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ORIGINAL PAPER

The availability of nitrogen from sugarcane trash on contrasting soils in the wet tropics of North Queensland

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Abstract Sugarcane crop residues ('trash') have the potential to supply nitrogen (N) to crops when they are retained on the soil surface after harvest. Farmers should account for the contribution of this N to crop requirements in order to avoid over-fertilisation. In very wet tropical locations, the climate may increase the rate of trash decomposition as well as the amount of N lost from the soil–plant system due to leaching or denitrification. A field experiment was conducted on Hydrosol and Ferrosol soils in the wet tropics of northern Australia using ^{15}N-labelled trash either applied to the soil surface or incorporated. Labelled urea fertiliser was also applied with unlabelled surface trash. The objective of the experiment was to investigate the contribution of trash to crop N nutrition in wet tropical climates, the timing of N mineralisation from trash, and the retention of trash N in contrasting soils. Less than 6% of the N in trash was recovered in the first crop and the recovery was not affected by trash incorporation. Around 6% of the N in fertiliser was also recovered in the first crop, which was less than previously measured in temperate areas (20–40%). Leaf samples taken at the end of the second crop contined 2–3% of N from trash and fertilizer applied at the beginning of the experiment. Although most N was recovered in the 0–1.5 m soil layer there was some evidence of movement of N below this depth. The results showed that trash supplies N slowly and in small amounts to the succeeding crop in wet tropics sugarcane growing areas regardless of trash placement (on the soil surface or incorporated) or soil type, and so N mineralisation from a single trash blanket is not important for sugarcane production in the wet tropics.

Keywords Crop residue · ^{15}N · Mineralisation · Soil organic matter · Decomposition · Mulch · Ammonium · Leaching · Incorporation

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Introduction

Sugarcane crops typically obtain only 20–40% of the nitrogen (N) they require from fertiliser, and as much as 60% of fertiliser N may be lost from the soil–crop system (Vallis et al. 1996) through leaching, runoff and denitrification. While some fertiliser N remaining in the soil is likely to be used

by subsequent crops, there is considerable concern about the fate of the N that is lost from cane growing soils due to its potential impact on water quality. In the Australian wet tropics, 57–77% of rainfall moves through the profile as deep drainage and 5–13% runs off (Bristow et al. 1998), providing significant mechanisms for losses of dissolved inorganic N (Furnas 2003).

Sugarcane trash retained on the soil surface after harvest as a 'trash blanket' represents an additional N source (30–60 kg N ha^{-1}) that should be taken into account in the crop N budget, to avoid contributing to N losses from the soil–crop system. When trash is first retained, more carbon (C) is mineralised than N since trash has a high C:N ratio between 70 and 120:1 (Robertson and Thorburn 2001; Basanta et al. 2003). Virtually all trash left in the field after harvest decomposes in the following year under wet tropical conditions (Thorburn et al. 2001), but gross mineralisation of N is closely matched by immobilisation (Robertson and Thorburn 2001). In pot experiments, 3.8–8.9% of crop N was derived from finely ground trash applied at 10 t ha^{-1} (Ng Kee Kwong et al. 1987). However, under field conditions there was a negligible contribution of trash N (applied at 5 t ha^{-1}) to crop N (Ng Kee Kwong et al. 1987), and the authors concluded that the value of trash in crop N nutrition came from long-term trash retention. Thus when a sugarcane production system in which trash was formerly burnt is converted to trash retention, soil organic N is expected to increase. A dynamic equilibrium is likely to be eventually reached where N inputs from trash are balanced by an increase in mineralised N (Robertson and Thorburn 2001), possibly permitting fertiliser N to be reduced by the amount of N in the annual trash application.

Fertiliser N may be reduced in response to long term trash blanketing but the amount is likely to be less than the amount of N contained in a trash blanket for several reasons. The first reason is that trash retention is likely to alter the soil water balance, probably increasing losses of N by leaching and denitrification (Robertson and Thorburn 2001; Thorburn et al. 2004). Secondly, there may be a positive yield response to the increased soil water available under the trash blanket, even in the wet tropics (Smith et al. 1984), and this may result in an increased crop N requirement (Thorburn et al. 2004). However, fertiliser rates for wet tropical soils might be excessive if growth is limited by poorly drained soils or limited radiation (Wood 1991) or if wet tropical soils preserve N more than expected (e.g. by anion exchange capacity).

In addition to the quantity of N delivered by decomposition of trash, the amount and timing of N mineralisation is of interest. Salter and Bonnett (2000) found that suckering increased in response to applications of fertiliser N late in the growing season, suggesting that increased concentrations of N in the soil solution, possibly from N mineralisation in trash blanketed soils, may also stimulate suckering. This is particularly likely to occur in the wet tropics as the warm wet conditions in these areas have potential to mineralise N throughout the year compared with cooler climates (Meier et al. 2003). This may be a particular risk if N is mineralised rapidly where trash is incorporated into the soil. This is a management practice that has been advocated in the wet tropics to overcome management difficulties such as waterlogging associated with trash blankets (Kingston et al. 2005).

Few experiments in the wet tropics have investigated the decomposition of trash and the movement of N from trash to the soil and plant either over time, or as effected by trash incorporation. The purpose of this study was to investigate (a) the contribution of trash to crop N nutrition in wet tropical areas, (b) whether the timing of N uptake by the crop is affected by incorporating trash into the soil, and (c) the retention of trash N in contrasting soils.

Materials and methods

Sites

Two field experiments were established on sugarcane farms near Babinda (17°20′24″ S, 145°55′48″ E) in the wet tropics region of northern Australia. The sites had contrasting soil types, which were used to identify the sites (Hydrosol Site and Ferrosol Site). At both sites, sugarcane had been grown for approximately 80 years and trash had been retained at the sites after harvest for at least 15 years. Variety Q166 was grown at both sites during the trial. Summary details of soil properties and operations are presented in Tables 1, 2.

