Department of Science, Information Technology, Innovation and the Arts

Managing the Nitrogen Cycle: Legumes

Final Report: Reef Water Quality Science Program Project 58C

Soil Processes, Science Division

June 2014

Great state. Great opportunity.

Queensland Government

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Key Results and Implications

- In 4 months of growth under conditions of minimal nitrogen (N) loss, actual crop recovery of applied N was ≈ 60% N for band-applied urea, ≈15% for surface-applied legume residues and ≈20% for incorporated legume residues in two soils of differing texture (loam and clay). Using the urea-N recovery (60%) as a benchmark, it was inferred that a further 45% (surface-applied) and 40% (incorporated) of the N applied in soybean residues may be recovered by the crop in the first growing season. This assumption needs to be verified with further work.
- The added N that is unaccounted for by crop uptake (viz., 40% of N added as urea) is likely added to the soil organic N pool and cannot be discriminated from that pool. Therefore the rate of mineralisation of this residual urea-N will be the same as that of the soil organic N pool. As indicated in dot-point 1, whether a part, or all, of the legume N that is unaccounted for (viz., 80%-85%) has become part of this pool remains to be clarified.
- The recovery of N from incorporated soybean residues was ≈5% higher than where residues were surface applied, but these differences were not significant at P=0.05. Retention of residues on the soil surface is beneficial from the viewpoint of erosion control and reduced tillage requirements, and this management practice is therefore preferable to incorporation**.**
- Losses of nitrate-N of legume origin occurs by both leaching and denitrification pathways and the relative importance will depend on soil type, position in the landscape and rainfall distribution. Under conditions that are conducive to denitrification, N losses are likely to be higher from surface-retained legume residues than incorporated residues.
- The period most likely for losses of nitrate-N of legume origin to occur is the first 60 days after application when the initial flush of mineralisation occurs.
- Management strategies most likely to limit the rate of production, and therefore risk of loss, of nitrate-N of legume origin is to plant the legume fallow crop into a trash blanket, spray out the legume close to planting of the cane crop, and direct planting of cane into standing stubble.
- To validly estimate crop N recovery, a measure is required of the contribution of soil organic N mineralisation to crop N uptake. This can only be achieved by including a nil applied N treatment in any field trial work. This treatment also has the benefit of providing data on the amount of soil mineralised over the growing season; this information will be required to develop a predictive tool for soil mineralisation potential as discussed in Section 9- Further Work.

Contents

1 Background

One of the three pillars that underpin the improved sugarcane farming system is the inclusion of a legume crop in a break-year between sugarcane crop cycles (each consisting of a plant cane and several ratoons). The legume crop can either be grown as a 'fallow' or as a crop harvested for 'grain'. Depending on the growth of the fallow crop (poor to excellent) and whether it is harvested for grain, the nitrogen (N) contribution from the fallow crop can range from being as low as 20 or 30 kg N/ha, to as much as 360 kg N/ha. In order for this N to be available for uptake by subsequent sugarcane crops, the legume residue needs to be broken down and the N transformed from organic into mineral forms (ammonium-N and nitrate-N) through the processes of mineralisation and nitrification. Although much of this mineralised N can be taken up by the sugarcane crop (thereby reducing the amount of inorganic fertiliser N needed), if it is not released in synchrony with crop demand, surplus nitrate-N may become of environmental concern. Nitrate-N is mobile in the environment; it can potentially be leached into ground water, lost as run-off, or be denitrified (contributing to greenhouse gas emissions from canelands). Furthermore, there is great uncertainty about the contribution of nitrogen from legume fallow crops to the ratoon crops following the plant crop.

The objectives of this project were to: assess the likely contribution of legume fallow crop nitrogen to the subsequent sugarcane crop nitrogen requirements under different soil/climate/cropping system conditions; develop advice for adjusting the N requirement for plant cane grown in rotation with legume; and develop an algorithm for the web decision support tool *SafeGauge for Nutrients* so growers can assess the likely availability of legume nitrogen to the plant cane. This assessment will take account of likely N mineralisation from legume residues and the risk of N losses occurring during the period between fallow crop spray out and plant cane N uptake.

2 Pot Trials

Two pot trials were undertaken to characterise the bioavailability of nitrogen from legume tops and roots under conditions conducive to N loss by leaching or denitrification.

2.1 Pot Trial 1

2.1.1 Soil

Kurosol (Kepnock Series) (0-20 cm) loamy yellow podzolic soil from Bundaberg

2.1.2 Soybean residues

^{15}N labelled soybean tops and roots were grown in sand culture at ESP with complete basal nutrient supply. Plant tops were harvested at full flowering by cutting at ground level, and roots were recovered from the sand. Tops and roots were dried at 40°C, and cut into pieces about 1 cm long (roots/stems) or 1 cm^2 (leaves).

2.1.3 Treatments

There were 12 treatments (4 N sources x 3 watering regimes) with 5 reps per treatment.

N Treatments:

- *Nil N*- control
- *Soy surface*- labelled soybean tops on surface, labelled roots incorporated
- *Soy incorporated*- labelled soybean tops incorporated, labelled roots incorporated
- *Urea*- Urea subsurface strip at N rate equivalent to added soybean total N

The equivalent of 718 mg total N/pot was applied to the soybean and urea treatments. This equates to approximately 180 kg N/ha. For the soybean treatments, the tops provided 563 mg N/pot and the roots 155 mg N/pot.

Watering Regimes:

- *Field Capacity*- Maintained at field capacity with any leachate returned to soil surface (20 pots).
- *Waterlogged*- Maintained at field capacity for first 35 days (5 weeks) then water equivalent to 20 mm rainfall event added to non-draining (20) pots. Soils were allowed to dry back to field capacity and then maintained at this water content. Water equivalent to 20 mm rainfall event added again after 70 days (10 weeks). Soils were allowed to dry back to field capacity and then maintained at this water content.
- *Leached*- Maintained at field capacity for first 35 days (5 weeks) then water equivalent to 20 mm rainfall event added to draining (20) pots. Leachate collected, volume measured, then frozen and analysed. Soils were allowed to dry to field capacity and then maintained at this water content. Water equivalent to 20 mm rainfall event added again after 70 days (10 weeks). Soils were allowed to dry back to field capacity and then maintained at this water content.

Pots were randomly positioned in the shadehouse. Total no. of pots: 60 (20 non-draining, 40 draining); 7 kg soil/pot.

2.1.4 Procedure

Three germinated 1-eyed setts of Q200 were planted in each pot on 11 April 2012. Plants were harvested on 27 August 2012 (138 days). Plants were weighed, dried at 60^0C for 48h, re-weighed, ground and analysed for total N.

