MANAGEMENT OF LEGUME BIOMASS TO MAXIMISE BENEFITS TO THE FOLLOWING SUGARCANE CROP

By

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Abstract

PREVIOUS studies on the wet tropical coast have shown that the management of soybean biomass can have important implications for residue decomposition and mineralisation of nitrogen. The traditional incorporation of soybean as a green manure resulted in rapid mineralisation and, at least on permeable soils under wet seasonal conditions, rapid movement of nitrate nitrogen below the root zone of the subsequent cane crop. However, it was shown that the rate of mineralisation could be slowed and more mineral nitrogen made available to the subsequent cane crop if the legume was managed as a standing crop or slashed and left on the surface. In these previous studies, yields of the following cane crop were not recorded due to uneven cane establishment, which was not related to legume management treatments. A subsequent experiment was conducted between 2001–2003 at Tully Experiment Station where a range of different soybean management treatments were imposed and then planted to sugarcane in June 2002 without any applied nitrogen. The mineralisation of nitrogen from the legume residue followed the patterns previously established, even though the 2002–2003 growing season was one of the driest on record and the soil type was a heavy clay. The cane yield following standing soybean or slashed soybean biomass left on the surface was not significantly different to that following green manure soybean, and in fact there was a strong trend for higher cane yields following standing or surface managed soybean biomass. Where soybean biomass was removed and no nitrogen fertiliser applied, the cane yield was reduced by up to 42%. The good yields following the surface and standing management of soybean biomass were shown to be associated with larger stalks that could be related to more nitrogen being available later in the growing season. Regardless of how soybean biomass was managed, CCS was unaffected. Managing legume biomass on the surface or as a standing crop ideally suits minimum/zero tillage, controlled traffic, legume-based farming systems that the Sugar Yield Decline Joint Venture is developing.

Introduction

In sugarcane cropping systems in Australia, fallow legumes have traditionally been incorporated as green manures at the end of the wet season. This normally coincides with flowering of the legume crop. Recent research conducted by the Sugar Yield Decline Joint Venture (SYDJV) has investigated a whole range of issues with respect to fallow legume species and management in sugarcane cropping systems (Garside and Bell, 2001). As part of this research program, Garside *et al.* (1998) followed the mineralisation and movement down the soil profile of nitrate nitrogen from a soybean crop incorporated on a permeable soil at Feluga on the wet tropical coast. They demonstrated that both mineralisation and movement down the profile proceeded very rapidly, with a nitrate nitrogen bulge moving from near the surface some 50 days after incorporation to a depth of 60 cm by around 140 days. Quite often, weather conditions on the wet tropical coast preclude sugarcane planting until several months after the fallow is incorporated, presenting the real possibility that the legume nitrogen will be situated well below the root zone when required by the sugarcane plant.

This situation encouraged Noble and Garside (2000) to investigate different methods of management of fallow legume biomass. They showed that by slashing a soybean crop and leaving the biomass on the surface, or by leaving the crop standing, the rate of nitrogen mineralisation and the movement down the profile could be substantially slowed. A subsequent sugarcane crop planted on the differently managed fallows established quite poorly, making it impossible to measure any significant effect of legume biomass management on sugarcane yield. In more recent studies in a relatively dry environment on a less permeable soil at Bundaberg, Bell *et al.* (2003) demonstrated that there was no cane yield reduction with surface management of soybean biomass compared with traditional incorporation. Further, they showed that the addition of 150 kg/ha N following a soybean fallow did not increase yield above that with no applied nitrogen. Garside *et al.* (1997) had previously demonstrated a lack of response to nitrogen fertiliser on the wet tropical coast following a soybean fallow. Nitrogen fertiliser is a substantial cost component of the sugarcane cropping system, so any strategy that can maximise the availability of legume nitrogen and reduce the need for nitrogen fertiliser should be encouraged.