Table 1 Selected soil properties at the experimental sites 29 days before treatments were applied (10/10/2001)

	Hydrosol Site				Ferrosol Site			
Soils								
FAO classification (FAO 1998)	Gleysol				Ferralsol			
Australian soil classification (Isbell 1998)	Hydrosol				Ferrosol			
pH (1:5 water, 0–0.15 m)	6.1				4.9			
Total C (%, 0–0.15 m)	1.69				2.54			
Total N (%, 0–0.15 m)	0.12				0.15			
Mineral N (kg ha^{-1}, 0–1.50 m)	51				93			
AEC[a] ($cmol_{(-)}$ kg^{-1}, 0–1.50 m)	0.7				2.4			
CEC[b] ($cmol_{(+)}$ kg^{-1}, 0–1.50 m)	1.7				0.2			
	CS[c]	FS[d]	Si[e]	Cl[f]	CS[c]	FS[d]	Si[e]	Cl[f]
Average texture[g] (%, 0–1.50 m)	21	26	23	30	14	6	15	65

[a]AEC, anion exchange capacity

[b]CEC, cation exchange capacity

[c]CS, coarse sand

[d]FS, fine sand

[e]Si, silt

[f]Cl, clay

[g]Average given as depth-gradients in texture were small

Table 2 Crop management operations during the field experiment at both sites

Operation	Hydrosol Site		Ferrosol Site	
Harvest date of previous crop	8/10/2001		9/10/2001	
Crop class at start of experiment	3rd ratoon		1st ratoon	
Treatments applied	7–8/11/2001		6–7/11/2001	
Microplot harvest dates	1/10/02	14/10/03	2/10/02	13/10/03
Block harvest dates	5/10/02	30/10/03	19/10/02	26/11/03

Trash was removed from the experimental sites where treatments were to be applied during the week after harvest of the preceding sugarcane crop. Approximately 1 month after harvest, 1.5 m × 0.67 m microplots, similar to the size of those used in previous sugarcane studies by Vallis et al. (1996) or Prasertsak et al. (2002), were established. As recommended for studying N mineralisation from residues (Hauck et al. 1994), they were confined by open metal boxes that were placed across the row and pushed 0.2 m into the ground to restrict the growth of sugarcane roots between microplots and the surrounding soil. Movement of ^{15}N beyond the limits of the microplots was tested through determining ^{15}N concentrations of leaves sampled from plants adjacent to the microplots (details of methods provided below). Soil moisture and temperature was monitored hourly with Campbell Scientific CS615 water content reflectometers and Campbell Scientific 107B soil temperature probes inserted close to the row and attached to a Campbell Scientific CR10X datalogger.

Labelled trash was obtained from potted sugarcane plants that had been grown prior to the field experiment and which had been fertilised with 9.6 atom% ^{15}N excess. This trash (0.4% N, 41.7% C, 5.9 atom% ^{15}N excess) was applied to microplots in four replicates at the rate of 10 t DM ha^{-1} (Table 3). Treatments (Table 3) consisted of (1) bare soil (the control), (2) ^{15}N-labelled trash applied to the soil surface (TS), (3) ^{15}N-labelled trash incorporated 0.1 m into the soil (TI) and (4) unlabelled trash applied to the soil surface (NF). This last treatment was fertilised with ^{15}N-labelled fertiliser, while the others were fertilised with unlabelled N fertiliser. Netting was pegged over the microplots to retain trash in place. Fertiliser was applied as a commercial ''one-shot'' mixture (24.6% N, 2.4% P,

Table 3 Experimental treatments applied to microplots

Treatment	Trash		Fertiliser
	Placement	Atom% ^{15}N excess	Atom% ^{15}N excess
Control	No trash	N/A	Unlabelled
Trash surface (TS)	Surface	5.9	Unlabelled
Trash incorporated (TI)	Incorporated 0.1 m	5.9	Unlabelled
Labelled fertiliser (NF)	Surface	Unlabelled	7.2

17.8% K, 1.8% S) at rates normally used by collaborating growers (130 kg N ha^{-1}). In treatments receiving 7.2 atom% ^{15}N excess from labelled fertiliser, the one-shot mixture was prepared with the same ingredients as the commercial product except that some of the urea used in the mixture was labelled with ^{15}N. In trash treatments, fertiliser was placed beneath the trash.

The growers applied herbicides for weed control during the experiment. Any weeds removed by hand from the microplots were placed on the ground within the microplots. Confidor® pesticide was applied in the first year at the Ferrosol Site to reduce the risk of cane grub damage, but treatment was not considered necessary in year 2.

Microplots receiving unlabelled fertiliser (i.e. the control, TS, and TI treatments) were arranged in a randomised complete block design with four blocks at each site. Microplots receiving labelled fertiliser (the NF treatment) were placed apart from the other treatments to avoid contamination of these treatments with the more labile fertiliser treatment. However, all plots were located over a small area (≤200 m^2) and total soil C, N, and mineral N in all blocks at days 0 and 362 were comparable.

The experimental sites were maintained for a second year to determine the residual effect of labelled trash and fertiliser N initially applied on leaf and soil N. Trash was applied to the surface of all microplots at field rates (ca. 10 t DM ha^{-1}) in the beginning of the second year. Fertiliser was again applied 1 month after harvest at the same rates used in the first year. However, neither trash nor fertiliser was labelled with ^{15}N in the second year.