2.1.5 Analytical methods

Soil analyses followed the methods specified in Rayment and Lyons (2011): pH (1:5 water), Method 4A1; EC (1:5), Method 3A1; chloride (1:5), Method 5A2a; total organic carbon, Method 6B2b; Colwell-P, Method 9B2; BSES-P, Method 9G20; exchangeable K, Method 15A1; KCl extractable ammonium-N and nitrate-N, Method 7C2b; and PBI_{Col}, Method 9I2b. Clay content was determined according to Thorburn and Shaw (1987) and HCl-P according to Guppy et al. (2000).

Total N and P were determined on plant tops and root material using micro Kjeldahl digest by block digestion. Nitrogen was determined by a modification of the method of Searle (1974) and P by a modification of the method of Murphy and Riley (1962) using an automated colorimetric procedure on a segmented flow analyser.

2.2 Pot Trial 2

2.2.1 Soil

Ferrosol (Woongarra Series) (0-20 cm) red volcanic clay loam from Bundaberg

2.2.2 Soybean residues

Soybean tops (3.4% N) and roots (1.5% N) were collected from a field experiment in Bundaberg, dried at 40^{o}C, and cut into pieces about 1 cm long (roots/stems) or 1 cm^2 (leaves).

2.2.3 Treatments

There were 8 treatments (4 N sources x 2 watering regimes) with 5 reps per treatment.

N Treatments:

- *Nil N*- control
- *Soy surface*- soybean tops on surface, roots incorporated
- *Soy incorporated*- soybean tops incorporated, roots incorporated
- *Urea*- Urea subsurface strip at N rate equivalent to added soybean total N

The equivalent of 609 mg total N/pot was applied in the soybean and urea treatments. This equates to approximately 150 kg N/ha, and for the soybean treatments, the equivalent of 3.4 tonnes dry matter/ha.

Watering Regimes:

- *Field Capacity*- Maintained at field capacity with any leachate returned to soil surface (20 pots).
- *Leached*- Maintained at field capacity for first 35 days (5 weeks) then water equivalent to 20 mm rainfall event added to draining (20) pots. Leachate collected, volume measured, then frozen and analysed. Soils were allowed to dry to field capacity and then maintained at this water content. Water equivalent to 20 mm rainfall event added again after 70 days (10 weeks). Soils were allowed to dry back to field capacity and then maintained at this water content.

Pots were randomly positioned in the shadehouse. Total no. of pots: 40; 7 kg soil/pot.

2.2.4 Procedure

Three germinated 1-eyed setts of Q200 were planted in each pot on 4 October 2012. Plants were harvested on 17 December 2012 (74 days) by cutting at ground level. Plants were weighed, dried at 60^{0}C for 48h, re-weighed, ground and analysed for total N.

2.2.5 Analytical methods

See Section 2.1.5 above.

3 Incubation Experiments

The objectives of the incubation experiments were to: (i) Determine the effects of soybean tops and soybean tops plus cane trash on soil mineral N (Incubation Experiment 1) and (ii) Compare the rate of mineralisation of N from soybean tops and roots (Incubation Experiment 2).

3.1 Incubation Experiment 1

3.1.1 Treatments

Amendments: Soybean residues and soybean residues + cane trash were incorporated into two soils at rates equivalent to 10 tonnes total C /ha.

Soils: Surface samples (0-20 cm) of two soils from the Mackay region (a loamy sand and a clay) were used as the test soils.

Watering regime: Field capacity

Destructive soil sampling times: 2 weeks, 4 weeks, 12 weeks

Replicates: 3

3.1.2 Timeline

The incubation experiment commenced on 31 July 2012 and concluded on 23 October 2012 (84 days).

3.1.3 Procedure

Amendments were thoroughly mixed through bulk soil samples at the appropriate rates and amended soil then packed to a bulk density of 1.3g/cm^3 in plastic tubes capped at one end. The tubes were 8.6cm in diameter and 10cm long. Deionised water was added to the tubes to bring the soil to field capacity by weight. Tubes were then loosely capped and incubated at 25^{o}C in an incubator. Tubes were removed every second day and watered to weight.

Soil solution samples (not reported) were taken under vacuum through micro-fibres at 7, 17, 24, 31, 59 and 84 days after set-up. Immediately following soil solution extraction at 17, 31 and 84 days, 3 tubes per treatment were destructively sampled, the soil was mixed, sub-sampled, and extracted for ammonium-N and nitrate-N using 2*M* KCl.

3.1.4 Analytical methods

Soil analyses followed the methods specified in Rayment and Lyons (2011): pH (1:5 water), Method 4A1; 2M KCl extractable mineral N (ammonium-N, nitrate-N), Method 7C2b.

3.2 Incubation Experiment 2

3.2.1 Treatments

Amendments: Soybean roots, soybean tops, and urea were incorporated into one soil at rates equivalent to 100 kg N/ha (weight basis: 100 mg N/kg soil)

Soil: Surface soil (0-20 cm) of a clay loam (Red Ferrosol: Woongarra Series) was used as the test soil.

Watering regime: All incubation jars were maintained at field capacity by daily weighing.

Destructive soil sampling times: 1 week, 2 weeks, 4 weeks, 8 weeks

Replicates: 4

3.2.2 Timeline

The incubation experiment commenced on 8 November 2012 and concluded on 6 January 2013 (59 days).

3.2.3 Procedure

Amendments were thoroughly mixed through bulk soil samples at the appropriate rates and amended soil then packed to a bulk density of 1.3g/cm^3 in plastic tubes capped at one end. The tubes were 8.6cm in diameter and 10cm long. Deionised water was added to the tubes to bring the soil to field capacity by weight. Tubes were then loosely capped and incubated at 25^{o}C in an incubator. Tubes were removed every second day and watered to weight.

Four tubes per treatment were destructively sampled on Day 7 (15/11/2012), Day 14 (22/11/2012), Day 28 (06/12/2012) and Day 59 (06/01/2013) after set-up, the soil was mixed, sub-sampled, and extracted for ammonium-N and nitrate-N using 2*M* KCl.

3.2.4 Analytical methods

Soil analyses followed the methods specified in Rayment and Lyons (2011) except mineral N (ammonium-N, nitrate-N) and dissolved organic C (DOC) were extracted with 0.5 M K_2SO_4 at a soil:solution ratio of 1:5, and ammonium-N and nitrate-N determined using Method 7C2b and DOC using Method 6B1.

4 Results: Pot Trials

4.1 Pot Trial 1

4.1.1 Soil

The soil (0-20cm) had the following properties: pH (1:5 water), 5.9; EC, 0.04dS/m; total organic C, 0.7%; Colwell-P, 33mg/kg; BSES-P, 40mg/kg; PBI$_{Col}$, 25; and exchangeable K, 0.06cmol$_c$/kg.