Due to the failure to obtain reasonable sugarcane establishment in the earlier study of Noble and Garside (2000), it was decided to repeat the soybean biomass management experiment at Tully Experiment Station (TES) in the period 2001–2003. Some additional legume management options were added to those previously employed and the legume management practices were interacted with tillage. This paper reports the results of both the soybean and sugarcane phases of the experiment.

Materials and methods

The experiment was conducted on Block 33 at Tully Sugar Experiment Station (17^0 59' S, 145^0 55' E) between December 2001 and June 2003. Soil type was a heavy clay of the Coom Series. The experiment was established on 27 x 1.8 m wide raised beds that had been formed in June 2001 and planted to sugarcane while testing a new double disc opener sugarcane planter. This cane was removed by spraying with glyphosate at 10 L/ha on November 14, 2001.

Soybean (variety Leichardt) was direct seeded at 50 kg/ha into the top of all the beds on December 12, 2001 using a triple row direct drill grain seeder. The soybean row spacing on the bed top was 37 cm. No fertiliser was applied and no pre-emergent herbicide was used, but Fusilade® was applied at 1 L/ha on January 14, 2002 to control volunteer sugarcane. Soybean establishment was good and a reasonable fallow legume crop was established.

Soybean management practices were commenced at mid-pod fill (April 8, 2002) when soybean biomass and nitrogen content was expected to be at its maximum (Garside *et al.,* 1996). At this time, the planted area was split into four replications each 27 beds wide x 15 m long. Within each replication, plots were randomly allocated to nine soybean management treatments. Hence, each treatment plot was 3 beds x 15 m in a randomised block design. The nine soybean management treatments were as follows:

- Green soybean fully incorporated (GI).
- Green soybean tops cut and left on the surface (GS).
- Green soybean tops removed and roots incorporated (GRI).
- Green soybean tops removed but roots not incorporated (GRNI).
- Mature soybean incorporated (MI).
- Mature soybean cut and left on the surface (MS).
- Mature soybean tops removed and root incorporated (MRI).
- Mature soybean tops removed but roots not incorporated (MRNI).
- Soybean left standing (LST).

On April 8, 2002, soybeans were sampled (2 x 1 m sections from the centre bed of each treatment plot) for biomass production in plots designated for GI, GS, GRI and GRNI. Total fresh weight was measured and a sub-sample was taken to determine dry weight and for subsequent tissue nitrogen analysis. The remainder of the fresh sample was returned to the plot. All tops were then removed from GRI and GRNI plots but were left on the surface for GS and GI plots. Eight of these plots (two from each replication) were then soil sampled using a 50 mm tube inserted with an electric powered precussion jack hammer in six increments to 90 cm (0–10, 10–20, 20–30, 30–50, 50–70 and 70–90) to measure soil mineral (nitrate + ammonium) nitrogen. All samples were stored in a cool room until dried at 40^0C, ground, extracted with KCl and analysed using an automated calorimetric method. On April 23, the first opportunity that weather permitted, the GI and GRI plots were incorporated with a light rotary hoeing taking care not to destroy the integrity of the beds.

On May 16 and 17, the mature soybean treatments (MI, MS, MRI and MRNI) were imposed. Each treatment was handled as described above for the green treatments. Biomass samples were not taken as previous experience (Garside *et al.,* 1996) had indicated that maximum biomass would have been achieved at or about the sampling on April 8 and the soybean crop was very even across the site.

Sugarcane, variety Q187[Φ] was direct planted with a double disc opener dual row planter across the entire experiment on June 3, 2002. No fertiliser or SuSCon® insecticide was applied at planting but setts were sprayed with Shirtan® fungicide as they passed through the planter. The entire experiment was sprayed with a mixture of Dual Gold® and Gesaprim® at 1.45 L/ha and 3 kg/ha, respectively for weed control on June 5. All plots in the experiment were then soil sampled to 50 cm in four increments (0–10, 10–20, 20–30 and 30–50) on June 6. Further soil samples (to 90 cm in 6 increments) to follow nitrogen mineralisation and movement down the profile were taken on September 23, 2002 and February 12, 2003.

