

SUGARCANE PRODUCTIVITY RESPONSE TO DIFFERENT FALLOW AND SOYBEAN RESIDUE MANAGEMENT PRACTICES IN THE BUNDABERG DISTRICT

By

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Abstract

GRAIN LEGUME ROTATIONS underpin the sustainability of the Australian sugarcane farming system, offering a number of soil health and environmental benefits. Recent studies have highlighted the potential for these breaks to exacerbate nitrous oxide (N₂O) emissions. An experiment was implemented in 2012 to evaluate the impact of two fallow management options (bare fallow and soybean break crop) and different soybean residue management practices on N₂O emissions and sugarcane productivity. The bare fallow plots were conventionally tilled, whereas the soybean treatments were either tilled, not tilled, residue sprayed with nitrification inhibitor (DMPP) prior to tillage or had a triticale 'catch crop' sown between the soybean and sugarcane crops. The fallow plots received either no nitrogen (N0) or fully fertilised (N145) whereas the soybean treatments received 25 kg N/ha at planting only. The Fallow N145 treatment yielded 8% more cane than the soybean tilled treatment. However there was no statistical difference in sugar productivity. Cane yield was correlated with stalk number that was correlated to soil mineral nitrogen status in January. There was only 30% more N/ha in the above-ground biomass between the Fallow N145 and the Fallow N0 treatment; highlighting poor fertiliser nitrogen use efficiency. Supplying adequate nitrogen to meet productivity requirements without causing environmental harm remains a challenge for the Australian sugar industry. The soybean direct drill treatment significantly reduced N₂O emissions and produced similar yields and profitability to the soybean tilled treatment (outlined in a companion paper by Wang *et al.* in these proceedings). Furthermore, this study has highlighted that the soybean direct drill technique provides an opportunity to enable grain legume cropping in the sugarcane farming system to capture all of the soil health/environmental benefits without exacerbating N₂O emissions from Australian sugarcane soils.

Introduction

Grain legume rotations are an integral part of a more sustainable sugarcane farming system. Leguminous crop rotations improve the productivity of the subsequent sugarcane crop (Garside *et al.*, 1999) and reduce populations of plant parasitic nematode (Stirling *et al.*, 2001).

The legume crop residues enable nitrogen fertiliser to be reduced for the plant cane crop (Bell *et al.*, 2003; Schroeder *et al.*, 2007) and provide soil cover that significantly reduces soil erosion (Halpin *et al.*, 2012).

Legume break crops are a strategic component to reduce the impact of yield decline which is defined as the loss in the productive capacity of soils under long-term monoculture (Garside *et al.*, 1997).

Despite all of these environmental benefits, soybean rotations may exacerbate nitrous oxide (N₂O) emissions from sugarcane soils (Wang *et al.*, 2012). Nitrous oxide is a potent greenhouse gas with a global warming potential 298 times that of carbon dioxide. Nitrogen losses to leaching and denitrification not only pose environmental risks, they reduce nitrogen use efficiency (NUE) in the sugarcane farming system.

This experiment was established to determine if a range of land management practices in a soybean/sugarcane farming system could affect N₂O emissions from soil and sugarcane productivity. This paper will report on the sugarcane crop response; treatment impacts on N₂O emissions will be documented in a companion paper (Wang *et al.*, 2015).

Materials and methods

This trial was established on a redoxic hydrosol soil type. There are currently 17 135 ha of this soil type under sugarcane production in the Bundaberg / Childers region (Mark Sugars, pers. comm.). The previous cane crop (third ratoon Q205^{fb}) was grown on row spacing of 1.57 m using GCTB culture and was ploughed out after harvest. The productivity was poor due to excessive levels of sugar smut (*Ustilago scitaminea*). The entire site was conventionally cultivated using two passes of a rotary hoe. Then the row area of each bed was deep ripped using a Yeoman ripper with three tynes 40 cm apart to a depth of 30 cm using RTK GPS auto-steer technology to ensure that sub-soil constraints due to compaction were minimised in the bed zone.

The site had micro-nutrients zinc, molybdenum and boron applied prior to forming domed 'beds' approximately 1.2 m wide to a height of 20 cm in the row centre. Each replicate was divided into six treatments; two were bare fallow and the remaining four were to be sown to soybean. Soybean CV A6785 was sown to establish 350 000 plants/ha on rows 90 cm apart on the abovementioned bed on 21 December 2012 with fertiliser LegumeMax at 260 kg/ha supplying 13 kg N, 27 kg P, 60 kg K, 16 kg S and 20 kg Ca/ha). The soybean crop was grown with current culture with supplementary irrigation, weeds controlled by pre and post emergent herbicides at registered rates.