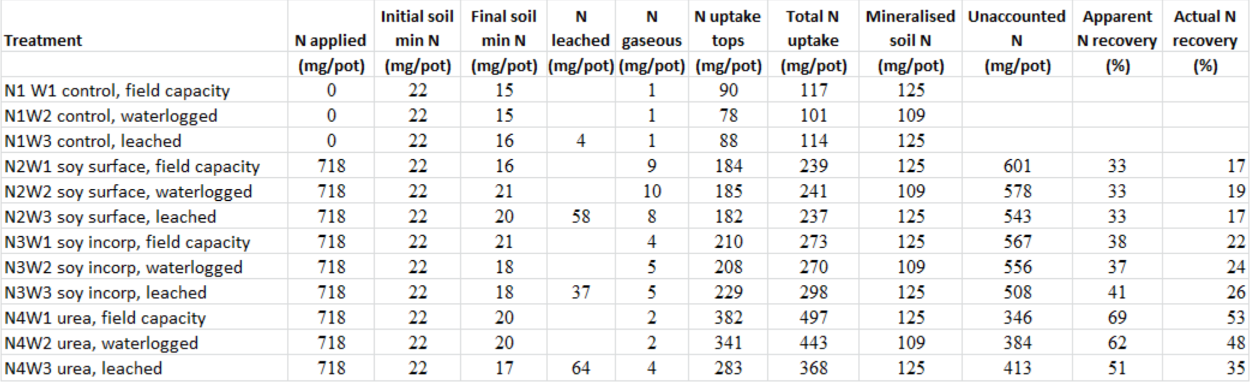
4.1.2 Soybean residues

The total N contents of the soybean residues were: leaf- 2.7%; stem- 1.12%; roots- 2.5%.

4.1.3 N budget

The N budget was calculated for each treatment (Table 1). Nitrogen uptake by the plants in the control (nil applied N) treatment was used as an estimate of N sourced from soil organic N mineralisation. Total N supplied from this source was calculated by assuming that the quantity of N in the below-ground component of the cane plants was 30% of that in the tops (Sparkes, unpublished data). Nitrogen lost by leaching ranged from 18% of the small amount of mineral N in the control to 9% (urea), 8% (soybean surface applied) and 5% (soybean incorporated), respectively, of the N applied. Nitrogen lost by denitrification was very low and did not exceed 4% of applied N in any treatment.

Table 1. Percentages of applied N recovered in crop tops in 138 days, and percentages lost by leaching or denitrification.



Treatment	N applied (mg/pot)	Initial soil min N (mg/pot)	Final soil min N (mg/pot)	N leached (mg/pot)	N gaseous (mg/pot)	N uptake tops (mg/pot)	Total N uptake (mg/pot)	Mineralised soil N (mg/pot)	Unaccounted N (mg/pot)	Apparent N recovery (%)	Actual N recovery (%)
N1 W1 control, field capacity	0	22	15		1	90	117	125			
N1W2 control, waterlogged	0	22	15		1	78	101	109			
N1W3 control, leached	0	22	16	4	1	88	114	125			
N2W1 soy surface, field capacity	718	22	16		9	184	239	125	601	33	17
N2W2 soy surface, waterlogged	718	22	21		10	185	241	109	578	33	19
N2W3 soy surface, leached	718	22	20	58	8	182	237	125	543	33	17
N3W1 soy incorp, field capacity	718	22	21		4	210	273	125	567	38	22
N3W2 soy incorp, waterlogged	718	22	18		5	208	270	109	556	37	24
N3W3 soy incorp, leached	718	22	18	37	5	229	298	125	508	41	26
N4W1 urea, field capacity	718	22	20		2	382	497	125	346	69	53
N4W2 urea, waterlogged	718	22	20		2	341	443	109	384	62	48
N4W3 urea, leached	718	22	17	64	4	283	368	125	413	51	35

4.1.4 N recovery

Nitrogen recovery from applied sources was calculated as apparent recovery (N in crop/applied N) and actual recovery (N in fertilised crop minus N in control crop)/applied N). The former measure is generally used for field data where no estimate of crop N uptake from an unfertilised treatment is available. Apparent recovery of urea-N was about 70% under conditions where N loss was minimal, and was considerably lower (51%) in the leached treatment due to the large loss of N recorded for this pathway. Apparent recoveries of soybean-N under minimal loss conditions were 33% (surface applied) and 38% (incorporated), respectively.

Actual N recoveries are lower than apparent recoveries because account is taken of the crop N uptake from mineralised soil N. Using this measure, only about 50% of the urea-N and 20% of the soybean-N was recovered in the 138 days of the experiment. If the N recovery from urea is considered to be the maximum obtainable by the crop receiving the fertiliser (i.e., 50%), then it can be inferred that about another 30% of the N in soybean residues will be released over a longer timeframe. The 50% of urea N that is not accounted for by current crop uptake is considered to have become part of the soil organic N pool through microbial assimilation and its availability will depend on the rate of N mineralisation from this pool.

4.1.5 Trends in mineral N (ammonium-N and nitrate-N) over time

Figure 1 shows the effect of time on mineral-N. There was little ammonium-N in the control while the very high initial level in the urea treatment declined rapidly and was similar to the control concentration by 50 days after application. The incorporated soybean tops resulted in an ammonium-N spike at about 20 days while the spike for the surface applied residues occurred at about 35 days. Nitrate-N in soybean residue treatments was initially much lower than for the urea or control treatments but rapidly increased at about 10 days and then slowly declined in all treatments to very low levels by 80 days (Fig. 1).