Weather

Rainfall recorded at Babinda was 2154 mm from November 2001 to October 2002 and 2900 mm from November 2002 to October 2003. These amounts represented 51 and 68% respectively of the 1901–2000 median rainfall (4261 mm)—these were among the driest years experienced during that period. Air temperature and radiation received during the experiment tended to be above the mean monthly values occurring during the same 100-year period (Fig. 1).

Soil sampling and analyses

Soil samples were collected to 0.3 m depth at 2–3 monthly intervals in the first year of the experiment, and at 6 monthly intervals in the second year. Samples were collected by taking eight cores with a jackhammer and metal sampling tubes (40 mm diameter) across the interrow–row–interrow cross-section of the microplots. Soil samples were taken from a new position in the microplot on each sampling occasion in order to avoid resampling from the same position. Cores were bulked in depth increments 0–0.05, 0.05–0.15 and 0.15–0.30 m. In addition to these samples, deeper soil samples were taken at selected times. Twenty-nine days before the treatments were applied, and after harvest of the first crop (362 days after application of the treatments), the soil sampling depth was extended to 1.5 m (in 0.3 m increments) in all microplots. Additional samples were obtained from 1.5 to 4 m depth (in 0.5 m increments) from a subset of microplots (one labelled fertiliser and one labelled trash treatment) at the sampling time 362 days after application of the treatments. After collection, all soils were transported to the laboratory under refrigeration (−20°C). In the laboratory, bulk soil samples were weighed, then gently crushed and thoroughly mixed before subsampling for subsequent analyses.

Gravimetric soil moisture was determined on a sample of ca. 100 g of soil dried at 105°C for 2–3 days. Bulk density was determined by dividing the gross sample weight adjusted for soil water by the

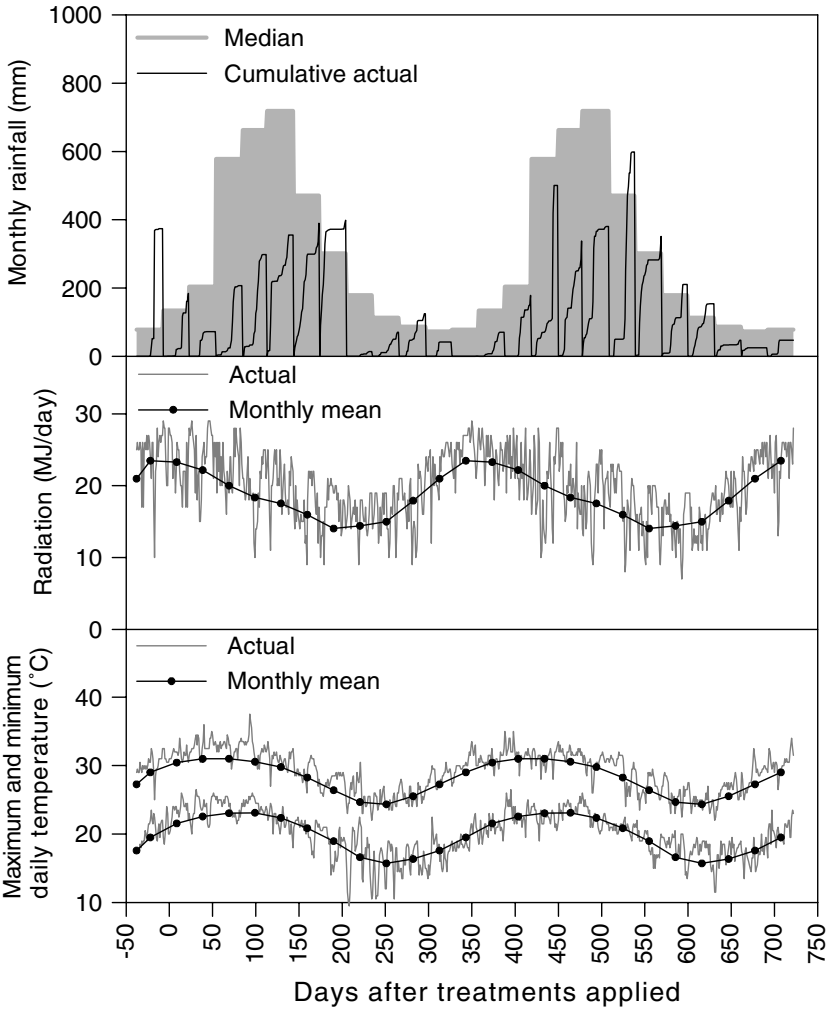

Fig. 1 Long-term median rainfall and mean radiation, maximum temperature and minimum temperature (1901–2000; Department of Natural Resources and Mines (Queensland) SILO database), and actual values occurring during the experimental period

volume of the auger tube. The bulk density for each increment in soil depth was averaged over all sampling occasions and a single value used in all calculations involving bulk density.

Total C, N, and ^{15}N abundance were determined with a method similar to Barrie et al. (1995) on air dried soils using a Europa C and N Single Isotope Mass Spectrometer and a Europa 20/20 Stable Isotope Mass Spectrometer coupled to a 1108 Carlo Erba Elemental Analyser.

Soil cation and anion exchange capacity were determined by compulsive exchange on soil samples to 4 m obtained on day 362 (Rayment and Higginson 1992).

Soil mineral N was determined on 15 g subsamples at field moisture. Soils were roller-mixed with 60 ml of 2 M KCl for 1 h, allowed to settle for a further hour, and the supernatant filtered through Whatman 54 filter papers. The KCl extracts were analysed for NH_4^+ and NO_3^- colorimetrically (Rayment and Higginson 1992). The 2 M KCl extracts were also analysed for ^{15}N using glass fibre filter paper discs (Brooks et al. 1989), and mass spectrometry as described previously. The mineral N concentrations of all 2 M KCl extracts were adjusted for soil moisture. Mineral N concentration was converted to kilograms per hectare by multiplying the mineral N concentration by the soil layer depth and bulk density.

