INFLUENCE OF SOYBEAN RESIDUE MANAGEMENT ON NITROGEN MINERALISATION AND LEACHING AND SOIL PH IN A WET TROPICAL ENVIRONMENT

By

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Abstract

A study was undertaken at the Sugar Yield Decline Joint Venture sub-station at Feluga in north Queensland in 1998 to investigate the effect of soybean residue management on nitrogen mineralisation and leaching, and soil pH. Three residue management practices were involved: residue incorporated, residue left standing and residue slashed and left on the surface. Changes in soil mineral nitrogen were monitored over a 136 day period from the initiation of residue management treatments (70 days prior to sugarcane planting) to two months after sugarcane was planted. At planting of the sugarcane, those treatments where residue had been incorporated to 20 cm had accumulated 206 kg/ha of the nitrogen originally contributed by the soybean crop over a depth interval of 110 cm. By contrast, in those treatments where residue was either left standing or retained on the soil surface, only 81 and 58 kg/ha, respectively had accumulated over the same depth interval. By day 136, most of the mineralised nitrogen in the residue incorporated treatment had moved to below 30 cm and the net loss of nitrate (the amount that had moved below 110 cm) was estimated to be 104 kg/ha. In those treatments where residue was not incorporated, the total amounts of nitrogen mineralised to nitrate appeared to be considerably less and most of this nitrogen was retained in the 0–110 cm zone. In addition, with the mineralisation of nitrogen in the surface soil layers, significant shifts in soil pH were observed associated with the generation of protons from the mineralisation process. These findings have significant implications for the management of legume residue. In order to effect maximum utilisation by the plant crop of nitrogen from the legume break, establishment of the sugarcane crop should occur as soon as possible after maturity of the break crop. Further, the legume residue should not be incorporated but retained on the surface to slow down the rate of mineralisation and allow better utilisation of legume nitrogen by the sugarcane crop. It is suggested that maximisation of the benefits of such strategies will be achieved by adopting a controlled traffic strategy with minimal soil disturbance for planting of sugarcane.

Introduction

The sowing of a legume crop species, in particular cowpea (*Vigna unguiculata*), as a break crop between plough-out of an old ratoon and re-planting to sugarcane the following autumn is an accepted practice within the Australian sugar industry. The legume crop provides a break from continual sugarcane that has a beneficial effect in reducing disease build up (Pankhurst *et al.*, 1999) and provides nitrogen for the subsequent sugarcane crop (Garside *et al.*, 1996). Further, a legume break provides ground cover for erosion and weed control over the wet season.

Over the past 5 years, a considerable amount of research has gone into selecting suitable legume species and developing management strategies to maximise their benefits. In this respect, soybean (Glycine max L. Merrill) has been found to be well suited since it fixes considerably more nitrogen than other potential legume species (Garside and Bell, 1999), has a relatively short growing season, and large biomass production (Garside *et al.*, 1996, 1998). However, with ploughing in of a soybean crop, there is potential for significant losses of mineralised nitrogen under conditions conducive to leaching and/or

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denitrification. Mineralisation and movement of nitrate nitrogen down the soil profile following the incorporation of soybean residue was reported by Garside *et al.* (1998) from a previous study at this site. By 137 days after incorporation, the nitrate bulge was at 50 cm.

In an effort to address the problem of nitrate losses through leaching, a study was undertaken to investigate the impact of soybean residue management on the rate of mineralisation and subsequent leaching of nitrate. In addition, temporal changes in soil pH associated with the mineralisation process were assessed.

Materials and methods

Site

The trial was established in November 1997 at the Sugar Yield Decline Joint Venture sub-station at Feluga, near Tully, north Queensland (17° 59'S; 145° 56' E). The long-term mean annual rainfall for the area is approximately 4300 mm, being concentrated between October and March. The rainfall at the site in 1998 was 3850 mm. The soil is a granite gravel of the Thorpe series (Murtha, 1986) classified as an Acidic Dystrophic Yellow Dermosol (Isbell, 1996).