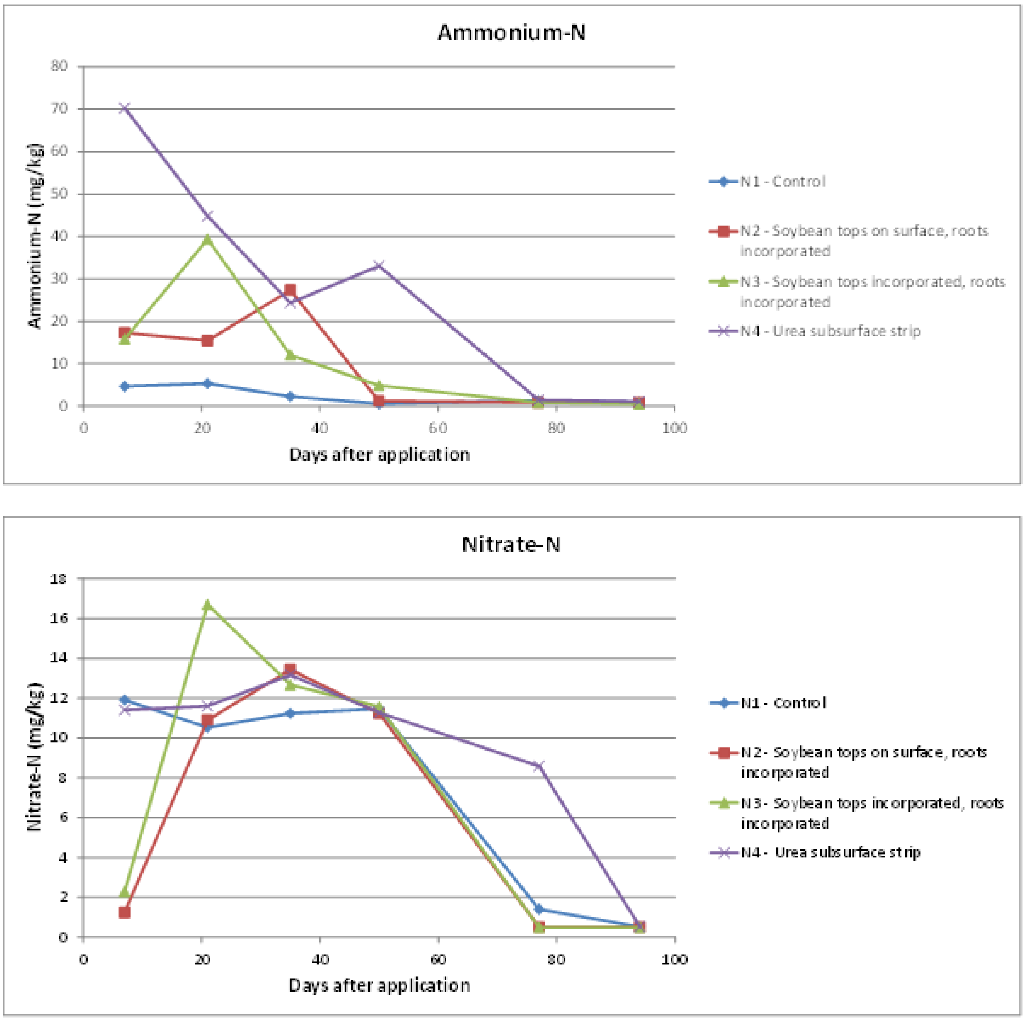


Figure 1. Changes in soil mineral N over time in soybean- and urea-amended soil.

4.1.6 Trends in nitrous oxide emissions over time

There was a flush of nitrous oxide emissions (indicative of nitrification and/or denitrification) from both incorporated and surface applied soybean residues in the 30 days prior to the imposition of different watering regimes, and emissions were higher in the case of surface application (Fig.2). Following the first watering event, losses tended to be highest for the waterlogged treatment and lowest for the leaching treatment, but these differences were not significant at P=0.05. For incorporated residues differences between watering regimes were much smaller (and not significant at P=0.05). The second watering event had no effect on cumulative nitrous oxide emissions from either surface applied or incorporated residues (Fig. 2).

Nitrous oxide emissions from sub-surface urea application were similar for the first 10 days but then diverged (although not significant at P=0.05) from 10 to 30 days even though differential watering regimes had not been applied (Fig. 2). Following the first watering event, emissions increased and the relativity already established between treatments was maintained with the leaching treatment emitting more nitrous oxide than either the waterlogged or field capacity treatments, although this difference was not significant at P=0.05 because of the large variability between reps of this treatment. Compared to the amount of N applied as soybean residue or urea, nitrous oxide emissions were minor (<1%).

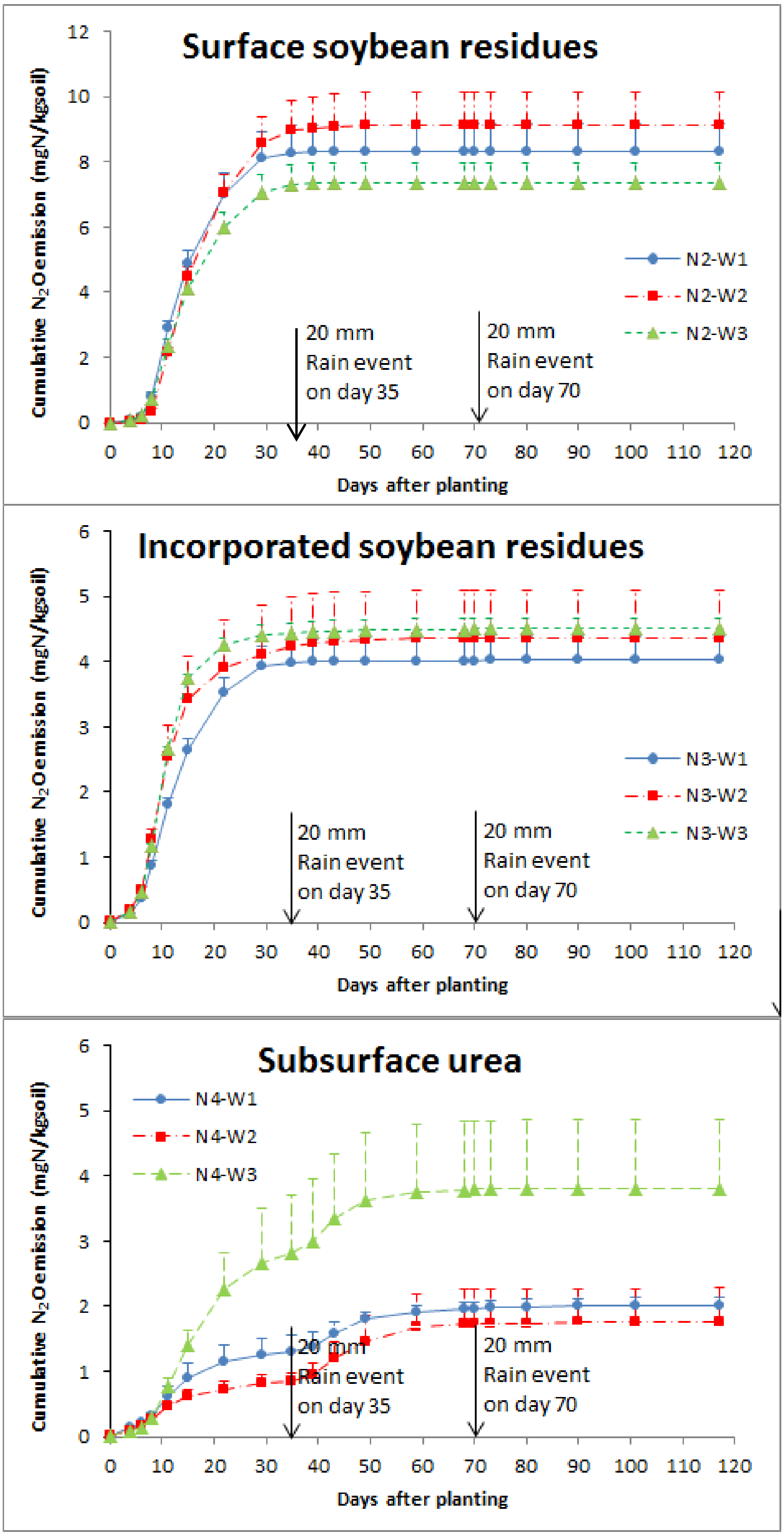


Figure 2. Trends in nitrous oxide emissions over time. Bars are the mean standard errors.

