Nitrogen supply to no-tillage crops, as influenced by mulch type, soil type and season, following pasture leys in the semi-arid tropics

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Summary. Past cropping research in the semi-arid tropics of northern Australia has shown that in this climate and on the predominantly sesquioxidic soils, recovery of fertiliser nitrogen (N) by crops is often low. Conceptually, no-tillage, legume ley farming offers features for coping better with the constraints of climate, soil and high fertiliser transport costs to this remote region. This paper summarises the N cycle in a system in which pastures provide N for successive crops, and mulch at the time of crop establishment is provided by the killing of new pasture growth. The aim was further to provide a sound foundation for managing N supply in relation to demand in a climate that causes high variation and uncertainty for pasture N_2 fixation and sequestering, the amount of early season re-growth (mulch), rate of mulch decomposition, nitrate leaching losses, and crop growth and N demand.

The research approach combined field studies with simulation modelling. A series of field studies that included bare fallow and grass and legume pasture leys on clay loam and sandy loam soils, were conducted at Katherine over 4 wet seasons to study subsequent mineralisation of N. Experimental results were used to test the performance of a simulation model for predicting the observed variations consequent upon the various management options.

Experimental results showed that the carbon (C) : N ratio of the residue and soil texture were important factors in determining N mineralisation, immobilisation, and nitrate leaching following chemical kill of pasture leys. However, the greatest variation was between seasons. A modified version of the CERES-Maize N model was able to simulate the accumulation of nitrate following a bare fallow and following pasture leys with high levels (above and below ground) of freshly killed residues with widely differing C : N ratio, the downward movement of nitrate-N in the soil and the interaction of these processes with seasonal rainfall.

Despite a capability for simulation of the soil N dynamics in a cropping phase following pasture leys, experimental results indicated how nitrate distribution following leys is influenced by pasture growth during the ley, and how this varied greatly with season and soil texture. The simulation capability reported here has been incorporated elsewhere into the development of a full system model, embracing both the ley phase and the crop phase.

Introduction

Soil nitrogen (N) supply is a major constraint for crop production on the sesquioxidic soils of northern Australia and fertiliser N is usually necessary to attain profitable crop yields (Jones *et al.* 1985). However, research into the efficient use of N fertilisers in this environment has generally yielded discouraging results. For example, Day (1977) reported 0 and 38% recovery of N applied to sorghum on a sandy soil and clay soil respectively in the same season, and Myers (1979) reported low recoveries when using N^{15} tracer techniques to evaluate N carrier (14–24%) and methods of application (16–28%) on a clay soil. Low N recoveries have been explained by low N demand due to crop water stress (Myers 1978), and also by excessive rainfall resulting in significant leaching losses (Wetselaar 1962; Day 1977; Myers 1983). Low efficiency of N utilisation by crops, together with high transport costs to this isolated region, makes N fertilisation a major cost deterrent to broadacre cropping.

In an attempt to find a cropping strategy that reduces the constraints of climate, soil and high fertiliser costs, McCown *et al.* (1985) proposed a no-tillage, legume ley farming system based on improved, high-yielding tropical pasture legumes. The key features of this system are the use of biologically fixed N as a partial substitute for fertiliser N, minimal soil disturbance with mulch cover, self-regenerating, legume ley pastures under crops, and integration of cropping with a livestock grazing enterprise.

Wetselaar and Norman (1960*a*) studied the N supply following legume and grass ley systems at Katherine using conventional tillage methods. They found that the incorporated legume material was rapidly mineralised with the onset of seasonal rains but recovery of the mineralised N by fodder crops was limited (<50%) because it was rapidly leached below the root zone before and during the crop.

The efficacy of pasture legumes to supply N to a following maize or sorghum crop in a no-tillage system has been evaluated (McCown *et al.* 1986; Jones *et al.* 1991, 1996; Thiagalingam *et al.* 1996). One year of pasture legume provided the equivalent of 10–90 kg of fertiliser N with variation due to soil type and rainfall. The earlier work of Wetselaar and Norman (1960*a*) and Myers (1983) indicates the importance of the seasonal pattern of soil N mineralisation and nitrate movement if the N supply in a no-tillage ley system is to be understood, anticipated and managed.

The research reported in this paper aims to improve the assessment of N inputs for cropping and thereby enhance management. However, the challenge ahead is that patterns of variation in N supply are strongly influenced by water supply. Due to high variability among soils as well as between seasons, we judged that the most efficient role of field experimentation was in developing and testing simulation models that could eventually be used to experiment with N management practices in a way that adequately dealt with interactions with the soil water balance and uncertainties in rainfall.

One implication of a simulation approach is that field studies are designed for efficient provision of data which enable models to be tested. Ideally, the data span extremes in the interest of providing a tested domain for the models that will enable the model to be used in applications with minimal risk of exceeding this domain. A second implication is that efficient experiments designed for this purpose generally do not have the same 'stand alone' interest or rigorous adherence to the design rules of conventional experiments where uncontrolled variation is countered by use of replication and randomisation. In the case of the field study conducted in conjunction with simulation modelling, rigour mainly concerns comprehensive and precise measurement of key system outputs and their determinants. Such data serves to test and, where justified, modify existing models.