The entire experiment received phosphorus at 20 kg P/ha as triple superphosphate and 100 kg K/ha as muriate of potash on September 19, 2002. No nitrogen fertiliser was applied to the experiment. Rainfall was recorded at a weather station located some 200 m from the site.

Measurements

Immediately after crop establishment, 10 m x 1.8 m (one bed width) was permanently marked on the centre bed of each treatment plot for subsequent crop growth measurements. Temporal counts of shoot/stalk numbers and the final harvest yield of sugarcane were recorded from this area. At harvest (June 10, 2003) all stalks in the area were counted, cut at ground level and weighed on a weighing platform set up on a tandem trailer to determine total wet biomass. Twenty stalks were randomly selected and partitioned into millable stalk, and leaf and cabbage by dividing them between the fifth and sixth dewlaps from the top of the stalk. Fresh weight of the 20 stalks, and leaf and cabbage were recorded and used to calculate the percentage millable stalk in the harvested product. Sub-samples of both were then mulched, weighed, dried at 70^0C for 72 hours, and re-weighed to allow calculation of dry biomass. The combination of percentage millable stalk and total wet biomass of the sample was used to calculate millable stalk yield. Four millable stalks were set aside to determine CCS using the small mill method.

Data for soil mineral nitrogen content for the various sampling dates and depths were converted from mg/kg to kg/ha using bulk density data collected at the site (S. Berthelsen, pers. comm.). The bulk densities used were 1.09, 1.21, 1.30,1.36, 1.35 and 1.41 g/cc for 0–10, 10–20, 20–30, 30–50, 50–70 and 70–90 cm depth increments, respectively.

Results and discussion

Seasonal conditions

This experiment was carried out during one of the driest periods on record for the Tully area. While the average annual rainfall is of the order of 4000 mm per year, rainfall for 2001, 2002 and 2003 (until the end of September) totalled 2810, 1729 and 1880 mm, respectively. Further, from the end of the soybean phase of this experiment (April 2002) to the harvest of the plant cane crop (June 2003) the total recorded rainfall was only 2459 mm. Details are provided in Table 1.

Table 1–Rainfall for the duration of the experiment–January 2002 to June 2003. The rainfall for December 2001 was 51 mm.

Year	Jan	Feb	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
2002	193	369	233	327	223	46	58	113	57	3	64	42
2003	320	188	322	472	256	182						

Soybean biomass production and nitrogen content

The soybean crop produced on average 5624 kg/ha dry matter with a nitrogen concentration in the tops of 3.06%. This represented 173 kg/ha N being accumulated in the soybean tops. Further, more recent studies have shown that more than 30% of the total N in a soybean crop is contained in below ground parts (Rochester *et al.,* 1998). Therefore, this crop of soybean probably contained in the order of 230 kg N/ha.

Nitrogen mineralisation and movement down the profile

Data for mineral nitrogen levels (mg/kg) at different depths for the various soybean treatments on June 6, September 23, 2002 and February 12, 2003 are shown in Figures 1–3, respectively. On April 8, prior to any treatments being imposed, there was no significant difference in mineral N levels at any depth between the different plots sampled. A mean total of 156 kg N/ha was calculated in the 90 cm of profile for the eight treatment plots sampled.

On June 6, two months after the implementation of the green (GI, GS, GRI and GRNI, but only 6 weeks after the incorporation of GI and GRI) soybean management treatments and almost 3 weeks after the implementation of the mature soybean management treatments (MI, MS, MRI and MRNI), the amount and distribution of mineral nitrogen in the profile had changed considerably in some of the treatments (Figure 1). Samples were only taken to 50 cm on this occasion as it was thought unlikely that mineral N originating from the soybean residue would have moved below this depth within 2 months. The data shown in Figure 1 support this decision, as levels at 30–50 cm were similar or slightly less than they were for the previous sample (data not shown) and there was no significant difference between treatments.