Microbial biomass N was determined using 15 g soil samples that were analysed following 24-h chloroform fumigation extraction incubation. Incu-

bation procedures were based on the method of Brookes et al. (1985) with the exception that soils were incubated at field moisture and extracted with 2 M KCl. Samples from the surface 0.05 m soil layer were also chloroform incubated for 10 days and subjected to ninhydrin N analysis (Amato and Ladd 1988).

Plant sampling and analyses

Trash depth was measured during the first year to provide an estimate of trash decomposition. As trash depth is highly variable and row profiles were mounded, trash depth was measured in a grid at increasing distances from each side of the row. Trash was also sampled by cutting an area of approximately 0.11 m × 0.08 m from those parts of the trash that were present on the soil surface in TS and TI treatments. Trash became brittle during decomposition so was not washed and consequently small amounts of soil and N fertiliser were likely to have adhered to trash samples.

The third leaf was sampled (as described by Calcino 1995) from two plants per microplot at intervals of 2–4 weeks throughout the experiment. At the end of the first year, microplots were harvested and partitioned into suckers (sucker stalks longer than 0.3 m to the top visible dewlap), fresh and dead stalks, dead leaves, green leaves and 'cabbage' (top leaves and immature stalk obtained by bending the top of the stalk to breaking point). Small suckers (less than 0.3 m long) were counted and discarded. Fresh stalks were pressed and amino N content determined on the extracted juice to determine whether the crop was suffering N stress (Keating et al. 1999). Stalk fibre left after juice extraction was analysed similar to other plant samples. Samples other than juice were oven dried at 70°C and leaves were finely ground for subsampling. Total C, N, and ^{15}N abundance of plant parts was determined with a mass spectrometer by the same method used for analysis of soils.

^{15}N calculations

The recovery of ^{15}N from applied trash and fertiliser in trash, soil, and plant samples was calculated as follows. The percentage of N in individual soil and plant material samples ('sinks') derived from ^{15}N-labelled trash and fertiliser ('sources') was calculated from

$$\%\text{N from source} = (\%^{15}\text{ N excess of sink}/\%\ ^{15}\text{N excess of source}) \times 100\% \quad (1)$$

where the $\%^{15}$N excess used for all sources and sinks was the ^{15}N abundance less an adjustment of 0.3663 for natural enrichment (Hauck et al. 1994). The %N from source of plant samples was adjusted for removal of soil containing ^{15}N from the microplots due to soil sampling.

The percentage of N in a sink derived from a source of ^{15}N was converted to the mass of N derived from that source as follows:

$$\text{Quantity N from source} = (\%\text{N from source}/100\%) \times \text{mass of total N in sink} \quad (2)$$

The percentage of a source of ^{15}N label recovered in a sink (for plant sinks this corresponded to N use efficiency, NUE) was determined as follows:

$$\text{Recovery }\% = (\text{Quantity N from source/mass of total N in source}) \times 100\% \quad (3)$$

Statistical analyses

Differences between treatments were identified using analysis of variance with Statistix 7.0 analytical software (differences at the 5% probability level were regarded as significant). The standard errors for the mass of ^{15}N excess derived from treatments was determined by using the variance calculated according to the formula of Kendall and Stuart (1977) for derived observations as follows:

$$\text{variance(z)} = a^2(w^2 \times \text{variance}(u) + u^2 \times \text{variance}(w) + 2uw \times \text{covariance}(uw)) \quad (4)$$

where z is the mass of ^{15}N excess derived from treatments (Equation 2), a is the mass of soil or plant material, u is the percent of N in the plant or soil, and w is the percent of N as ^{15}N excess in the plant or soil (^{15}N abundance less 0.3663; Hauck et al. 1994).

Results

Yields

Millable stalk yields, juice amino N, and total dry weight of the above-ground parts of crops in the different treatments were not significantly affected by trash management at either site (data not shown).

^{15}N recovery

The effect of treatments on the recovery of ^{15}N in soil and crops was usually not significant apart from a fertiliser/trash difference (Tables 4–6), consistent with the greater quantity of N applied in fertiliser. Incorporation did not increase the recovery of trash ^{15}N by crops. This pattern of ^{15}N recovery was consistent at both sites.

Total N recovery in above-ground plant parts from fertiliser or trash at the end of the first year was very low (Tables 4–6), representing a 4–5% NUE from fertiliser, 2–3% NUE from incorporated trash, and 2–4% NUE from surface trash. If 30% of plant N is assumed to occur in the roots (van Dillewjin 1952), then NUE increases to 6–8% for fertiliser and 3–6% for trash. However, ^{15}N in early-detached leaves was not measured. In addition, despite the use of metal boxes to confine the microplots, leaves sampled on day 238 from plants immediately adjacent to microplots had approximately 0.4% N derived from labelled trash and 0.2% N derived from labelled fertiliser. These proportions of N derived from labelled fertiliser were approximately an order of magnitude lower than the recovery by crops within the microplots (Table 6), and so do not have a major impact on the interpretation of the results. Nevertheless, the results of Tables 4–6 represent a lower limit of N obtained from ^{15}N treatments since early-detached leaf and labelled N uptake by plants outside the microplots are not included in these calculations of crop N derived from treatments.