This paper focuses on the effects of mulch type, soil texture and rainfall on soil N dynamics, and on the testing of a model to simulate the effects of these factors. First, we report the results of field experiments conducted to quantify the N dynamics, and second, performance of the model for simulating N supply following pasture leys.

Materials and methods

Four experiments were conducted at Katherine Research Station over 1985–90 in which soil mineral N was studied following: (i) grass and legume leys which had been established for 1, 2 or 3 wet seasons; (ii) a sorghum crop with N fertiliser applied; and (iii) a bare fallow. Only a brief outline of the experimental design and procedures used in these experiments is reported here. A more complete description is available in Dimes (1996).

Soils

Experiments were conducted on 2 sesquioxidic red earth soils; the 'clay' soil is a Fenton clay loam (formerly Tippera) and the 'sandy' soil is a Venn sandy loam (formerly Blain) (Lucas *et al.* 1985). Chemical and physical properties of the 2 soils are described in Williams *et al.* (1985). The 2 soils are about 20 km apart in the Katherine (14°28'S, 132°18'E) district of the Northern Territory.

Clay soil experiments

Soil nitrate-N accumulation following leys of 1 year (experiment 1) and 3 years (experiment 2) was studied on the clay soil. Ley treatment plots were established in mid January 1985 (experiment 1) or mid January 1986 (experiment 2). Swards of perennial grass (*Urochloa mozambicensis*), naturalised annual grasses (mostly *Digitaria* spp.), a forage legume (*Stylosanthes hamata* cv. Verano) and DK55 grain sorghum (*Sorghum bicolor*) were sown or, in the case of the naturalised annual grasses, allowed to re-generate on land where sorghum had grown in the previous 2 seasons (experiment 1) or native pastures had grown for at least 2 years (experiment 2).

Dates for chemically killing pasture leys are shown in Figure 1. Nitrate-N was monitored for consecutive wet seasons in experiment 2. Annual grass plots were not sampled in this experiment.

In experiment 2, the sorghum main plots grew 2 crops (1986 and 1987), each with 40 kg N/ha applied. Following the 1987 sorghum crop (harvested May), plots were disc ploughed twice, and from January 1988, kept free of weeds by chemical means. These plots are referred to as the 'bare fallow' treatment in experiment 2.

Sandy soil experiments

Soil nitrate-N accumulation following leys of 1 year (experiment 3) and 2 years (experiment 4) was studied on the sandy soil. *Urochloa* and Verano stylo swards were sown in mid January 1985, on land which had grown native grasses without added fertiliser since 1978.

Experiments 1 and 3 were conducted in the same wet season with close scheduling of nitrate-N sampling (Fig. 1).