Experimental design

This experiment was part of a larger factorial experiment established to measure the effect of lime at 0, 2.5, 5 and 10 t/ha and gypsum at 0 and 5 t/ha on growth of a soybean cover crop and subsequent sugarcane crop. There were three replications. Three additional plots each receiving 5 t/ha of lime and no gypsum were established in each replicate for the application of soybean residue treatments. Hence the design for this experiment was a randomised block with three residue management treatments and three replications. The residue management treatments were residue incorporated, residue standing and residue slashed and left on the surface.

The lime and gypsum treatments were surface broadcast and incorporated to a depth of 20 cm using a disc plough in November 1997, prior to planting soybeans. Plot size was 6 m × 20 m. Replicates were separated by a 5 m discard and 1.5 metres was left between individual plots within replicates. Inoculated seed of soybean variety Leichhardt was sown into raised ridges, 75 cm apart, on December 16, 1997. The vegetative biomass of the soybean crop was measured on the 19 February 1998 (65 days after planting) and at physiological maturity of the crop on April 16 (118 days after planting) by sampling 4 × 1 m sections of row in each plot. Nitrogen content of the soybean tops was determined on these samples.

Soybean residue treatments were imposed on June 11, 1998. In plots where the soybean crop was incorporated, the crop was ploughed under to a depth of 20 cm using a disc plough. In plots receiving surface residue management treatments, the crop was cut using a rotary slasher and left on the surface, while those treatments having residue standing were left intact. Sugarcane (variety Q117) was planted over the entire area on August 6, 1998. The plots having standing and surface soybean residue were direct planted without any cultivation. Potassium at 100 kg/ha as muriate of potash and phosphorus at 20 kg/ha as single superphosphate was applied at planting. No nitrogen fertiliser was applied to the sugarcane.

Soil analysis

Soil samples were collected to 110 cm depth from each of the plots prior to the establishment of lime and gypsum treatments in November 1997. Samples were obtained using a 50 mm diameter truck-mounted hydraulic core sampler and composite samples for each depth interval were formed from three cores per plot. Cores were sectioned into the following depth intervals: 0–10, 10–20, 20–30, 30–50, 50–70, 70–90 and 90–110 cm. Prior to chemical analysis, soils were air-dried and ground to pass a 2 mm sieve. Soil pH was determined in both water (pH_w) and 0.01 M $CaCl_2$ (pH_{Ca}) in a 1:5 soil-to-solution ratio. Soil extractable inorganic nitrogen was determined using the methodology of Rayment and Higginson (1992).

Further soil samples were collected from the soybean residue treatments at physiological maturity of the soybean (April 16, 1998), and on May 25 (day 1), August 3 (day 70) and October 8 (day 136). The May 25 sample was taken just prior to the establishment of the stubble management treatments on June 11, while the August 3 sample was just prior to sugarcane planting on August 6. Sampling strategy was as described previously.

Net acid addition estimates

In an effort to quantify the net acid addition (NAA) between May and October samplings over the 0–30 cm depth interval, a modified Helyar and Porter (1989) model was used.

$$NAA = [(pH_M - pH_O) \times pH_{BC}] \times BD \times V \quad (1)$$

where the subscripts M and O refer to the pH_{Ca} as measured in 0.01 M $CaCl_2$ in May 1998 and

October 1998; pH_{BC} is the pH buffering capacity of the soil (kmol H^+/kg.pH unit); BD is soil bulk density (kg/m^3); and V is the soil volume in the depth interval under consideration (m^3/ha). pH buffering capacity was estimated using a pedotransfer function described by R. Merry (pers. comm.), that takes into account soil organic carbon and field texture. Soil bulk density measurements previously undertaken by M.V. Braunack (pers. comm.) on the site were used in the calculation.

Statistical analysis

Statistical analysis of the data was undertaken using Genstat 5. Preliminary analysis of the soil chemical data was undertaken to determine whether transformation was required to standardise the variances. A simple ANOVA was used to analyse the data on a treatment by individual depth interval basis.