Recovery of N in soil >100% (Tables 4, 5) may be caused by various reasons, including overstatement of soil bulk density by our method of soil collection. If a bulk density of 1.4 g cm^{-3} for the Hydrosol or 1.2 g cm^{-3} for the Ferrosol was used in the calculations, which were within range of the bulk densities measured at the sites during the experiment, it would have given total N recoveries of 100% in the labelled fertiliser treatment. Although use of the site average

Table 4 Balance of ^{15}N in soil and above-ground plant parts of microplots (1 m^2) at the end of year 1 (day 327) from surface (TS) and incorporated (TI) trash and fertiliser (NF) treatments at the Hydrosol Site (±1 standard error)

Source	Partition	Treatment		
		NF (mg ^{15}N m^{-2})	TI (mg ^{15}N m^{-2})	TS (mg ^{15}N m^{-2})
Applied ^{15}N		1,091±12	247±10	247±10
^{15}N recovered in soil and plant				
Soil	0.0–0.3 m	508±187	14±13	31±16
	0.3–0.6 m	282±75	33±13	58±13
	0.6–0.9 m	155±25	27±9	51±28
	0.9–1.2 m	119±21	28±27	37±15
	1.2–1.5 m	172±12	15±8	19±16
	Plot total	1,236±195	116±43	196±53
Plant	Cabbage	6±1	1±0	0±0
	Dead leaf	5±1	0±0	2±0
	Dead stalk	7±1	1±0	0±0
	Green leaf	12±3	1±0	1±0
	Millable stalk	11±2	4±2	6±3
	Suckers	3±1	1±0	1±0
	Plot total	43±7	8±2	10±4
Total recovered		1,280±196	124±44	206±53
% recovered in soil		113±27%	47±12%	79±16%
% recovered in plant		4±1%	3±1%	4±2%
% recovered in total		117±26%	50±12%	83±17%

^{15}N recovered in plant parts and soil was significantly greater in NF treatments except in cabbage, dead stalk and millable stalk (not significantly different in any treatment)

Table 5 Balance of ^{15}N in soil and above-ground plant parts of microplots (1 m^2) at the end of year 1 (day 327) from surface (TS) and incorporated (TI) trash and fertiliser (NF) treatments at the Ferrosol Site (±1 standard error)

Source	Partition	Treatment		
		NF (mg ^{15}N m^{-2})	TI (mg ^{15}N m^{-2})	TS (mg ^{15}N m^{-2})
Applied ^{15}N		1,091±12	247±10	247±10
^{15}N recovered in soil and plant				
Soil	0.0–0.3 m	515±129	88±37	111±44
	0.3–0.6 m	307±24	55±28	50±30
	0.6–0.9 m	128±43	59±24	48±18
	0.9–1.2 m	152±85	43±14	2±1
	1.2–1.5 m	92±21	5±4	23±7
	Plot total	1,194±155	250±67	234±65
Plant	Cabbage	10±1	2±0	1±1
	Dead leaf	9±2	0±0	0±0
	Dead stalk	0±0	0±0	0±0
	Green leaf	23±3	2±1	3±0
	Millable stalk	15±2	0±2	1±1
	Suckers	2±0	0±0	1±0
	Plot total	59±4	6±2	7±2
Total recovered		1,253±155	256±67	241±66
% recovered in soil		109±16%	102±32%	95±34%
% recovered in plant		5±1%	2±1%	3±1%
% recovered in total		115±15%	104±32%	98±33%

^{15}N recovered in plant parts and soil was significantly greater in NF treatments except in soil depths 0.6–0.9 and 0.9–1.2 m, dead stalk and suckers (not significantly different in any treatment)

Table 6 Percentage of N derived from surface (TS) and incorporated (TI) trash and fertiliser (NF) treatments in soil and above-ground plant parts of microplots (1 m^2) at the end of year 1 (day 327) at the Hydrosol and Ferrosol Sites (±1 standard error)

Sink for treatment N	Treatments		
	NF (%)	TI (%)	TS (%)
Hydrosol Site			
Soil 0.0–1.5 m	1.6±0.22	0.2±0.07	0.3±0.08
Above ground plant parts	4.1±0.39	0.9±0.27	1.2±0.47
Ferrosol Site			
Soil 0.0–1.5 m	1.1±0.14	0.3±0.07	0.2±0.06
Above ground plant parts	4.8±0.19	0.6±0.19	0.5±0.19

The percentage of N in all sinks was significantly greater from NF treatments than from trashed treatments

overstates recovery in soil, this does not alter the central result that only a small proportion of N was recovered in the plant while most was recovered in the soil.

The proportion of total soil N (0–0.3 m) derived from trash during the experiment was low (<1%) at all times, except on day 187, and not effected by trash management (Fig. 2). The proportion of N derived from fertiliser and trash did not change significantly with increasing soil depth (to 1.5 m, data not shown) After harvest of the first crop, N derived from both trash and fertiliser was detected below 1.5 m (<440 mg ^{15}N m^{-2} in trash treatments and <1,180 mg ^{15}N m^{-2} in fertiliser treatments). However, soil samples collected below 1.5 m were unreplicated and so these results cannot be considered representative of average recovery in all microplots.

Changes in plant N

Leaf N ranged from 1.1% to 2.5% over both years and was not significantly affected by trash treatments (Fig. 3). Leaf N for the bare control and NF treatments was not significantly different from TI and TS treatments (data not shown). In the first crop, no differences in leaf N between the two sites occurred after flowering when new leaf production ceased. In the second crop, there was significantly higher average leaf N at the Ferrosol Site, possibly due to differences in soil N fertility between sites, although leaf N tended to be above critical concentrations (Reuter et al. 1997) in both years at both sites.