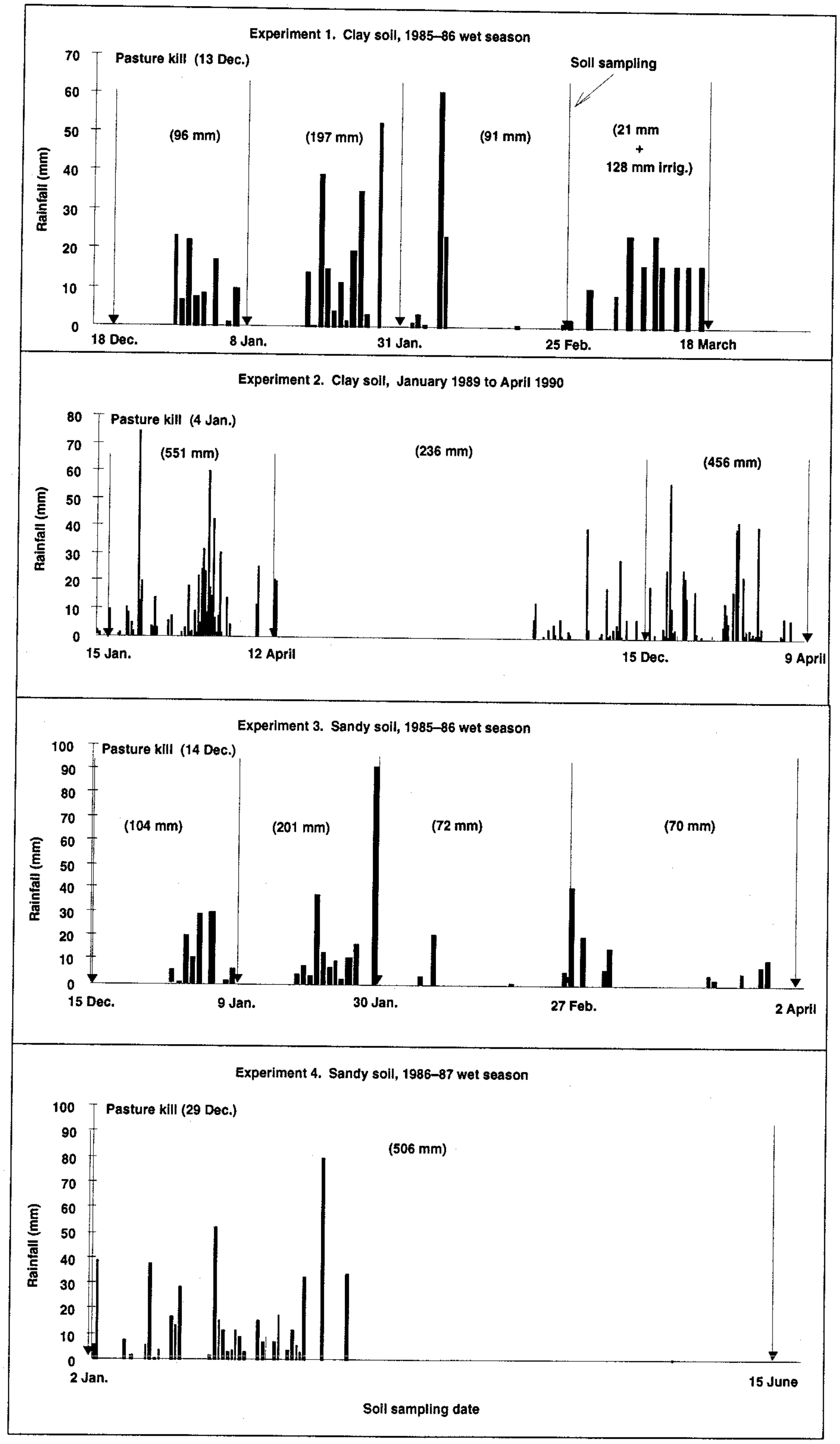

Figure 1. Rainfall and soil sampling dates (arrowed) for four experiments conducted at Katherine over December 1985–April 1990.

Experimental design

Plots monitored for nitrate-N in this study consisted of subplots in a split-plot, randomised, complete block experiment with ley treatments as main plots. On the clay soil, experiments had 4 replicates and subplots were 3 by 12 m. On the sandy soil, experiments had 3 replicates and subplots were 3 by 16 m. Different experiments on the same soil type were conducted on adjacent parcels of land.

Management in a ley phase

All main plots were fertilised with basal applications of nutrients other than N known to be in low supply in these soils (Jones *et al.* 1985). Urea-N was applied to the non-legume ley plots at 50 kg N/ha in experiments 1, 3 and 4, and 40 kg N/ha in experiment 2. In the case of longer leys, urea application to ley plots was repeated in the second growing season.

During the dry season, standing residues above 10 cm were removed (September–October) using a forage harvester to simulate removal in a grazed ley.

Management in a 'cropping' season

Ley pastures and sorghum ratoons re-generated with the early rains of the wet seasons. Re-generating vegetation was fertilised with nutrients other than N. Weeds were chemically and/or manually controlled to maintain pure stands of pasture or sorghum. Glyphosate (4 L/ha) was applied to pasture swards and sorghum ratoons following the first planting rain which fell within the normal crop planting window (mid December–early January).

Following chemical kill, soil nitrate-N profiles were monitored on subplots where the soil remained undisturbed and the previous vegetation decomposed on the soil surface. All treatment plots were kept free of vegetation by chemical means over the remainder of the wet seasons.

Soil sampling

Soils were sampled soon after pasture kill and at intervals during the wet-cropping season (Fig. 1). Soils were also sampled in September 1985 for experiments 1 and 3 before any storm rains (not shown in Fig. 1). At each sampling, 2 (experiments 1 and 3) or 4 (experiments 2 and 4) cores of 50 mm diameter were taken in each subplot to a depth of 1.8 m. The cores were separated into 8 (or 9) layers and soil from equivalent layers bulked before subsampling. Because the sandy loam soil was conducive to leaching, cores were taken at the final sampling in each wet season to a depth of 3 m (with 12 intervals).

Soil chemical analyses

Soil nitrate and ammonium-N were determined on 2 mol KCl/L extracts of moist soil by a Chemlab continuous flow analyser using the methods described by Best (1976), and Crooke and Simpson (1971). Ammonium-N levels were found to be relatively unchanged across sampling dates. This is in agreement with the suggestion of Myers (1975) that all ammonium-N formed is rapidly transformed to nitrate in this environment. Results for nitrate-N are therefore reported in this study as an index of the net mineralisation following ley treatments and assumes that denitrification is not an important loss mechanism for these free-draining soils as shown by Wetselaar (1967).

Dried (60°C) soils sampled at pasture kill were analysed for organic carbon (C) using an automatic dry combustion method (Nelson and Sommers 1982).

Above-ground biomass, root mass and N concentrations

Surface material (i.e. recent vegetative growth plus any older residues) was sampled for dry weight and N concentration at pasture kill of swards and sorghum ratoons. Six quadrats (0.5 by 0.5 m for pastures and 1.5 by 0.5 m over 2 rows for sorghum) per main plot were harvested in experiments 1 and 3. In experiments 2 and 4, only selected subplots were chemically killed and 4 quadrats (0.5 by 0.5 m) per subplot were harvested for the perennial grass and legume treatments.

Perennial grass and legume plots in experiment 2 (clay soil) were sampled for root mass (live plus dead) and N content near (6 Jan.) pasture kill in January 1989. Soil cores of 50 mm diameter to 90 cm depth were taken from areas sampled for above-ground biomass (1 per quadrat). Each core was separated into 7 layers (0–5, >5–15, >15–30, >30–45, >45–60, >60–75, >75–90 cm) and equivalent layers for paired cores bulked. This gave 2 root samples per layer for each subplot.