Results and discussion

Soybean growth

A significant vegetative biomass response to gypsum and lime was observed at the first sampling of the soybean on February 19, 1998 (Table 1). With increased additions of both lime and gypsum there was a corresponding increase in above ground biomass, suggesting that soybean was responding to elevated soil Ca levels. Indeed, mean soil Ca levels down the entire soil profile prior to the application of amendments was 0.62 $cmol_c$/kg, which would be classified as marginal for sugarcane production (Calcino, 1994). However, these initial biomass responses did not persist to final harvest at physiological maturity on 16 April 1998. At physiological maturity there were no significant treatment effects with respect to above ground biomass production and its nitrogen concentration. Above ground biomass production for the sampling at physiological maturity was 6933 kg/ha at a nitrogen concentration in the tops of 3.91%. Hence a mean value of 271 kg N/ha was estimated as being potentially available in the soybean tops for mineralisation and conversion to inorganic nitrogen.

Changes in soil nitrate under residue management

The soil mineral nitrate profiles for the three soybean residue management treatments are presented in Figure 1. On day 1 (May 25), two weeks prior to incorporation of soybean residue on June 11, the nitrate profiles were similar for all residue management treatments and concentrations of NO_3-N ranged from 1 to 2.1 mg/kg (Figure 1a). By day 70 (August 3), just prior to planting the cane crop on August 6, significant differences between the incorporated treatment and the other two non-incorporated treatments were clearly evident (Figure 1b). Significantly higher concentrations of mineral NO_3-N (range 2–32 mg/kg) were observed to 80 cm depth under the incorporated treatment compared to the other two treatments (range 4–14 mg/kg), suggesting that under the incorporated treatment there was a considerably higher rate of mineralisation. By day 136 (October 8), the NO_3-N bulge had moved from 15 cm to 60 cm down the profile under the incorporated treatment, presumably due to leaching, whereas there was a less prominent bulge and it was still in the 20–40 cm depth for the two non-incorporated treatments (Figure 1). The depth of the bulge for the incorporated soybean residue treatment at 136 days is similar to that measured at this site previously (Garside *et al.*, 1998)

In an effort to establish the degree of nitrogen mineralisation and potential losses, the concentration of nitrate nitrogen down the entire profile (0–110 cm) from May 25 (Day 1) through to October 8 (Day 136) for the three treatments was calculated (Table 2). By day 70 (August 3) the NO_3-N content in each of the profiles had increased by 183.6, 39.0 and 60.4 kg/ha for the incorporated, surface retained and standing

Table 1—Soybean biomass responses to lime and gypsum applications 65 days after establishment.

Growth parameter	Lime rate (t/ha)				$LSD_{(0.05)}$
	0	2.5	5.0	10	
Biomass (kg/ha)	1183	1314	1392	1510	231
	Gypsum rate (t/ha)				
	0	5			
Biomass (kg/ha)	1235	1464			163