Trash applied at the start of the experiment supplied only a small proportion of leaf N to the first (up

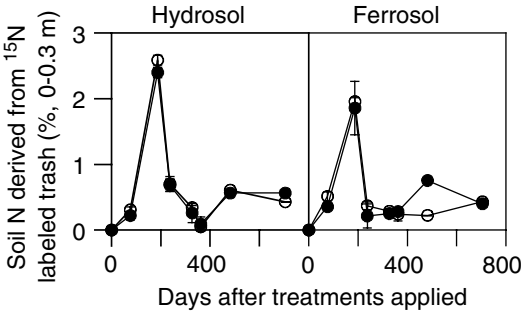

Fig. 2 Soil N derived from surface (●) and incorporated (○) trash in the top 0.3 m of soil during the field experiment at the Hydrosol and Ferrosol Sites. Vertical bars represent ±1 standard error of the means

to 5.2%) or second (2.1% at harvest) crops (Fig. 3). N supplied from trash was not significantly affected by incorporation. Fertiliser applied at the beginning of the experiment supplied up to approximately 40% of leaf N in the first 30–60 days of the experiment, with the supply decreasing markedly after that during the first crop, and being approximately 2.5–2.9% of leaf N at harvest of the second crop.

Changes in soil C and N

The mass of C and N in applied labelled trash was a small proportion (~5% of soil C and ~1% of soil N) of total C and N in the surface 0.0–0.3 m of soil. Consequently, total soil C and N in the treatments where trash was applied was not significantly different from the bare control during the experiments (data not shown).

Soil mineral N (0–0.30 m) ranged from 17 to 60 kg N ha^{-1} during the experiment (Fig. 4) and was not significantly affected by treatments. Mineral N in the soil profile to 1.5 m before and after the first crop (days −29 and 362) averaged 45 and 84 kg N ha^{-1} at the Hydrosol Site and 93 and 107 kg N ha^{-1} at the Ferrosol Site. In the first year, there was a trend for more soil mineral N to be derived from ^{15}N-labelled trash that was incorporated (5.5–11.2%) than placed on the soil surface (4.3–6.7%), and also for more soil mineral N to be derived from trash at the Hydrosol Site.

Form of mineral N

The form of mineral N was usually dominated by NH_4^+-N at both sites (Fig. 4). Below 2 m soil depth,

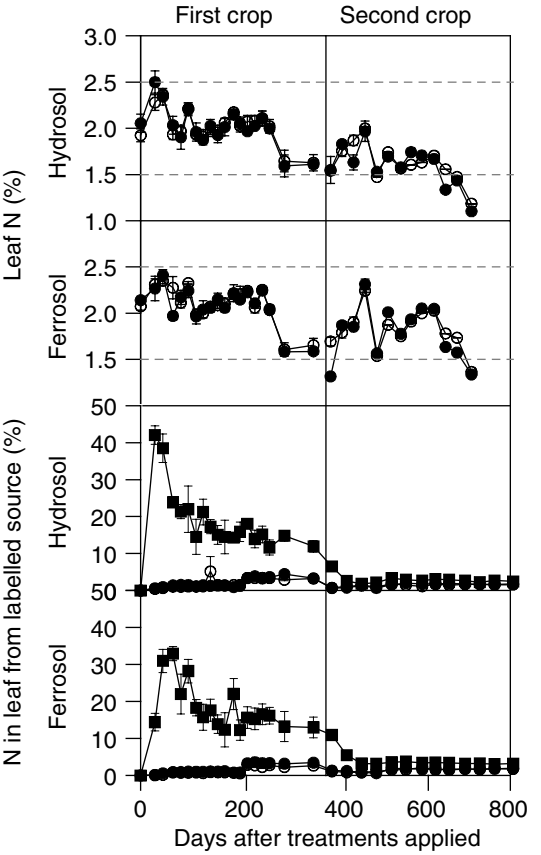

Fig. 3 Leaf N and percentage of leaf N derived from surface (●) and incorporated (○) trash and fertiliser (■) in the two sugarcane crops grown in the 2 years of the experiment at the Hydrosol and Ferrosol Sites. Vertical bars represent ±1 standard error of the means

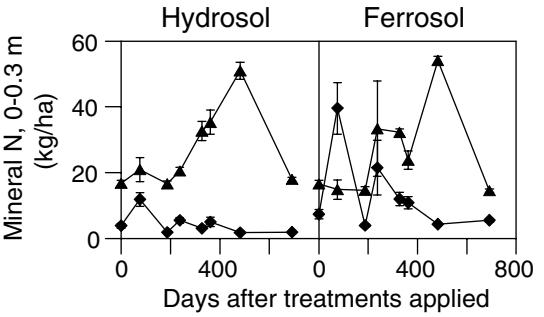

Fig. 4 NH_4^+-N (▲) and NO_3^--N (◆) during the experiment in the 0–0.3 m soil layer at the Hydrosol and Ferrosol Sites. Vertical bars represent ±1 standard error of the means

this pattern was reversed at the Ferrosol Site, although the extent to which this occurred was difficult to determine as only two samples were taken below

1.5 m at each site (Fig. 5). Although significant quantities of mineral N were measured at each site (Fig. 4), NO_3^--N represented only a small percentage of anion exchange capacity (Fig. 6). Ammonium-N represented a small proportion of cation exchange capacity at the Hydrosol Site, but a large proportion of the small cation exchange capacity at the Ferrosol Site.

Changes in trash N

Little above-ground trash remained from the TS treatment by the end of the first year at each site (Fig. 7a, b), consistent with decomposition in other wet tropical areas (Thorburn et al. 2001). Trash N concentration increased and C:N ratio decreased significantly during the first year of the experiment (Fig. 7e–h). Trash N concentration was significantly higher in the TS treatment compared to the TI treatment on sampling dates following trash application. Trash C concentration (Fig. 7c, d) was also significantly greater in the TS than TI treatment at the Hydrosol Site. However, the trash C:N ratio was not significantly different between trash management treatments and, for both sites and treatments, the trash C:N ratio declined below 30:1 by around day 200.