Insect incursions of Green Vegetable Bug (*Nezara viridula*) were controlled with insecticide application. At 111 days after planting (DAP), when the soybean crop was at maximum biomass, dry matter production was determined via destructive sampling in a 4.57 m² quadrat in each plot. Samples were dried at 60 °C until they reached constant dry weight, the samples were weighted then ground <2 mm. To determine plant nitrogen content of the above-ground dry matter ground samples were digested by a semi-micro Kjeldhal procedure, then the digestate was diluted prior to automated colorimetric analysis.

This method was modified from (Searle, 1974) and (Heirich, 1990). Soybean grain yield was attained via small plot self-propelled header 168 DAP by harvesting 8 m of the centre row of the plot. Once grain yields were documented, N content of grain crop removed and nitrogen content determined. Nitrogen contribution of the legume crop was calculated as the difference in N in total dry matter production less N in grain removed, it was assumed that only 77% of the legume N was in the above ground biomass. Fallow plots were maintained in a relatively weed free status via herbicide applications.

Following soybean harvest, the soybean plots had a range of management practices imposed (Table 1). Briefly, the soybean residue was incorporated via rotary hoe (T3) replicating current industry practice; left undisturbed on the surface (T4); a nitrification inhibitor–DMPP sprayed onto the soybean residue and soil surface at 3.5 L/ha with 1000 L water/ha prior to incorporation with a rotary hoe (T5); or had a 'catch crop' of triticale cv speedy sown directly into the soybean stubble, allowed to grow for 66 days until being sprayed out with Glyphosate (T6).

All plots had a pass of a single tyne ripper to a depth of 30 cm in the centre of the bed prior to planting. Due to the dry conditions the site was pre-irrigated prior to planting sugarcane. Thus treatments T4 and T6 had no significant soil disturbance between soybean and sugarcane crops,

whereas treatments 1, 2, 3, and 5 were fully cultivated. The treatments were replicated four times as a randomised complete block design.

Table 1—Treatment list.

Treatment	Description
T1	10 month Bare Fallow Tilled N0
T2	10 month Bare Fallow Tilled N145
T3	Soybean Tilled
T4	Soybean DD
T5	Soybean + DMPP +Tilled
T6	Soybean + Triticale DD

Sugarcane (Q238⁴) was planted using a conventional whole-stick planter with fertiliser CK55(S) supplying 25 kg N, P, K, S/ha to all plots except T1. The fertiliser distributor was emptied then filled with a triple super phosphate / potassium sulphate fertiliser blend to supply identical amounts of nutrients P and K in the absence of N for the N0 treatment. The sugarcane crop was grown using current industry best practice with weeds controlled via herbicides, the crop was fully irrigated using high pressure travelling irrigator.

Eighty six DAP, all plots received a blend of muriate and sulphate of potash to supply adequate K and S at fill-in. Only the Fallow N145 (T2) received nitrogenous fertiliser at 120 N/ha at this time.

All soybean plots had their N requirement supplied at planting based on nutrient management guidelines that takes into account nitrogen contribution from the soybean phase (Schroeder *et al.*, 2007).

All fertiliser was supplied to the open planting drill prior to being filled-in with 'go-devil' or ratooning discs to minimise soil disturbance, fill the planting drill and provide an acceptable profile for mechanical harvesting in one pass. All tractor operations were performed using RTK GPS auto-steer technology.

Sugarcane crop growth was measured early, mid-season and final harvest using quadrat size of 5.49m², 9.15m² and 27.45m² respectively. The early dry matter yield was determined at crop fill-in 86 DAP, the mid-season sample was 190 DAP and the crop was harvested 371 DAP.

All yields were determined via destructive sample, sub-sampled, dried at 60 °C and ground <2 mm and nitrogen content determined.

Final yields consisted of a quadrat of three 1.83 m rows by 5 m row length, with stalks counted, total biomass recorded, sub-samples partitioned into trash and millable stalk, and CCS determined on a six-stalk sample sent to SRA for CCS determination by NIR.

A sub-sample of millable stalk and trash (consisting of dry trash, green leaf and cabbage) was mulched, weighed wet and dried at 60 °C as described by (Liu and Kingston, 1993).