Roots were extracted from soil by the method of Ward *et al.* (1978). Roots were placed on filter paper and oven-dried at 60°C. Charcoal and other extraneous matter were removed from the dried samples before weighing. Root samples from below 30 cm were combined for grinding and analysis for Kjeldahl N.

Root biomass and N concentration of the perennial grass and legume pastures on the sandy soil (experiment 4) were determined in December 1989 using the same procedures described for the clay soil. At this time, the ley pastures were at the start of their fifth growing season.

The CERES-Maize N submodel

The CERES-Maize N model (Jones and Kiniry 1986) simulates the major soil N transformations (mineralisation, immobilisation, nitrification, denitrification) and nitrate leaching. It is initialised with a few readily obtainable inputs (soil organic C, residue amount and C:N ratio, soil ammonium- and nitrate-N concentrations). The model operates on a daily time step and simulates N transformations in specified soil layers and nitrate transfer between layers. Soil water balance and soil temperature are simulated using inputs for daily maximum and minimum temperature, incident radiation and rainfall, and used when simulating moisture and temperature effects for the various N processes within and between layers.

A modified version of the model (Dimes and McCown 1992) which more closely describes the soil organic N status of the soils and a no-tillage system, was used in this study. The major modifications include: a variable soil C:N ratio for the humic fraction (17:1 for clay soil and 21:1 for sandy soil, see Wetselaar and Norman 1960*b*; Spain *et al.* 1983; Dimes 1996); decomposition and N release from the stable organic N pool restricted to the top 90 cm; a labile, or biomass, N pool (LABN) initialised assuming 5% of soil total N in layers to 90 cm; and a surface residue decomposition routine which controls the rate of surface residue additions to the top soil layer. A complete description of the experimental details which formed the basis for these changes are reported in Dimes (1996) including ancillary experimentation using soil samples from experiments 2 and 4.

Model testing and development

In experiments 2 and 4, all state variables required for initialising the N model were measured. These included the root biomass (Fig. 3) and N content of preceding vegetation and determination of the potentially mineralisable organic N fraction (Stanford and Smith 1972) which was used as the basis for specifying the LABN pool in the modified N model. Experiments 2 and 4 therefore provide data on which the modified model has been developed and calibrated for soils either uncomplicated by fresh residues (bare fallow) or containing residues (legume or grass) with differing effects on mineralisation of N.

Experiments 1 and 3 quantified nitrate-N in the soil for a wider range of residue C:N ratios and provided information on the in-season variation for net soil N mineralisation and nitrate leaching with soil texture. These data are independent of those used to modify the CERES model and so can be used to demonstrate the capability of the modified model for simulating soil N supply following a grass or legume pasture in the Northern Territory.

Simulation details

Meteorological data (temperature and solar radiation) were recorded at the Katherine Research Station. Daily rainfall was recorded at both the sandy and clay soil sites.

The model was initialised with measured values for residue mass and C:N ratio (below and/or above ground), organic C (all layers to 1.8 m), and nitrate and ammonium-N (all layers to 1.8 m) for each treatment on the date of pasture kill (Fig. 1). The change in soil nitrate-N up to the final sampling date in each wet season was then simulated. For experiment 2, the 2 wet seasons were simulated separately. For the second season, the model was initialised with measured mineral N at 15 December 1989, and surface and root residues were set according to the simulated levels at 12 April 1989.

For experiments 1 and 3, root biomass of the previous vegetation was not measured. To initialise the root residue pool, a root:shoot ratio of 3:1 was assumed for both experiments. This root:shoot ratio was an average ratio determined from a range of samplings at Katherine for the grass and legume systems. Root C:N ratio was assumed to be similar to that measured for the above-ground material.

For the sandy soil, nitrate-N was measured to a depth of 3.0 m at the end of each wet season, while simulations were initialised with a soil profile depth of 1.8 m. Simulated nitrate in the soil profile and that simulated as having leached beyond 1.8 m have therefore been added together to more adequately compare the simulated and observed net seasonal mineralisations for the sandy soil. Observed nitrate distributions which indicated that leaching beyond 3.0 m would not have been significant, if at all, was the basis for adopting this procedure.

Results

Preseason pasture growth

Dry matter and N yield of pasture and sorghum re-growth in response to early storm rains before pasture kill are given in Table 1. The perennial grass pasture consistently produced the highest dry matter yields for

Table 1. Dry matter yield (± s.e.), nitrogen yield (± s.e.) and C:N ratio of pastures and sorghum ratoons at pasture kill for experiments 1–4

Rainfall from 1 November to pasture kill for experiments 1–4 was 279, 431, 198 and 207 mm respectively, however, for experiment 4 rainfall includes 46 mm at the end of October