4.1.7 Trends in leaching losses over time

Nitrate-N and ammonium-N concentrations in leachate from the two events on 16 May 2012 and 26 June 2012 are presented in Fig. 3. The leachate concentrations were very variable in all treatments. Only in the first event were there high concentrations, and nitrate-N, being anionic, always greatly exceeded ammonium-N concentrations. When compared to the amount of N applied as soybean residue or urea, leaching losses were <9%.

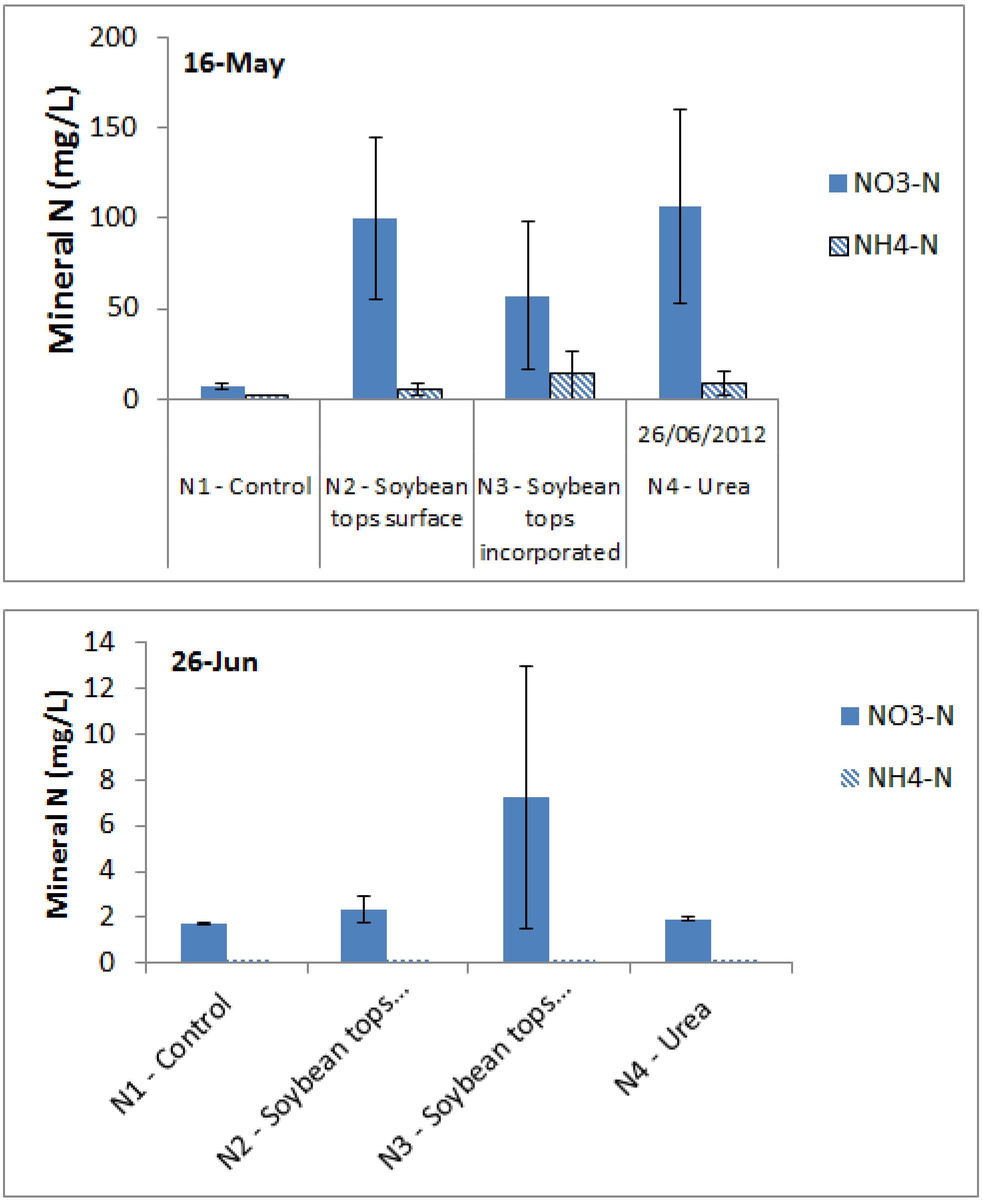


Figure 3. Mineral N concentrations in leachate on two occasions. Bars are the mean standard errors.

4.2 Pot Trial 2

4.2.1 Soil

The soil (0-20cm) had the following properties: pH (1:5 water), 5.6; EC, 0.03dS/m; Walkley Black organic C, 1.1%; Colwell-P, 66 mg/kg; BSES-P, 48mg/kg; PBI$_{Co}$l, 490; and exchangeable K, 0.24cmol$_c$/kg; clay content, 59%.

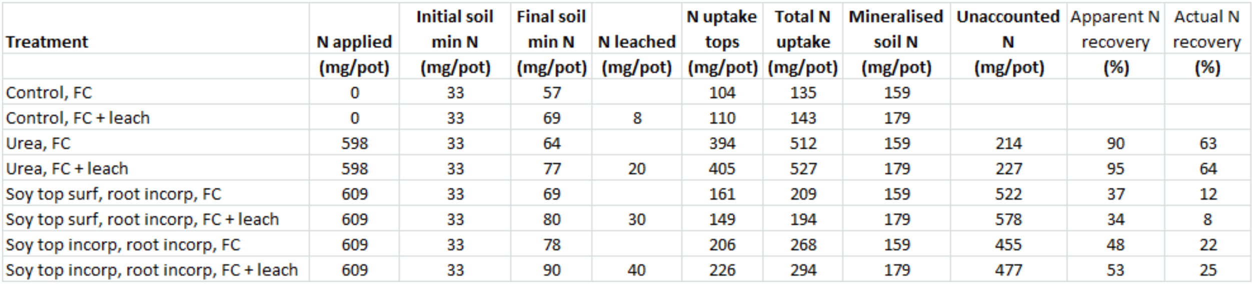
4.2.2 Soybean residues

Total N concentrations in the soybean tops and roots were 3.4% and 1.5%, respectively.