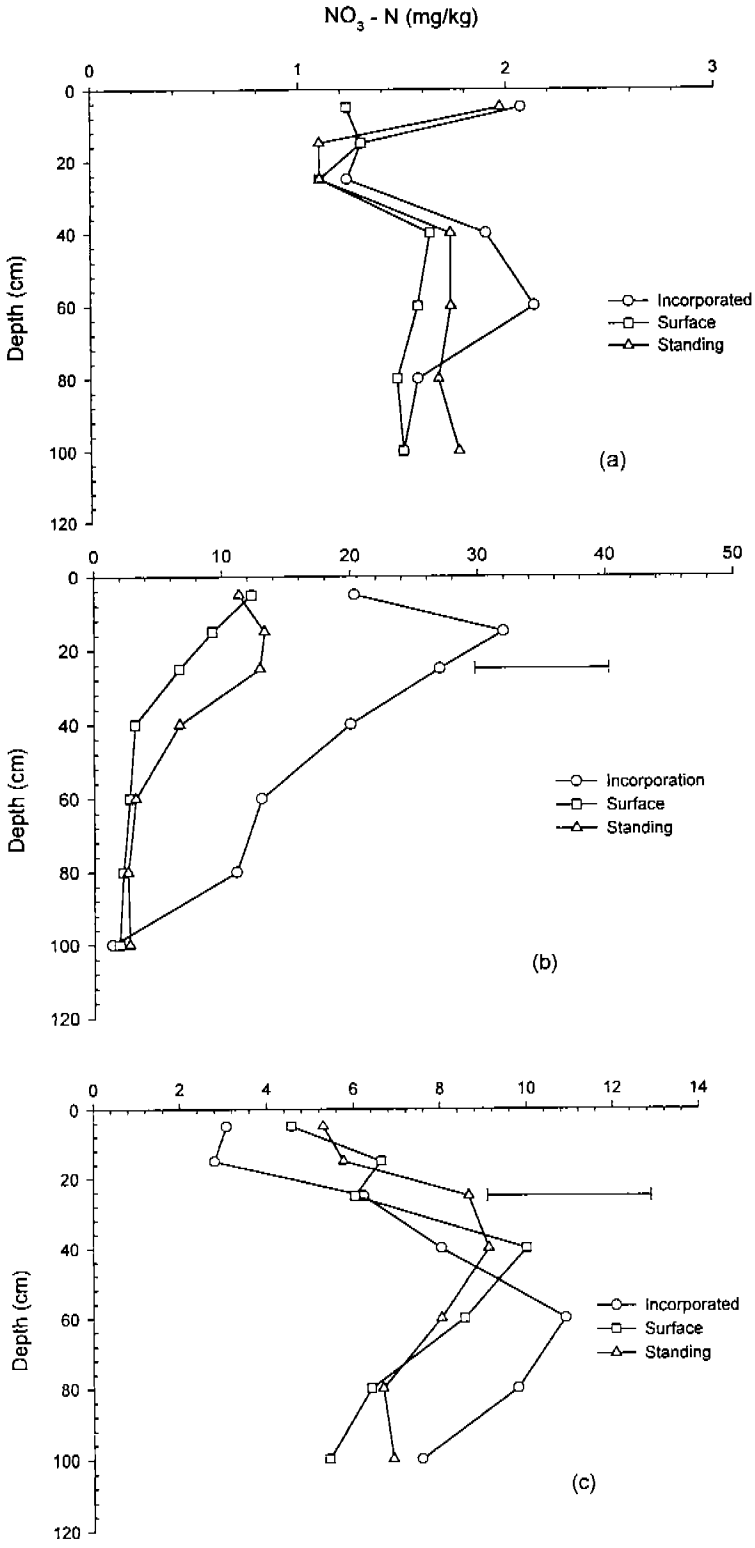

Fig. 1—Soil nitrate profiles under different soybean residue management systems at (a) time day 1 (just prior to incorporation of material), (b) 70 days after incorporation (just prior to establishment of a cane crop) and (c) 136 days after incorporation. Horizontal bars represent the least significant difference $p<0.05$.

Table 2—Nitrate nitrogen contents of soil profiles to 110 cm under different residue management systems. Positive changes in NO_3-N content between days 70 and 136 represent a net loss from the profile, while a negative value reflects a net addition to the profile.

Residue management	Days after incorporation of soybean crop			Difference between 70 and 136 days
	0	70	136	
	kg NO_3-N/ha			
Incorporated	22.5	206.1	101.6	104.5
Surface retained	19.1	58.4	93.6	–35.2
Standing	21.5	81.9	97.4	–15.5

treatments, respectively (Table 2). However, by day 136 the NO_3-N content in the residue incorporated treatment had declined to 101.6 kg/ha while, in the surface retained and standing treatments, it had increased to 93.6 and 97.4 kg/ha respectively (Table 2). Subtracting NO_3-N contents between days 70 and 136 offers an insight into the dynamics of the mineralisation process. In the case of the residue incorporated treatment the net addition of mineralised nitrate to the profile had declined to reflect a loss of 104.5 kg NO_3-N/ha from the system over this period. In contrast, the surface retained and standing treatments showed net increases of 35.2 and 15.5 kg NO_3-N/ha respectively over the same period. This would suggest that mineralisation of nitrogen was occurring at a faster rate than losses in the surface retained and standing treatments during this period. Clearly the substantial loss of mineralised nitrate in the case of the incorporated treatment represents a significant 'waste' of the potential 271 kg N/ha initially added in the soybean crop. Virtually none of this nitrogen is likely to have been used by the cane crop as, by day 136, the cane crop had only been in the ground 63 days and took at least 30 days to emerge.