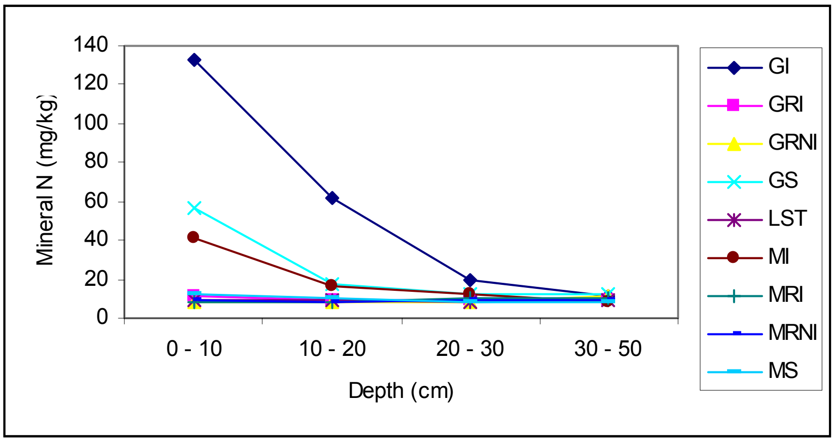

Fig. 1—Levels of mineral N (mg/kg) over 50 cm on June 6, 2 months after implementation of green soybean management treatments (but only 6 weeks after incorporation of GI and GRI) and 3 weeks after implementation of the mature soybean management treatments. *Lsd 5% = 42 (0–10 cm), 17 (10–20 cm), 4 (20 –30 cm), NSD (30–50 cm).*

There was a large increase in mineral N in the top 30 cm where green soybean material had been fully incorporated (GI) and a much smaller increase in the top 20 cm when the tops were left on the surface (GS). The only other treatment showing any mineralisation of N at this stage was the mature crop fully incorporated (MI) treatment that had only been implemented 3 weeks previously (Figure 1). All other treatments were showing very low levels of mineral N. The magnitude of the mineralisation with GI in the six weeks since incorporation can be gauged by comparing the amount of nitrogen in the top 50 cm on April 8 (81 kg/ha) and June 6 (275 kg/ha) (Table 2), with the 194 kg/ha differential representing ca. 85% of the total crop N content measured at the time of incorporation. Low levels of mineral N were recorded whenever the above ground soybean biomass had been removed (GRI, GRNI, MRI, MRNI) and the level was not affected by tillage (GRI vs GRNI and MRI vs MRNI) (Figure 1).

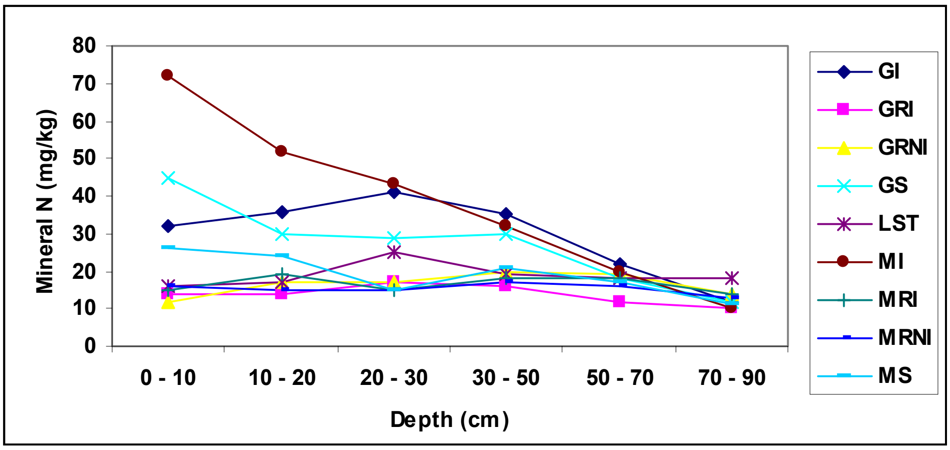

Fig. 2—Levels of mineral N (mg/kg) over 90 cm on September 23, 6 months after implementation of green soybean management treatments, 4.5 months after implementation of the mature soybean management treatments and 3.5 months after cane planting. *Lsd 5% = 19 (0–10 cm), 13 (10–20 cm), 13 (20–30 cm), 10 (30–50 cm), NSD (50–70 cm), NSD (70–90 cm)*