In the TS and TI treatments, the percentage of N in trash that originated from the labelled trash declined significantly during the first year of the field experiment as N in the trash came from other sources

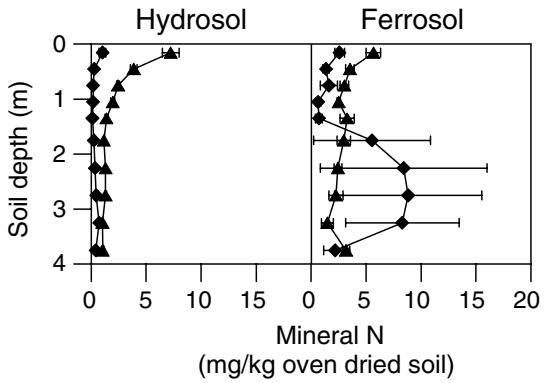

Fig. 5 NH_4^+-N (▲) and NO_3^--N (◆) in deep (4 m) soil profiles taken after harvest of the first crop (day 362) at the Hydrosol and Ferrosol Sites. Horizontal bars represent ±1 standard error of the means. Samples below 1.5 m consist of two replicates and are provided for information only

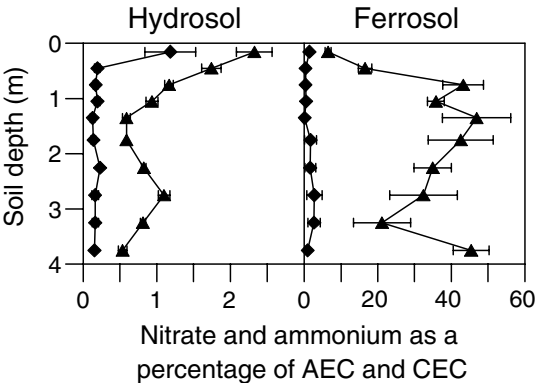

Fig. 6 Percentage of cation exchange capacity (CEC) occupied by ammonium (▲), and anion exchange capacity (AEC) occupied by nitrate (◆) at the Hydrosol and Ferrosol Sites after the first harvest (day 362). Horizontal bars represent ±1 standard error of the means. Samples below 1.5 m consist of two replicates and are provided for information only

(Fig. 8). There was a trend for this decline to be more rapid when trash was incorporated, and at the Ferrosol Site. At both sites, the percentage of N in surface trash from the labelled fertiliser increased to around 30% at day 40, then declined slightly during the rest of the year. At the end of year 1, the N in the small amount of remaining surface trash was derived approximately 40% from trash, 20% from fertiliser, and the balance from other sources.

Other effects of trash

Microbial biomass C and N determined by ninhydrin-reactive N assay fluctuated widely during the experiment (by up to 3,085 µg microbial biomass C g^{-1} OD soil and 455 µg microbial biomass N g^{-1} OD soil). Microbial biomass C and N were significantly greater in trashed treatments than in the bare control treatment on a few occasions (days 237 and 482 in the Hydrosol and day 187 in the Ferrosol), but were not significantly different between TS and TI treatments.

Significantly more small suckers (<0.3 m long) were counted in trashed treatments (15–23 counted m^{-2}) at the Hydrosol Site at the first harvest (day 327) compared to the bare control plots (no suckers). At the Ferrosol Site, significantly more large suckers (≥0.3 m long) were counted in the treatment with incorporated trash (2 suckers m^{-2}) compared to other treatments (<0.8 suckers m^{-2}).

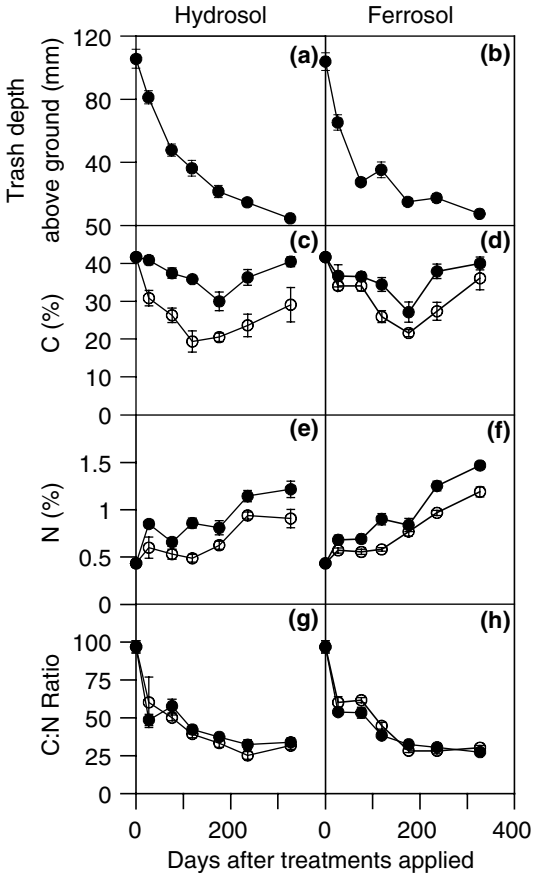

Fig. 7 Average depth of trash above ground at 0.7 m from the row (near centre of interrow), carbon, nitrogen and C:N ratio of surface-applied (●) and above-ground pieces of incorporated (○) trash during the first crop after treatment application at the Hydrosol and Ferrosol Sites. Vertical bars represent ±1 standard error of the means

There were generally no consistent differences between treatments in soil moisture measured either with data loggers or through soil sampling, at any time, except when sampled after the wet season in May 2002 (day 187) at both sites and in July 2002 (day 237) at only the Hydrosol Site. Then, average soil gravimetric and volumetric water content (to 0.05 m) was marginally (<0.02 m^3 m^{-3}), but significantly greater in treatments with surface and incorporated trash than the bare control (data not shown).