Changes in soil pH under residue management

Soil pH was monitored on day 1 and day 136 for the three residue management treatments. With time there was a decrease in soil pH down the entire profile in all residue management treatments (Figure 2), indicating that the mineralisation of organic nitrogen, along with the uptake of cations, resulted in net proton addition. However, in the case of the incorporated treatment, the shape of the curve in October 1998 differed from the two non-incorporated treatments (Figure 2). This can be ascribed to the acid neutralising influence of the incorporated residue that had been mixed with the top 20 cm of soil. The net acid addition (NAA) over the 0–30 cm depth interval for the incorporated, surface retained and standing treatments was estimated to be 15.8, 21.5 and 21.5 kmol H^+/ha respectively. The lower net acid addition observed under the incorporated treatment is indicative of the influence of the decomposing residue and the release of alkalinity that would effectively neutralise a portion of the acidity generated during nitrogen mineralisation. Increased acid generation in surface soils as observed in the two non-incorporated treatments is commonly observed in no-tillage production systems (Phillips and Young, 1973).

General discussion and practical implications

The results from this study clearly demonstrate that the addition of soybean residue to the soil results in significant amounts of nitrate nitrogen generation that is readily available for plant uptake. However, at least on the wet tropical coast, residue management significantly influences the efficacy of this legume nitrogen. Data presented here shows that the traditional practice of incorporating the residue results in rapid mineralisation and subsequent movement down the profile through leaching. Contrasting with this, the retention of residue either on the soil surface or as a standing crop reduces the rate of mineralisation and subsequent release of nitrate thereby resulting in significantly reduced leaching. Although processes other than leaching, such as denitrification and surface runoff, which may result in significant nitrate losses have not been taken into account, it is unlikely that they contributed significantly to the nitrogen dynamics in this study. Associated with these mineralisation processes and subsequent leaching of nitrate was a significant decline in soil pH which was more pronounced in the non-incorporated treatments.

There are several field implications for the sugarcane farming system on the wet tropical coast that emerge from this study. First, to effect

