study, the pasture

was N-deficient and the proportion of N cycled in urine by the reference steers averaged 42% of total N excreted. Whitehead (1995) observed similar proportions of N cycled in urine for cattle consuming a diet containing 1.5% N. Steers preferentially consumed grass at the beginning of the trial; however, the proportion of total N excreted via urine increased in the second half of the grazing period when leucaena comprised a higher proportion of the steers' diet (D. Jones, personal communication) until all edible leucaena was consumed. Animals grazing productive leucaena-grass pastures high in protein would be expected to excrete more than 60% of consumed N via urination.

The leucaena-grass pastures at Mt Cotton were grazed through winter and this practice may have increased N losses from urine patches. High rates of ammonia volatilisation, nitrification and leaching, and immobilisation of N in soil organic matter (Boddey *et al.* 1997) would have occurred as the cold conditions inhibited signal grass growth and N uptake. Thus, urinary N deposited on the ground under cool, dry winter conditions in subtropical Australia would be exposed to losses until the beginning of the following growing season. Similar problems of synchronicity between N release from leguminous mulch and N uptake by companion crops have been identified in alley cropping systems, where low crop recoveries of 5–30% of mulch N have been recorded (Sanginga *et al.* 1995).

Boddey *et al.* (1996) and Cadisch *et al.* (1994) suggested that lower levels of utilisation of the legume component may improve the amount and quality (N concentration) of litter in *Brachiaria* spp. pastures, and minimise losses of N transferred via excreta. Since leucaena is highly palatable, and utilisation levels of the leucaena component of mixed swards are frequently high, most N will be cycled through the excreta of grazing animals. It is common for leucaena hedgerows to be completely defoliated with minimal treading damage or senescence losses of leucaena herbage. For sustainable production of leucaena pastures, especially on acid soils, lower levels of utilisation would ensure a higher proportion of N cycled via the plant litter pathway, which is more stable, uniformly distributed and less subject to losses. The use of less palatable legumes (*e.g.* *Calopogonium mucunoides* and *Chamaecrista rotundifolia*) would further reduce levels of utilisation, promote legume biomass production, N fixation, and effi-

cient N cycling via plant litter, thereby improving the sustainability of tropical pastures grown on infertile soils.

The huge variation in soil mineral N observed in this experiment was assumed to be a consequence of the uneven spatial distribution of the excreta in the grazed pastures. Whitehead (1995) reported that cattle excreta patches might cover only 30–40% of the pasture surface annually when grazed under moderate stocking rates, with more even distribution of excreta occurring at higher stocking rates. Fisher *et al.* (1997) reported that, at 1 head/ha, the deposition of faeces was biased toward the sides of the paddock, with more even distribution at 2 head/ha. However, imposing high stocking rates to uniformly distribute cycled nutrients may increase volatile losses of N from elevated levels of N excreted via urine associated with high levels of leucaena EDM utilisation.

Soil N levels at Mt Cotton (185 and 212 kg/ha N for Paddocks 1 and 2, respectively) were similar to values reported by Cadisch *et al.* (1994) for pastures on a red latosol in Brazil (152 kg/ha N in a pure grass pasture, 189 kg/ha N in a grass-legume mixture and 252 kg/ha N in a pure legume sward). The reasons for the small change in soil N over the duration of the trial may have been due to:

- Non-random spatial distribution of faeces and urine patches over the paddock, reducing the effectiveness of the sampling strategy;
- Low BNF input into the system due to the poor N fixation and low leucaena yields;
- Cold, dry weather conditions making N excreted via faeces, being largely organic, unavailable as decomposition and incorporation by the soil fauna would be slow;
- Losses of urinary N by volatilisation due to dry conditions being exacerbated by poor grass and leucaena growth (inefficient N uptake) during winter; and
- Large quantities (416–575 kg/ha EDM) of grass ground litter of high C:N ratio favouring immobilisation of plant-available N at dung and urine patches by soil microbes (Vallis and Gardener 1984).

It was estimated in the current experiment that 25% (9 kg/ha) of the N on offer in EDM, or 28% of total N cycled, was cycled via other pathways such as the plant litter pathway (senescence and treading) and N translocation (from shoots to roots) within grass and leucaena. Litter, translocation and subsoil (root/nodule exudates and

decomposition) N fluxes were not measured in this study. Significant quantities (>50%) of plant N can be retained underground in crowns, roots and nodules of leucaena trees (Jayasundara *et al.* 1997). Furthermore, Sanginga *et al.* (1990) observed significant accumulation of fixed N in leucaena roots (60%) compared with shoot material (20%) under regular cutting. Hence, heavy grazing of legumes could result in significant cycling of fixed N via the sloughing and mineralisation of roots and nodules. Consequently, the amount of BNF measured in this study may be an underestimation of the total BNF input to the grazing system.

#### *Accuracy of estimated data*

The components of the N fluxes of the pasture system that were derived from published relationships (forage intake, N retained in liveweight, and urinary and faecal output) were well estimated in the current experiment. The summation of the components of N cycled via grazing animals (N retained in LWG, and N returned via urine and dung) equalled the estimation of total N consumed by the cattle for Paddock 1 and slightly underestimated (3%) total N consumed in Paddock 2 (Table 5). Since these components were derived independently, we have confidence that the use of these relationships to model animal metabolism and performance was valid. Therefore, we are reassured that the measured and derived data accurately estimated N cycling in the leucaena-grass pastures.

#### **Conclusions**

The heavily grazed leucaena-signal grass pastures at Mt Cotton were neither productive nor sustainable. Animal production was considered low and the high LWG expected from good leucaena-based pastures (1 kg/hd/d) was not achieved. Amelioration of the soil nutrient deficiencies that limited N fixation and N accumulation was required to maximise productivity. However, low soil nutrient status was exacerbated by poor soil physical structure (high bulk density and anaerobic conditions), which restricted root growth, soil exploration and nutrient uptake. This significantly and negatively affected N fixation and N cycling. BNF contribution was very low at 15 kg/ha N, causing a N deficit in the system.

Remedial measures such as deep ripping, liming, incorporating large amounts of organic matter and mounding of leucaena rows are required to address the poor physical structure of the podzolic soil thereby improving drainage/aeration, water storage and nutrient availability.

Manipulation of N-cycling pathways by synchronising N cycling with pasture N demand, *i.e.* summer grazing, and reducing the level of leucaena utilisation (promoting nutrient cycling via litter) is likely to improve the sustainability of the pasture system. The high level of utilisation of leucaena EDM currently adopted increased the proportion of N excreted via faeces and urine and exposed more than 50% of the fixed N to losses by denitrification, volatilisation and leaching.

It is unlikely that many commercial leucaena plantings will occur on such chemically and physically infertile soils as the Mt Cotton podzolic. However, some graziers are reporting a decline in leucaena yields after vigorous initial growth during establishment on fertile soils. This may be associated with soil chemical imbalances inhibiting N fixation, which in turn reduce pasture and animal productivity. The frequency of occurrence of this phenomenon needs to be investigated and grazing/fertiliser management strategies devised.

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