4.2.3 N budget

The N budget was calculated for each treatment (Table 2) using the same methods as described in Section 3.1.4. Nitrogen lost by leaching ranged from 24% of the small amount of mineral N in the control to 3% and ≈5% of the N applied as urea and soybean residues, respectively.

Table 2. Percentages of applied N recovered in crop tops in 74 days, and percentages lost by leaching or denitrification.



Treatment	N applied (mg/pot)	Initial soil min N (mg/pot)	Final soil min N (mg/pot)	N leached (mg/pot)	N uptake tops (mg/pot)	Total N uptake (mg/pot)	Mineralised soil N (mg/pot)	Unaccounted N (mg/pot)	Apparent N recovery (%)	Actual N recovery (%)
Control, FC	0	33	57		104	135	159			
Control, FC + leach	0	33	69	8	110	143	179			
Urea, FC	598	33	64		394	512	159	214	90	63
Urea, FC + leach	598	33	77	20	405	527	179	227	95	64
Soy top surf, root incorp, FC	609	33	69		161	209	159	522	37	12
Soy top surf, root incorp, FC + leach	609	33	80	30	149	194	179	578	34	8
Soy top incorp, root incorp, FC	609	33	78		206	268	159	455	48	22
Soy top incorp, root incorp, FC + leach	609	33	90	40	226	294	179	477	53	25

4.2.4 N recovery

As for Pot Trial 1, nitrogen recovery was calculated as apparent N recovery (N in crop/applied N) and actual N recovery (N in fertilised crop minus N in control crop)/applied N). Apparent N recovery for urea was about 90%. Apparent N recoveries for the soybean treatments under minimal loss conditions were 37% (surface applied) and 48% (incorporated), respectively.

As expected, actual N recoveries were lower than apparent recoveries. Actual N recovery was 63% of the urea N, while 25-38% of the soybean N was recovered in the short term (Table 2). If the N recovery from urea is considered to be the maximum obtainable by the fertilised crop, then it can be inferred that about 40% of the N in soybean residues will be released later in the plant cane season. The 40% of urea-N that is not accounted for by uptake by the fertilised crop is considered to have become part of the soil organic N pool.

5 Results: Incubation Experiments

5.1 Dynamics of N mineralisation

5.1.1 Incubation 1

Mineralisation of soybean residues caused a flush of ammonium-N production in the first 14 days of incubation and this ammonium-N was quickly nitrified in the same time period in both soils (Fig. 4). By 28 days, both nitrate-N and ammonium-N had dropped to much lower concentrations suggesting initial mineralisation in the first 14 days was followed by some immobilisation in the period 14-28 days. Nitrate concentrations then rose during the period 28-84 days as net mineralisation predominated.

The soybean plus cane trash treatment showed a similar trend of net initial mineralisation followed by partial immobilisation and then net mineralisation, but the concentrations of nitrate produced in both soils were always much lower in this treatment than the soybean only treatment. The wide C/N ratio of cane trash (??) compared to that of the soybean residues (??) would result in some immobilisation of N mineralised from the soybean residues, resulting in the lower observed nitrate-N concentrations.

Except for the control treatment, dissolved organic C concentrations were high and stable (though variable) through time for all treatments (Fig. 4). This suggests high levels of microbial activity and a carbon-nitrogen limited microbial community in the control soil.

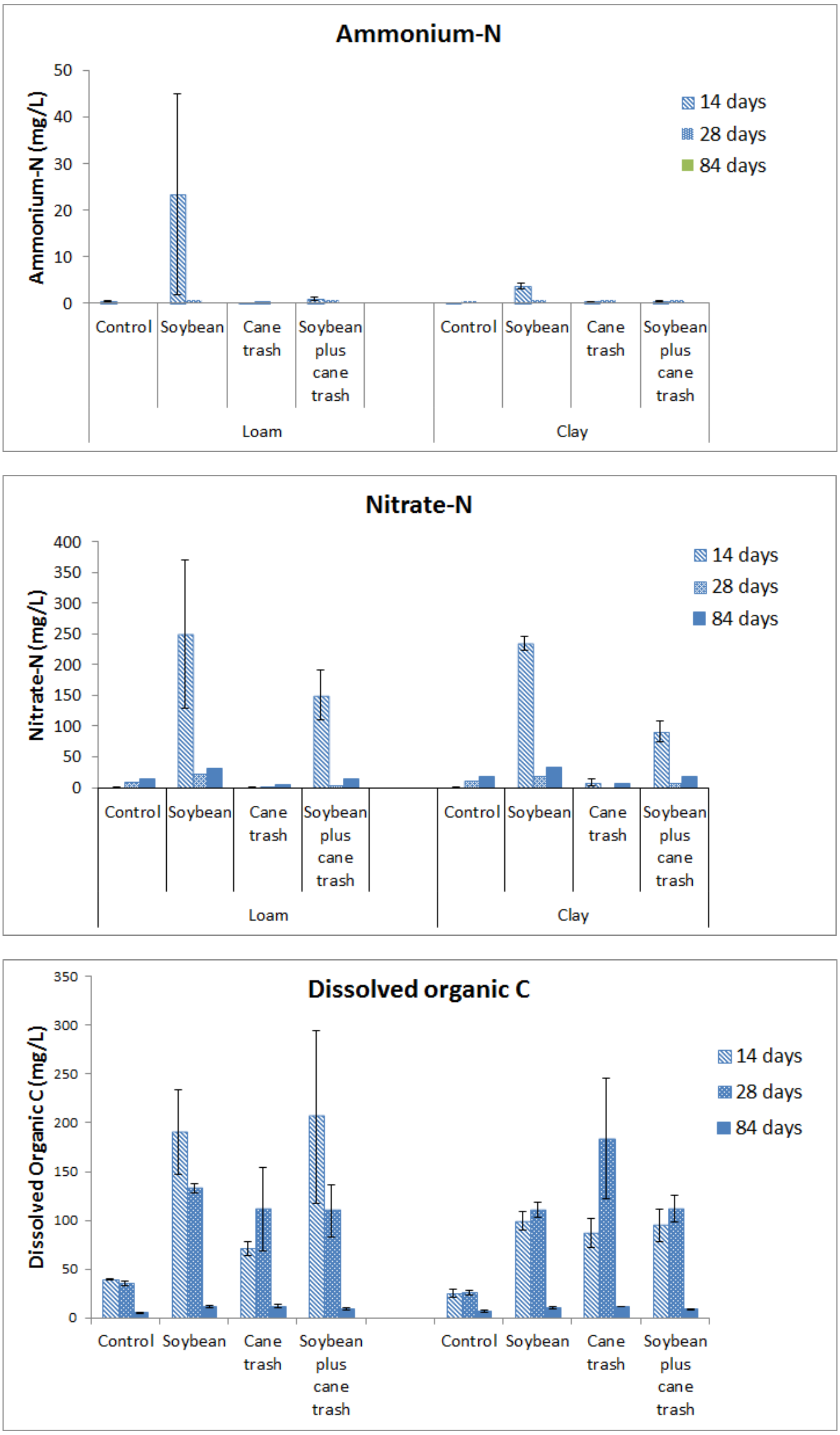


Figure 4. Trends in mineral N and dissolved organic C over time.