Ley treatment	Dry matter yield (kg/ha)	Nitrogen yield (kg N/ha)	C:N ratio[A] (kg N/ha)
	Experiment 1 (1985–86)		
Perennial grass	2488 ± 255	17 ± 1	59
Annual grasses	1455 ± 22	17 ± 2	34
Sorghum	1081 ± 118	13 ± 1	34
Legume	1496 ± 101	28 ± 3	22
	Experiment 2 (1988–89)		
Perennial grass	3110 ± 269	—	50[B]
Legume	955 ± 107	—	20[B]
	Experiment 3 (1985–86)		
Perennial grass	2161 ± 267	11 ± 2	77
Legume	1115 ± 127	14 ± 2	32
	Experiment 4 (1986–87)		
Perennial grass	3999 ± 293	39 ± 6	41
Legume	2742 ± 265	50 ± 5	22

[A] C:N ratio assumes dry matter is 40% carbon.
[B] C:N ratio assumed for initialising N model.

this period of growth and in 2 of the 4 experiments the amount of above-ground N in this pasture almost equalled or exceeded the amount of above-ground N in the legume. However, the C:N ratio for the perennial grass at pasture kill was always high to very high when compared with the C:N ratio of 25:1 typically used as the critical C:N ratio for net mineralisation of mineral N (Parnas 1975; Jansson and Persson 1982).

Dry matter and N yields for the legume varied more with season and soil type than the perennial grass. For example, dry matter yield of legume pasture on the clay soil in 1985–86 (experiment 1) was 1496 kg/ha, but in the 1988–89 preseason (experiment 2), it was only 955 kg/ha despite greater rainfall. However, C:N ratios were generally in the low 20s and favourable for mineralisation of N.

The annual grass and sorghum treatments on the clay soil in 1985–86 produced less dry matter than the perennial grass, but had about the same N yield. As a consequence, the C:N ratios for annual grasses were more favourable for rapid decomposition and N mineralisation compared with the perennial grass.

Influence of type of pasture on nitrate-N in the soil profile at pasture kill

Nitrate-N concentrations in the soil at pasture kill and at the end of the wet season are presented in Table 2. For the perennial grass treatments, nitrate-N levels at pasture kill did not exceed 10 kg N/ha in any season on either soil type. By comparison, soil nitrate-N at pasture kill was much greater for the legume treatments (as high as 42 kg N/ha on the sandy soil and 136 kg N/ha on the clay soil) across seasons and soil type. However, there was considerable variation in the amount of N at pasture kill of the legume for a given soil. Hence, nitrate-N at pasture kill varied by a factor of 2 between seasons on the sandy soil and by a factor of >3 on the clay soil.

Nitrate-N shown in Table 2 for the end of wet-season sampling provide an estimate of the net mineralisation for the different treatments in a cropping season following pasture kill. Soils with previous legume pasture exceeded the N supply of soils with previous perennial grass by factors ranging from 2 to 4 across soil type and seasons. Using results of sequential sampling in experiment 1 (see Fig. 5), the rate of nitrate-N formation following the legume was about 1.3 kg N/ha.day whenever rainfall (or irrigation) distribution was favourable. This rate would seem adequate to satisfy the needs of a moderate-yielding cereal crop (Myers 1988).

When the soil following annual grass species and ratoon sorghum was sampled, the amounts of nitrate-N at planting and at the end of the wet season were intermediate between the legume and the perennial grass.

Influence of soil type on net mineralisation and leaching

The capacity of the clay soil to mineralise N was much greater than the sandy soil following legume leys and this can largely be explained by variation in soil organic matter levels [e.g. 0.66 and 1.42% soil organic C (0–50 mm layer) for sandy and clay soil under legume pasture respectively; see also Williams *et al.* 1985]. Another important difference between soil type is the movement of nitrate down the profile. Nitrate profiles for the legume treatments in experiments 1 and 3 are plotted in Figure 2 and show the difference in nitrate movement for the soil types under similar rainfall regimes (Table 1 and Fig. 1).

For the clay soil, nitrate-N accumulated in the surface soil and there was no nitrate peak formed at depth (Fig. 2*a*). About 80% of nitrate-N was positioned above 60 cm at the 8 January sampling.

For the sandy soil, nitrate leaching was observed under the growing legume pasture. An increase in nitrate-N levels between 3 September and 15 December 1985 was associated with a peak in the 45–90 cm layer before pasture kill (Fig. 2*b*). Although there was an increase for nitrate-N in the top 15 cm for the 9 January

Table 2. Nitrate-N (kg N/ha ± s.e., 0–180 cm depth) measured under leys and sorghum ratoons at pasture kill and at the end of the wet season for experiments 1–4

Rainfall from pasture kill to final sampling was: experiment 1, 531 mm (including 128 mm as irrigation in March); experiment 2, 551 mm (1989) and 456 mm (1989–90, from 15 December 1989 to 12 April 1990); experiment 3, 446 mm; and experiment 4, 506 mm

Ley treatment	Pasture kill	After fallow[A]	End of season	Net change
		Experiment 1 (1985–86)		
Perennial grass	9 ± 1	—	63 ± 2	54
Annual grasses	14 ± 1	—	89 ± 4	75
Sorghum	34 ± 2	—	81 ± 7	47
Legume	37 ± 5	—	149 ± 4	112
		Experiment 2 (1989)		
Perennial grass	2 ± 0.3	—	40 ± 2	38
Bare fallow	309 ± 15	—	292 ± 26	−17
Legume	136 ± 22	—	181 ± 22	45
		Experiment 2 (1989–90)		
Perennial grass	—	122 ± 11	179 ± 13	57
Bare fallow	—	335 ± 18	400 ± 13	65
Legume	—	217 ± 19	291 ± 41	74
		Experiment 3 (1985–86)		
Perennial grass	2 ± 1	—	40 ± 2	38
Legume	23 ± 9	—	89 ± 10	66
		Experiment 4 (1987)		
Perennial grass	0.3 ± 0.2	—	27 ± 7	27
Legume	42 ± 6	—	81 ± 3	39

[A] Measured on 15 December 1989 after 1st season fallow.