Diurnal soil temperatures in the row soil were initially 3–4 °C higher in the bare control (33–35 °C) than the trashed soils immediately after treatments were applied. Soil temperature differences between

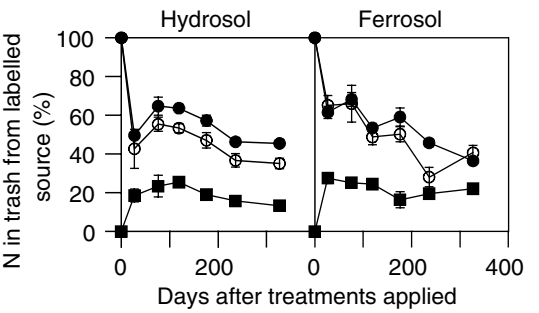

Fig. 8 N in decomposing trash derived from trash in the ^{15}N-labelled surface (●) and incorporated (○) trash treatments, and derived from fertiliser in the labelled fertiliser with surface trash (■) treatment during the first year of the experiment at the Hydrosol and Ferrosol Sites. Vertical bars represent ±1 standard error of the means

the bare control and trashed treatments gradually decreased to zero over the following 80–95 days.

Discussion

In these experiments, trash decomposition was virtually complete after 1 year, but there was no significant effect of a single trash blanket on the amount or timing of N taken up by the crop. Soil mineral N and leaf N derived from trash increased at 200 days after treatments were applied (in May; Figs. 2, 3), when the trash C:N ratio had decreased to around 30 (Fig. 7g, h). Despite this small release of N from trash, total soil mineral N and leaf N in treatments with trash applied were not significantly different from the bare control treatments. For this reason, the appearance of suckers in all trashed treatments after the greatest release of trash N (day 237), was unlikely to be related to N from trash treatments as previously hypothesised (Salter and Bonnett 2000).

The lack of a difference in soil N, N mineralised, or microbial biomass N between trashed and bare control treatments suggests that differences in trash management may need to be maintained for more than 1 year before such differences can be measured. Soil microbial biomass, N mineralisation, and total N remained significantly higher in trash blanketed soils in a field experiment with paired soils having a 10 year history of green cane trash blanketing and burning, despite the application of a trash blanket to both sites for 1 year (Sutton et al. 1996).

Up to 4 years of surface trash application were required before differences in microbial biomass C in surface trash and burnt trash treatments could be measured at a number of other sites (Robertson and Thorburn 2001; Sutton et al. 1996). Similarly, no response to a single year of trash blanketing was measured in trashed and bare control treatments in this experiment where both sites had a 15 year history of trash retention.

Incorporation had no significant effect on crop uptake of trash N. While no previous studies have investigated N released from incorporated trash, the results are consistent with the conclusions from pot studies of Ng Kee Kwong et al. (1987) that increasing the trash-soil contact (by grinding trash to 1 mm) would have little effect on crop uptake of trash N in the field. The lack of response of N mineralisation from trash when it is incorporated is markedly different to that from better quality residues such as legumes in sugarcane soils. For example, Garside and Berthelsen (2004) found that N mineralisation occurred rapidly from legume residues incorporated into the soil compared to when they were retained on the soil surface. This difference in N mineralisation from trash and legume residues may be related to biochemical quality (De Oliveira et al. 2002), and/or silica content (Anderson 1991; Tian et al. 1992) of trash compared with legume residues, and is consistent with the generally slower than expected decomposition of surface trash (Thorburn et al. 2001).

A smaller proportion of crop N was derived from fertiliser (~5%; Table 6) than reported elsewhere (20–40%; Vallis et al. 1996), probably due to the presence of considerable soil mineral N throughout the experiment (>20 kg mineral N ha^{-1} in the 0–0.3 m layer, Fig. 4). Some fertiliser N not used by the crop was immobilised in trash (Fig. 8) and soil organic matter (Tables 4–6), and available for uptake by the second crop (Fig. 3). However, there was also evidence that some applied N (from trash and fertiliser sources) may have leached to 1.5 m or lower (Tables 4, 5). While our results indicate that nitrate occupied a small proportion of anion exchange capacity (Fig. 6), substantial quantities of nitrate have accumulated under sugarcane at depths below 4 m in other Ferrosols in this region in contrast to native vegetation (Rasiah et al. 2003).

Trash retention appears to be useful in retaining (by immobilisation) mineralised N in wet tropical soils as N mineralisation occurs rapidly compared to subtropical areas (Meier et al. 2003), but the possible reduction in fertiliser N due to trash retention was not able to be quantified with this experiment. Trash retained in Australian wet tropical sugarcane cropping systems contains approximately one third of the N applied in fertiliser. This is likely to contribute to the N uptake of subsequent crops since the first crop obtained more than 50% of N from sources other than the current year's trash and fertiliser (Fig. 3; Table 6). However, the soils in this experiment have low to moderate total soil C and N concentrations, for which reductions in N fertiliser rates are not usually recommended (Schroeder and Wood 2001). There was also evidence of loss of N by leaching in these soils (Tables 4, 5). Therefore, the amount by which N fertiliser rates could be reduced in response to long term trash retention, if at all, requires further study.

Conclusions

We conclude that trash supplies N only slowly and in small amounts to the succeeding crop in wet tropics sugarcane growing areas, regardless of trash placement (on the soil surface or incorporated) or soil type. Thus, trash is not a useful source of N in the short term and the timing of N mineralisation is of little importance for sugarcane production in the wet tropics. Despite the negligible contribution of trash to crop N in the following year, trash is an important part of N management in this farming system since it immobilises N to retain it within the root zone for longer periods.

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