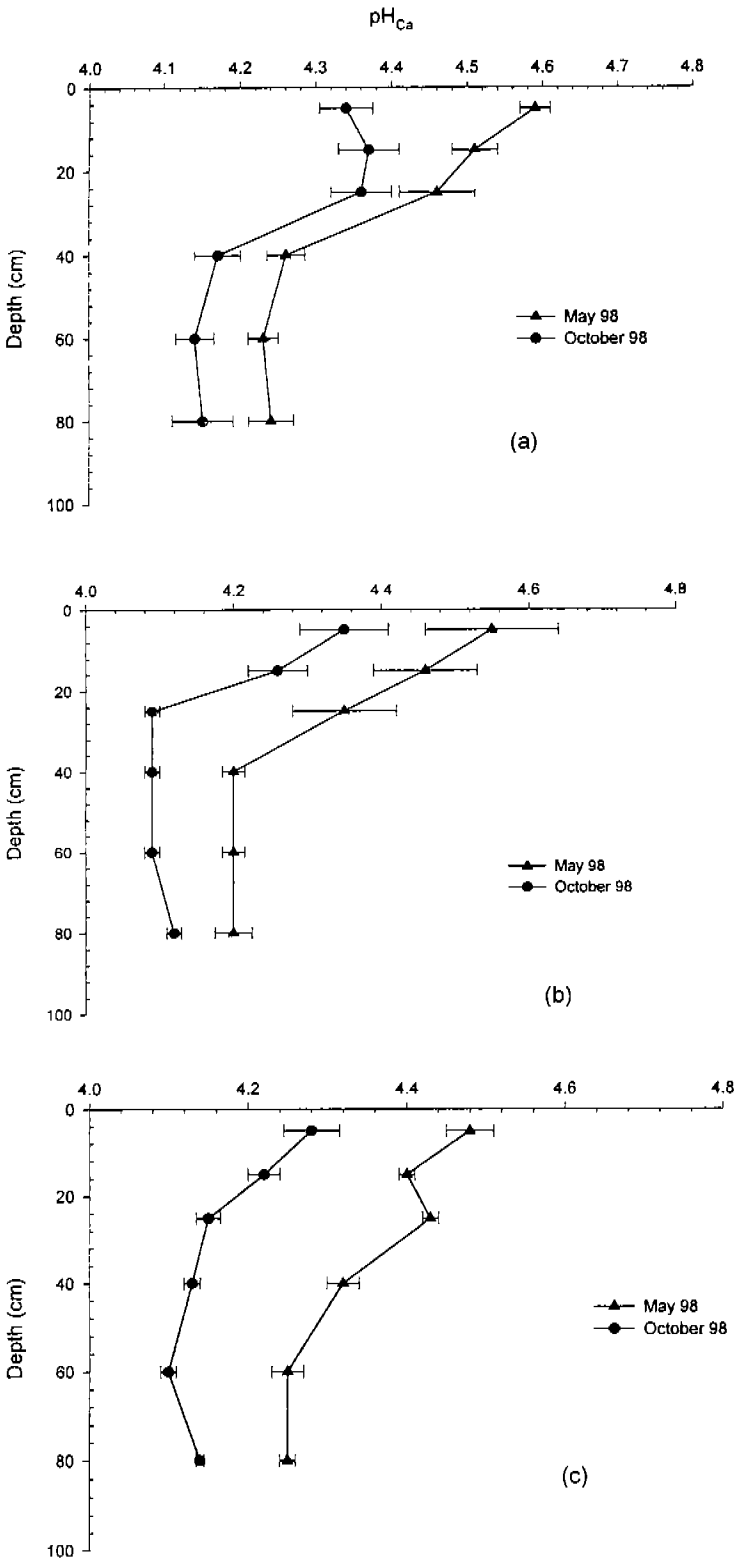

Fig. 2—Temporal changes in soil pH_{Ca} associated with (a) the incorporation of soybean residue (b) surface retention and (c) standing residue. Horizontal bars represent the stand error of the mean.

maximum utilisation by the plant cane crop of nitrogen generated from soybean residue, establishment of the sugarcane crop should occur as soon as possible after the maturity of the break crop. Second, the soybean residue should not be incorporated but should be maintained on the soil surface, even though this is likely to result in a slight increase in acidity. Third, a practical means of reliably establishing a sugarcane plant crop without intensive land preparation will be necessary to accommodate these two requirements. Such technology is now becoming available with the development of strategic tillage (Braunack *et al.*, 1999). It is not hard to envisage the removal of the old ratoon with herbicide or a narrow line of cultivation, the establishment of a soybean crop through direct drilling several rows into the old cane mound, and the direct planting of sugarcane into surface retained soybean residue. In such a system significant benefits in timeliness of operations are likely to be realised (McPhee *et al.*, 1995). However, the increase in acidity with surface residues will mean that, in some areas, a method of incorporating lime in a reduced tillage system will need to be developed and/or periodic cultivation may need to be employed. Conversely, the reduction in pH with surface management may be able to be used to advantage in areas such as the Burdekin, where increasing alkalinity has been associated with reduced efficacy of chlorpyrifos for cane grub control (Robertson *et al.*, 1998, Chandler *et al.*, 1998).

The data presented here came from a single legume species grown on a relatively permeable soil in a high rainfall area. The wider application of these results requires further evaluation. However, some leads as to their general applicability can be gained from other rotation studies being conducted as part of the Sugar Yield Decline Joint Venture. First, in a previous study at this site (Garside *et al.*,1998), it was shown that the mineralisation and movement down the profile of nitrate nitrogen from incorporated peanut residue followed a similar pattern to that from soybean residue. This suggests that the trends measured here are not specific to soybean, but are applicable to other legumes. Second, the results from rotation experiments conducted in lower rainfall, higher latitude areas, such as Mackay and the Burdekin, clearly indicate that soybean can grow as well and contribute as much nitrogen in these environments as on the wet tropical coast (Garside *et al.*, 1999). Finally, the major differences between more southerly cane growing areas and the wet tropical coast are that the former has lower annual rainfall and generally less permeable soils. Both of these factors tend to suggest that surface maintenance of legume residues as opposed to incorporation is unlikely to result in the same benefits in these more southerly cane growing areas, but this needs to be evaluated. Regardless, providing there is no adverse effect on the growth of the following sugarcane crop, advantages associated with reduced tillage and more timely establishment of the sugarcane crop are likely to be realised with surface management of legume residues.

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