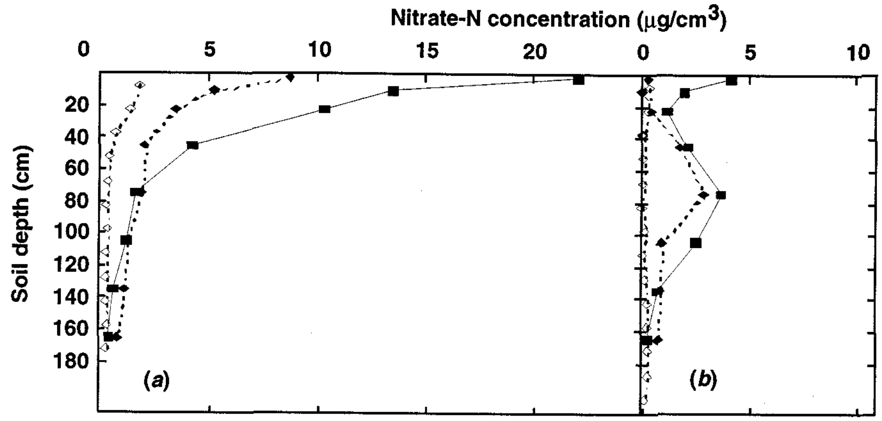

Figure 2. Distribution of nitrate-N in the soil profile under a legume pasture on (*a*) clay soil (experiment 1) and (*b*) sandy soil (experiment 3), before (2 and 3 September respectively, ◇), at (18 and 15 December respectively, ◆) and after pasture kill (8 and 9 January respectively, ■) in the 1985–86 wet season.

sampling, only 35% of the available N was above 60 cm at a time when a crop would be establishing a root system, if sown at pasture kill.

Considerably more leaching of nitrate occurred in the clay soil in the 1988–89 season. Poor growth of legume pasture and high rainfall in the period before pasture kill (Table 1) resulted in considerable mineralisation with little N uptake by the legume (Table 2). A peak of nitrate-N formed in the 30–60 cm layer under the growing pasture with only 50% of nitrate-N above 60 cm at pasture kill (data not shown). By the end of the wet season, nitrate-N in the 150–180 cm layer had increased indicating losses from the sampling zone were likely.

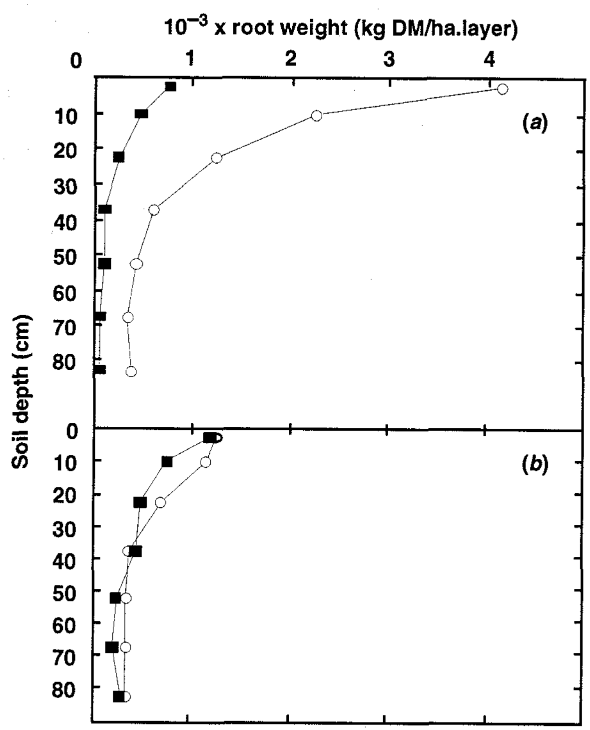

Figure 3. Distribution of root mass for the perennial grass and legume ley pastures on (*a*) clay soil (experiment 2, 6 January 1989) and (*b*) sandy soil (experiment 4, 22 December 1989). ○ Grass, 9416 and 4475 kg/ha for (*a*) and (*b*) respectively; ■ legume, 1829 and 3530 kg/ha for (*a*) and (*b*) respectively.

Root mass and N content of pasture leys

Mass and N content of the root system under the pasture leys is an important factor that will influence mineral N in a ley farming system. Figure 3 shows the distribution of root mass at pasture kill measured for treatments in experiments 2 and 4. The total mass of roots (i.e. dead plus live) under grass (9416 kg/ha) on the clay soil was 5 times that of the legume (1829 kg/ha.90 cm). However, in other studies, roots under the legume pasture on this soil have been measured as high as 6000 kg/ha . 90 cm (J. P. Dimes unpublished data). On the sandy soil, root mass for the grass (4475 kg/ha.90 cm) and legume (3530 kg/ha.90 cm) pastures were similar.