Treatment effect on nitrogen uptake was determined via TKN analysis of the individual (millable stalk and trash) components. N uptake is the product of the dry weight of harvested biomass and nitrogen concentration of the components.

Soil mineral N status was determined by 2M KCl extraction and colorimetric techniques (Rayment and Higginson, 1992).

Samples were taken approximately on a six weekly basis for the 0–30 cm depth with the entire profile sampled to 100 cm at the beginning and end of the crop cycle. For the purpose of this paper, concentrations of ammonium (NH₄) and nitrate (NO₃) from the 'bed' area have been used to determine the quantity of N available to the cane crop.

Each plot was sampled in April 2014 to determine treatment impact on plant parasitic nematode populations. Nematodes were extracted by placing the soil on a Baermann tray for 96 h and the suspension sieved twice through a 38 µm sieve (Whitehead and Hemming, 1965).

Treatment effect on profitability was analysed using the Farm Economic Analysis Tool (FEAT) (Cameron, 2005) using the final yield and CCS results of individual plots. All treatment inputs were included in the analysis with the exception of the cost of the nitrification inhibitor (DMPP) which isn't commercially available. The cost of all material inputs was attained from a local agribusiness, prices supplied exclusive of GST.

Data were analysed using Genstat (release 16.1, VSN International) as a general analyses of variance. Pair-wise test of means were conducted at $P = 0.05$ using Fischer's Protected LSD.

Results and discussion

Soybean crop

The soybean crop grew well, yielding an average of 9.6 t/ha and 4.03 t/ha for maximum biomass and grain production respectively. There was an average of 3.36% N in the crop at the time of sampling for maximum biomass resulting in 418 kg N/ha in both above and below ground crop residues. The 418 kg N/ha was calculated assuming that the above ground biomass contributes 77% of the total biomass N (including roots, grain and shoots).

Soybean grain removed 246 kg N/ha at harvest resulting a nitrogen contribution of 172 kg N/ha remaining in crop residue. There was no difference in productivity between the soybean plots (Table 2), as all plots were grown identically with treatment differentiation to occur after the soybean harvest.

Table 2—Soybean dry matter production, nitrogen in dry matter, grain yield, nitrogen removed in harvested grain and nitrogen returned as stubble.

Treatment	Dry matter production (t/ha)	Nitrogen in dry matter (kg N/ha)	Grain yield (t/ha)	Nitrogen removed in harvested grain (kg N/ha)	Nitrogen returned as stubble (kg N/ha)
Soybean Tilled	9.3	399.2	4.08	246.4	152.8
Soybean DD	9.7	424.7	4.10	250.7	174.0
Soybean + DMPP +Tilled	9.9	435.2	4.07	247.0	188.2
Soybean + Triticale DD	9.4	412.8	3.87	238.9	173.9
P value	0.689	0.645	0.663	0.883	0.461
LSD	n.s.	n.s.	n.s.	n.s.	n.s.

Soil mineral nitrogen

Soil sampling to 100 cm depth post-harvest of the soybean crop demonstrated no significant difference in profile mineral nitrogen content with values of 69.5 kg N/ha and 76.9 kg N/ha for the soybean and fallow plots respectively. However profile concentrations of NH_4 were higher in the soybean treatment in the 10–30 cm and 30–60 cm depths compared to the fallow treatment (Figure 1). Whereas, the soil NO_3 concentration was greater at depth 30–100 cm in the fallow plots compared to the soybean plots (Figure 2).