5.1.2 Incubation 2

The second incubation experiment showed a similar rapid decline in ammonium-N and a concomitant increase in nitrate-N as was observed in Incubation 1 (Fig. 5). However, there was no evidence of the decline in nitrate-N that was observed in Incubation 1 between 14 and 28 days, followed by a subsequent increase; nitrate-N concentration in Incubation 2 increased continually, but began to plateau after 30 days.

There was no significant difference (P=0.05) between nitrate-N production from soybean tops and roots although roots tended to produce slightly more nitrate than the tops. This was expected because the roots had a slightly lower C/N ratio than the tops (12 cf. 13).

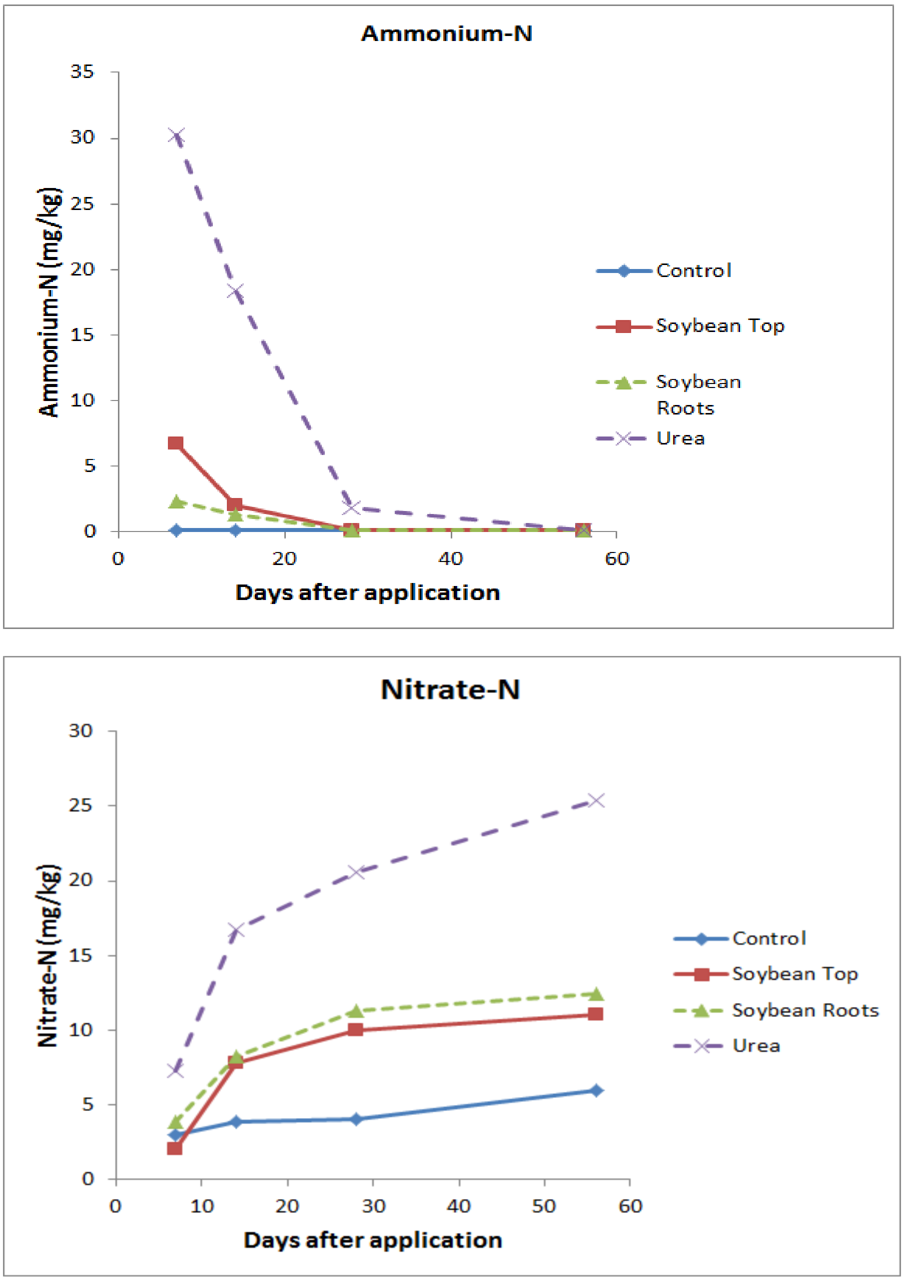


Figure 5. Trend of mineral N over time in Incubation 2.

6 Discussion: Pot Trials

6.1 Crop N uptake from soybean residues compared to urea

Soil N mineralisation was higher in the Ferrosol (basaltic clay loam soil) in the second pot trial than in the Kurosol (yellow podzolic soil) of the first pot trial (Table 3). Although Pot Trial 2 was of shorter duration than Pot Trial 1 (74 d compared to 138 d), shadehouse temperature and radiation were higher and dry matter yields for the urea treatments maintained at field capacity were similar (Trial 1: 61.6 g/pot; Trial 2: 72.7 g/pot) as were the N uptakes (Trial 1: 497 mg N/pot; Trial 2: 512 mg N/pot).

In both experiments, crop N uptake from urea was higher than that from the soybean residues, and N uptake from surface-applied soybean residues was always lower than from incorporated residues (Table 3).

Table 3. Summary of soil N mineralisation and crop N uptake from two pot trials using different soil types.

Treatment	Trial	N added (mg N/pot)	Soil N mineralisation (mg/pot)	Crop N uptake (mg/pot)
Urea	1	720	125	497
	2	600	159	512
Soy surface	1	720	125	239
	2	600	159	209
Soy incorporation	1	720	125	273
	2	600	159	268

6.2 Crop N recovery from soybean residues compared to urea

Apparent N recovery from urea was higher in Trial 1 than in Trial 2, despite very similar crop N uptakes. However this is an artefact caused by the higher contribution of soil mineral N to crop N uptake in Trial 2 than in Trial 1, and coupled with the lower N application rate in Trial 2. Actual N recoveries are lower than apparent recoveries for both trials (as would be expected) and there is less divergence between the two trials.