By September 23, there were again substantial changes in the distribution of nitrogen throughout the profile (Figure 2) with a substantial reduction in the mineral N in the surface 10 cm following GI (and indications of movement down the profile) and higher levels in the surface following MI and GS. There were also indications of mineralisation in the top 20 cm with MS. In general, surface management of residue and/or late incorporation tended to maintain more mineral N in the surface layers of the soil relative to incorporation of green material . By February 23, 2003 (Figure 3) mineral N had generally moved deeper into the profile, particularly with the GI treatment. Further, there was less mineral N in the surface layers than for GS, MS, MI and LST, particularly in comparison with GS.

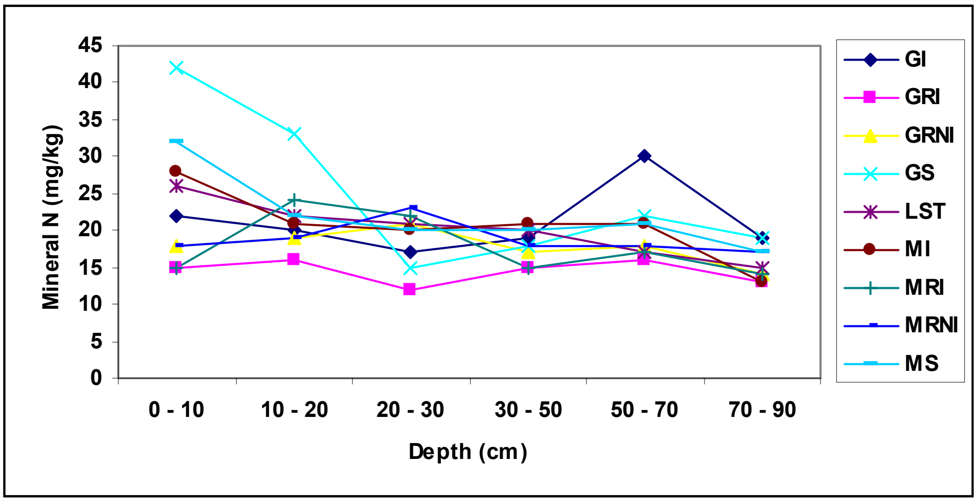

Fig. 3–Levels of mineral N (mg/kg) over 90 cm on February 12, 2003, 10 months after implementation of green soybean management treatments, 8.5 months after implementation of the mature soybean management treatments and 7.5 months after cane planting. *Lsd 5% = 15 (0–10 cm) with NSD at all other depths.*

The distribution and movement of N down the profile can be seen very clearly in Table 2 where total mineral N in the top 50 cm is calculated for the period April 8, 2002 to February 12, 2003. Basically, wherever large amounts of N were mineralised they moved down the profile quite rapidly. For example, GI and MI were very obvious in this respect. GS and MS showed similar trends but mineralisation was slower and more mineral N was available for a longer period. Further, where the soybean material was removed the profile had relatively low levels of N during the early stages of sugarcane growth.

Table 2—Total mineral N (kg/ha) in the soil profile to a depth of 50 cm at different times after the implementation of various soybean residue management treatments.

Soybean residue management	Date			
	April 8, 2002	June 6, 2002	Sept. 23, 2002	Feb.12, 2003
GI	81	275	226	123
GRI	"	59	98	92
GRNI	"	58	108	116
GS	"	131	204	155
MI	"	102	284	140
MRI	"	57	107	114
MRNI	"	54	101	118
MS	"	59	135	140
LST	"	53	121	136

Millable stalk, CCS and sugar yields

Data for millable stalk and sugar yields are shown in Table 3. There was no effect of soybean management treatment on CCS, which averaged 9.1 and was probably low because of the very early harvest. There were significant effects of soybean management on both cane and sugar yield, with a clear trend for the highest yields to come from surface managed or standing soybean residue.