The susceptibility of roots to decompose depends largely on their C : N ratio. The average C : N ratio of the grass roots in the soil layers sampled was 59 : 1 on the clay soil and 46 : 1 on the sandy soil. For legumes, the root C : N ratio was much lower, 25 : 1 for clay soil and 23 : 1 for sandy soil. For both grass (4475 kg/ha.90 cm) and legume (3530 kg/ha.90 cm) pastures, the C : N ratio of roots was very similar to the above-ground biomass.

Results of simulation

Experiments 2 and 4. The observed and predicted amounts of total nitrate-N in the soil profile (to 1.8 m depth for the clay soil and 3.0 m depth for the sandy soil) at the end of wet seasons for experiments 2 and 4 are presented in Figure 4. The model was able to predict the

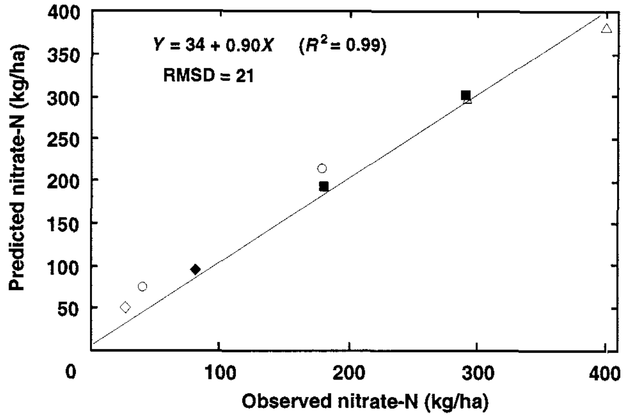

Figure 4. Observed and predicted nitrate-N (kg/ha) in soil at the end of wet seasons for treatments to 1.8 m depth in experiment 2 and 3.0 m depth in experiment 4. Legume (■), perennial grass (○) and bare fallow (△) treatments on clay soil; legume (◆) and perennial grass (◇) on sandy soil. For the clay soil, the lower value plotted for each treatment is at the end of the 1988–89 season and the higher value is at the end of the 1989–90 season.

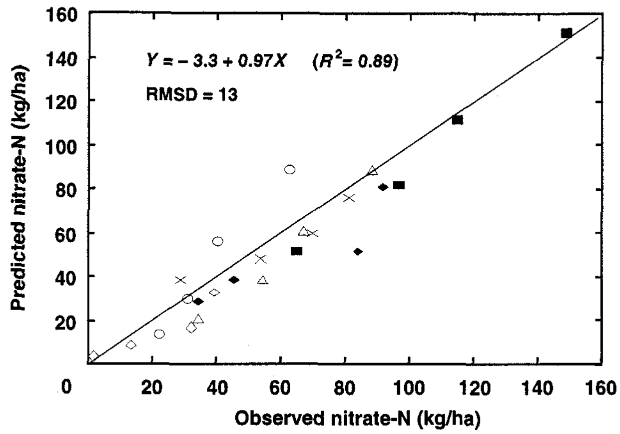

Figure 5. Observed and predicted nitrate-N in soil to 1.8 m depth for four sampling dates in the 1985–86 wet season for treatments in experiments 1 and 3. Legume (■), perennial grass (○), annual grasses (△) and sorghum (x) treatments on clay soil; legume (◆) and perennial grass (◇) on sandy soil.

nitrate-N in the profile for grass, legume or bare fallow treatments, on 2 soils, and for 1 or 2 seasons, with a root mean squared deviation (RMSD) of 21 kg N/ha. The observed amounts of nitrate-N at the end of the wet seasons varied from 23 kg N/ha in the sandy soil to 400 kg N/ha in the clay soil.

Simulation of the bare fallow treatment in experiment 2 provides an interesting example of the value of coupling experimental measurement with system simulation. The bare fallow had been fallowed the previous wet season and when sampled in January 1989, it had accumulated 309 kg N/ha. From 5 January to 12 April 1989, 551 mm of rain fell and there was a net decrease (17 kg N/ha) in nitrate-N in the profile. Having initialised the model at the 5 January concentration, the simulated nitrate-N in the profile at 12 April was 298 kg N/ha, very close to that observed (292 kg N/ha, Fig. 4). However, output from the model indicated that total nitrate losses from the 1.8 m profile was about 80 kg N/ha (72 kg N/ha leached and 8 kg N/ha denitrified) and there had been an additional 69 kg N mineralised from the soil organic matter during this period. The field measurements can only indicate the net effects of the processes that cause losses or gains of nitrate for the profile in contrast to the fuller understanding provided by the simulation.

For the perennial grass treatments on both soils, nitrate-N was being over-predicted by the model. Given the C:N ratios of the freshly killed pasture residues in this treatment (Table 1), this result suggests that immobilisation of N is not adequately described by the model.