Similar trends are obtained when comparing apparent and actual N recoveries from soybean residues, with apparent recoveries being higher and more divergent between trials than actual recoveries. It is apparent that actual N recoveries are a more realistic and reliable assessment of N availability from different sources than apparent N recoveries; the latter are strongly influenced by the mineralisation of soil N which varies between soils and across experimental conditions.

Averaged across both trials, actual N recoveries of urea, surface-applied soybean residues and incorporated residues are approximately 60%, 15% and 20%, respectively (Table 4). The lower recovery from surface-applied residues is probably a combination of higher gaseous losses (see Fig. 2) and lower rates of mineralisation as a consequence of less contact between residue and the soil microbial population.

The unaccounted 40% of the urea-N is assumed to have been incorporated into the soil microbial biomass and, as such, has become part of the soil organic N pool with an intrinsically low rate of mineralisation. If the recovery of 60% urea-N is used as the benchmark of N availability to the crop receiving N from a readily available N source, then it can be inferred that an additional 45% (surface-applied) and 40% (incorporated) of soybean-N may become available to the current crop.

Table 4. Summary of apparent and actual N recoveries by sugarcane from two pot trials using different soil types.

Treatment	Trial	Apparent N recovery (%)	Actual N recovery (%)
Urea	1	90	63
	2	69	53
Soy surface	1	37	12
	2	33	17
Soy incorporation	1	48	22
	2	38	22

6.3 Effect of soybean residue placement on N availability

The cane crop recovered less N from surface-applied soybean residues than incorporated residues (Table 4). However, surface application simulates legume fallow crop spray-out and zero-till planting of cane into standing stubble which is beneficial from the viewpoints of erosion control and reduced tillage. Hence, although slightly less efficient in terms of recovering legume N, this management practice is preferable to incorporation.

7 Discussion: Incubation Experiments

In the cane farming system, best management practice for handling soybean fallow crops is to spray out the legume, leave residues standing and direct-plant the cane crop into standing stubble. As the cane crop develops, high C/N ratio leaf trash will accumulate and it is likely that this will interact with any remnant soybean residue and cause temporary N immobilisation as demonstrated in Fig. 4. However, the rapid mineralisation that occurs with soybean-only residues (Fig. 4) indicates that N will be released quickly from this source.

The Six Easy Steps (and regulated method) currently use the legume above-ground biomass to calculate N discounts from this source when deriving fertiliser N requirements. It is apparent that after the initial rapid mineralisation (0-30 days: Fig. 5), the rate of nitrate production from legume roots and tops is very similar to the rate of nitrate production from the unamended soil (Fig. 5). This raises the question of whether the long term recovery of N from the legume material equals the recovery of N from urea, which is demonstrated in the pot experiments to be 60% (Section 4.2).

8 Decision Support

The results from the pot trials and incubation experiments can be synthesised to: (i) provide guidance on the management of legume fallow crop residues, and (ii) provide estimates of the contribution of legume-sourced N to cane N requirements.

8.1 Management of legume fallow crops

Results from this project indicate that incorporated legume residues mineralise more quickly and produce lower nitrous oxide gas emissions than surface applied residues. However, the overall amounts of mineral-N produced are not significantly different (P=0.05) and the slower rate of mineralisation of surface retained residues has the advantage of releasing N in better synchrony with the ability of the crop to take up N as the root system develops. Surface retention of legume residues also has the benefit of reducing erosion risk because surface cover is maintained.

8.2 Estimating the N contribution of legume fallow crops

The Six Easy Steps program currently uses the fallow crop dry biomass and an assumed %N to calculate the likely N contribution from a legume fallow crop to the following cane crop [kg N/ha = fallow crop biomass (t/ha) x % N plus 30% allowance for below-ground N] (Garside and Bell, 2001; Schroeder et al., 2005). If grain is harvested from the fallow legume crop, then the N contribution is assumed to be 1/3 of the legume fallow crop biomass contribution. The comment is made in Schroeder et al. (2007) that ‘Data from the Yield Decline Joint Venture and BSES trials suggest that N applied to the first ratoon sugarcane crop after a good legume crop can possibly be reduced. The reduction in N applied will depend on several factors which include legume residue management, soil type, climate and tillage practices’.

The results of the current project suggest that the following modifications (in italics) should be made to the process for calculating the N contribution from a legume fallow crop:

Calculate the quantity of N in the legume fallow crop (A) as:

A (kg N/ha) = 1.3 x [Estimated fallow crop dry biomass (t/ha) x assumed %N]

If the fallow crop is harvested for grain, then the quantity of N remaining in the above-ground biomass = 1/3 A

Calculate the N contribution of the legume fallow to the plant cane crop (B) as:

B (kg N/ha) = 0.6 x A

(assumes that 60% of the total N in the legume fallow is mineralised during the growing season of the plant crop).

In the current Six Easy Steps, a 6 t/ha soybean crop with an assumed N concentration of 3.5% will give a calculated N contribution of 270 kg N/ha. If harvested for grain, the calculated N contribution is 90 kg N/ha.

Using the revised calculations above, the calculated N contribution from the legume fallow would be:

Calculate the quantity of N in the legume fallow (A) as:

A = 270 kg N/ha

If the fallow crop is harvested for grain, then the N contribution of the legume fallow = 1/3 A = 90 kg N/ha

Calculate the N contribution of the legume fallow to the plant cane crop (B) as:

B (kg N/ha) = 0.6 x A = 160 kg N/ha

If harvested for grain,

B (kg N/ha) = 0.6 x 90 = 50 kg N/ha

9 Further Work

- These results have highlighted the need to re-assess the contribution of soil N mineralisation to crop N uptake because of its direct effect on the calculation of N recovery from any N source (fertiliser, amendments, crop residues) by the crop to which the N source was applied. Furthermore, the assessment of the residual value of fertiliser, amendments or crop residues to the subsequent crops can only be determined by assessing the rate of N mineralisation from the soil N pool. This is because the residual N from the various N sources applied to the previous crop cannot be distinguished from the larger soil N pool. A diagnostic tool (plant-based or soil-based) must be developed to assess the likely contribution of soil N to crop N uptake and therefore be used to guide N requirements.
- Data from the incubation and pot experiments suggest that once the large initial flush of N mineralisation from legume residues is over (i.e., ≈20% of added total legume N is mineralised), the rate of the slower subsequent mineralisation phase of the residues is not different to that of the unamended soil. Therefore, the assumption in this report that the amount of N mineralised from the legume residues to the amended crop is equivalent to that measured for urea (i.e., ≈60%) may not be correct. A further incubation experiment will be required to determine how much of the legume N is mineralised after the first flush. The results will directly impact on the calculation of the contribution of legume N to the initial amended crop.

10 References

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