Although not significantly lower yielding ($p < 0.05$), full incorporation of both green (GI) and mature (MI) soybean residue tended to produce lower millable stalk yields than the GS, MS and LST treatments.

In fact, GS produced a significantly higher sugar yield than GI. Where the soybean tops were removed (MRI, MRNI and, particularly GRI and GRNI) millable stalk yields were significantly lower than where the residue remained.

In fact, the comparison between two treatments, where the only difference was removal (GRNI) or non removal (GS) of the soybean tops, resulted in a millable stalk yield increase in favour of GS of 42%. Tillage *per se* appears to have had virtually no influence as demonstrated by the very similar millable stalk yields recorded between GRI and GRNI, and MRI and MRNI. The main effect of tillage was through its stimulation of nitrogen mineralisation as in GI and MI.

The trend towards higher millable stalk yields (although non-significant), with MRI and MRNI compared with GRI and GRNI, is possibly associated with the small amount of nitrogen in leaf litter that may have entered the soil prior to the mature treatments being imposed, although this was not discernable from the soil nitrogen data (Table 2).

Table 3–Millable stalk and sugar yields (t/ha) as influenced by different soybean residue management strategies.

Soybean residue management	Yield (t/ha)	
	Millable stalk	Sugar
GI	81	6.9
GRI	69	6.3
GRNI	65	5.8
GS	92	8.8
MI	82	7.4
MRI	75	6.8
MRNI	75	7.0
MS	92	8.3
LST	88	8.3
Lsd 5%	15, ($p = 0.009$)	1.7, ($p = 0.023$)

Yield components

Final stalk numbers and individual stalk weights are shown in Table 4. There were never any significant differences between treatments for shoot/stalk number at any sample time throughout the growing period, so only the final stalk numbers are presented. Differences between treatments in millable stalk yield were clearly associated with differences in individual stalk size with the largest stalks being produced by the surface management treatments GS and MS, followed by LST. The smallest stalks were recorded with GRI and GRNI.

The relationship between individual stalk weight (ISW) and millable stalk yield (MSY) could be explained with the linear equation $MSY = -6.88 + 85.54 \times ISW$ ($p < 0.001$), with this relationship accounting for 95% of the variation in cane yield between treatments. Further, there was also a significant linear relationship between the nitrogen available (kg/ha) in the top 50 cm of soil on February 12 (NFEB) and ISW, suggesting that nitrogen availability in February had an effect on yield through stalk size. The equation for this relationship was $ISW = 0.397 + 0.00490 \times NFEB$ ($p = 0.006$) and accounted for 64% of the variation in individual stalk weight.

Table 4—Final harvested stalk numbers (10^3/ha) and individual stalk weight (kg) for cane grown following different soybean biomass management.

Soybean residue management	Yield (t/ha)	
	Final stalk no. (x 10^3/ha)	Individual stalk wt. (kg)
GI	83	0.98
GRI	78	0.89
GRNI	77	0.84
GS	80	1.16
MI	80	1.02
MRI	77	0.99
MRNI	76	0.99
MS	79	1.16
LST	80	1.10
Lsd 5%	NSD	0.16, (p =0.005)

General discussion

The results of this experiment confirm previous reports by Garside *et al.* (1998), Noble and Garside (2000) and Bell *et al.* (2003) that the traditional method of incorporating legume fallows as green manures at the end of the wet season is not the most appropriate way of handling legume biomass. Better utilisation will be achieved by, at least, not incorporating until the soybean crop is mature. However, the data presented here indicates that the most appropriate strategy is to leave the soybean biomass on the soil surface, either as a mulch or as a standing crop. This experiment was conducted on a heavy clay soil under very dry conditions, yet mineralisation and movement down the profile of incorporated material still occurred, albeit more slowly than previously recorded by Garside *et al.* (1998). Standing crop or surface managed biomass mineralised and moved down the profile more slowly. The end result of differences in rates of N mineralisation and subsequent leaching appeared to be a shortage of nitrogen during the stalk-filling period in the incorporated treatments that resulted in reduced yields. This result is consistent with the findings of Bell *et al.* (2004, These Proceedings), who have shown that stresses that impeded crop growth rate during the stalk-filling period will reduce the ability of crops to capitalise on high stalk densities.