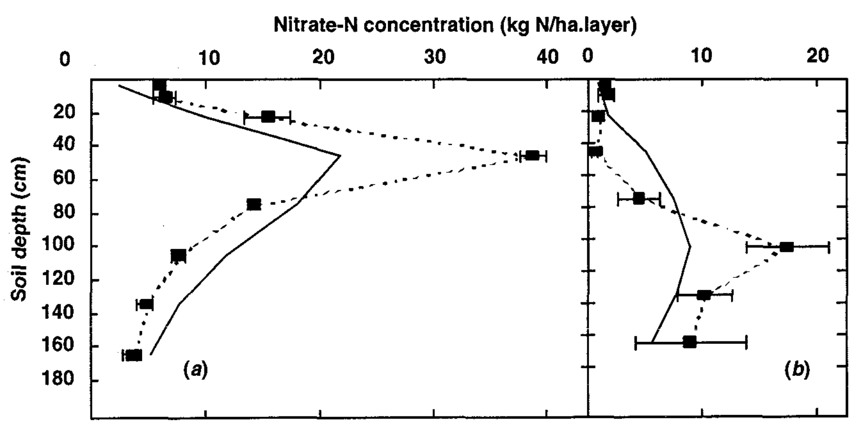

Figure 6. Observed (- - -) and predicted (——) distribution of nitrate-N for legume treatments on (*a*) clay soil and (*b*) sandy soil at the end of January 1986.

Experiments 1 and 3. Results for simulation of nitrate-N in soil profiles to 1.8 m depth for experiments 1 and 3 are presented in Figure 5. The larger number of points in this figure is because each sampling date shown in Figure 1 is represented for each treatment.

Data points in Figure 5 lie close to the 1 : 1 line showing that there is good general agreement for the pattern of N mineralisation for the treatments simulated. The fit for the perennial grass treatment is again not as good as for the other treatments simulated. The change in amounts of nitrate-N during the season for grass and legume pasture and sorghum residues for 2 soils is predicted with a RMSD of 13 kg N/ha. The observed nitrate-N in the profile ranged from 2 kg N/ha on the sandy soil to 150 kg N /ha on the clay soil.

Figure 6 shows the observed and predicted distributions of nitrate-N in soil layers for the legume treatment on the clay and sandy soils at the end of January 1986 after a period of high rainfall (Fig. 1). For both soils, the position of the predicted nitrate-N peak in the profile coincides with the observed peak, although the shape of the predicted peaks is more dispersed than the observed.

Discussion

The field experiments reported here indicate how various grass and legume leys can influence the amount of early formed nitrate that leaches below the root zone. They have also provided some measure as to how much N would be mineralised in a cropping season following chemical kill of preseason vegetation. Variability in seasonal rainfall caused differences in the performance of the ley system for conserving and supplying N in a cropping season. A simulation capability was developed to quantify these seasonal effects so that the consequences, both biological and economic, could be considered when comparing alternative management strategies for supplying N to crops in this environment.

The degree to which residue amount and C : N ratio (for both above- and below-ground materials), soil type and seasonal factors influence mineralisation of nitrate-N during a wet season is evident from the data presented here. The model closely simulated the effects of these factors on N mineralisation (see Figs 4 and 5). Simulation of nitrate movement in the profile was quite good on the clay soil. However, simulation of leaching on the rapidly draining sand presents a more difficult challenge for the storage overflow water balance model in CERES, and a flow-based model (e.g. SWIM, Ross 1990) may be required for better simulations.

In general, it may be concluded that the simulation capability reported here is adequate for dealing with the complex interaction of nitrate mineralisation, nitrate movement and variable rainfall patterns and therefore provides a valuable tool for assessing the longer-term potential of a no-tillage, legume ley farming system for this environment. In its current form, it has immediate application for assessing a range of management issues in a ley farming system. For example, the timing of pasture kill and the implications of decomposition rate of surface material for maintaining an adequate level of mulch to sow and establish a crop (Abrecht and Bristow 1990; Abrecht *et al.* 1996) or the role of N fertilisers in supplementing N from pasture leys. It also has application for assessing the potential for nitrate leaching during the cropping phase thereby providing some insights into the possible consequences for acidification for higher N input systems in this environment.

An obvious omission from the current work is the effects of a growing crop on the soil water and N dynamics. Experimental results reported here have also indicated how nitrate distribution following the legume ley is influenced by the performance of the pasture ley, especially in the re-generation phase just before the cropping season. Hence, while the capability for simulating N supply in the soil following pasture kill is an essential part of the system for simulation, it only represents part of the story. Work is underway elsewhere to develop a full system model of both the ley pasture phase and the crop phase which incorporates the simulation capability reported here (McCown *et al.* 1996). The capability of the system model to simulate the N dynamics of both the pasture and cropping phase is demonstrated by Jones *et al.* (1996) and the application of this system model for assessing the economic performance of different management strategies for a ley farming system is presented by Carberry *et al.* (1996).

Acknowledgments

This work was funded by the Australian Centre for International Agricultural Research. The authors thank Brett Martell and Vicki Fraser for their aptitude and diligent efforts in completing the field and laboratory work referred to in this paper.

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Received 14 September 1995, accepted 19 November 1996