The removal of soybean biomass adversely affected millable stalk yield and sugar yield, presumably due to a nitrogen limitation during stalk filling. These treatments (GRI, GRNI, MRI and MRNI) were included in this experiment for two reasons. First, they provided an indirect means of measuring the impact of tillage exclusive of soybean biomass management. Direct comparisons between GRI and GRNI, and also MRI and MRNI (Table 3) showed no yield differences indicating that the single tillage operation carried out in this experiment had no direct impact, except through its impact on nitrogen dynamics when combined with soybean biomass. Second, with the current economic climate in the sugar industry and drought affecting many grazing areas, growers have shown increasing interest in green harvesting their fallow legumes for stock feed. Comparisons between GRNI and GS and also MRNI and MS give a measure of the impact of removing soybean biomass on subsequent sugarcane yield when no fertiliser nitrogen is applied. The millable stalk yield reductions measured here from implementing GRNI and MRNI, as opposed to GS and MS, were 42% and 22%, respectively. Of course, other studies (Garside *et al*., 1997, 2001; Bell *et al.,* 2003) have shown that the benefits of a legume break are reflected in both nitrogen fixation and soil health but, with all treatments in this study containing a soybean fallow, the magnitude of the soil health component could not be quantified. However, recent reports by Stirling *et al.,* (2003) suggest that the removal of soybean biomass may reduce the magnitude of the soil health benefits, due to the reduction in the amount of organic matter added to the soil.

Practical implications

The Sugar Yield Decline Joint Venture has a strong focus on developing improved farming systems for the Australian sugar industry based on controlled traffic, minimum or zero tillage and legume-based fallows to break the sugarcane monoculture (Garside, 2002, 2003). In order to maximise the benefits from such a system, a strategy that avoids the need for soil disturbance to incorporate legume biomass must be developed. The results of this study clearly show that a change from the traditional green manure incorporation practice (GI) can be affected without adverse consequences. In fact, retaining the legume biomass on the surface as a mulch or leaving it standing are likely to have positive effects on the value of the legume to the following sugarcane crop. At the very least, not incorporating the legume until the crop is mature (MI) is likely to be a more appropriate strategy than the traditional green manure incorporation. Further, there is accumulating anecdotal evidence that if cane is planted soon after the incorporation of green soybean material (and probably green material of some other legumes), cane establishment can be adversely affected. In contrast, there have been no reports of adverse establishment effects following surface management or the incorporation of mature soybean material.

Finally, the proximity of the sugar industry to coastal Queensland and the Great Barrier Reef is raising increasing concerns about the adverse effects of pesticide and nutrient contamination of runoff to streams discharging into the Great Barrier Reef lagoon. Although not tested in this study, previous research has shown that no nitrogen fertiliser is required following a well-grown soybean crop (Garside *et al.,* 1997; Bell *et al.,* 2003).

Similarly, Bell *et al.* (2003) have shown that reduced tillage after the legume fallow offers real advantages in reducing runoff and likely off-site movement of nutrients and pesticides by maximising rainfall infiltration. The work reported in this study, along with other findings (Garside *et al.,* 1998; Noble and Garside, 2000) have shown that the risks of rapid mineralisation of N from fallow legumes and resultant leaching of N down the profile and into groundwater can also be minimised through appropriate tillage and biomass management without any yield sacrifice. There is also every chance that costs will be reduced and yields probably improved by adoption of the combination of management practices discussed here. In an associated paper in these proceedings (Garside *et al.,* 2004, These Proceedings), the results of initial large scale experiments involving minimum tillage, controlled traffic and legume breaks are discussed.

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