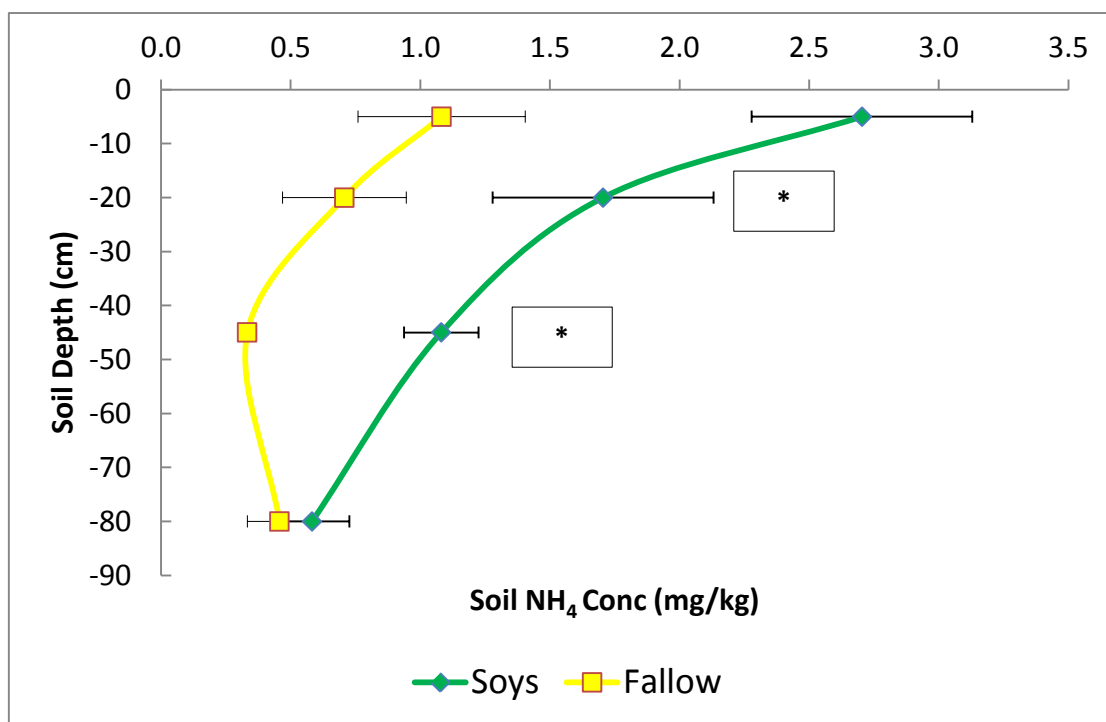


Fig. 1—Soil profile ammonium (NH₄) content (mg/kg) in fallow and soybean treatments post-harvest of the soybean crop. * represents statistically different at P = 0.05.

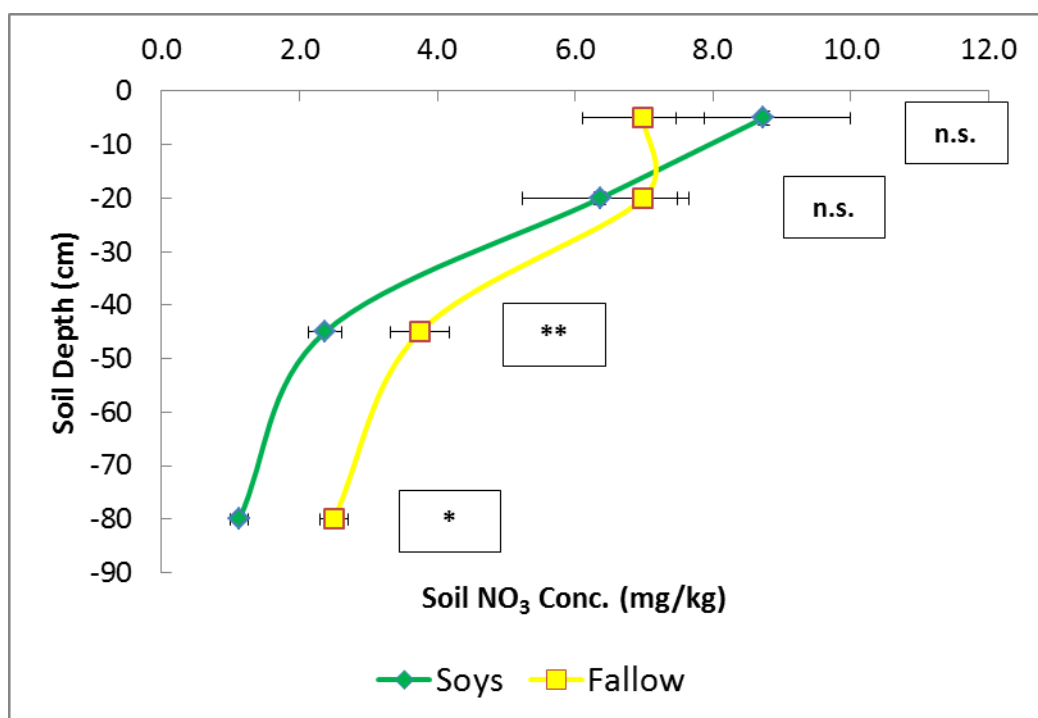


Fig. 2—Soil profile nitrate (NO₃) content (mg/kg) in fallow and soybean treatments post-harvest of the soybean crop. * and ** represents statistically different at P = 0.05 and P = 0.001, respectively.

Soil mineral nitrogen sampling demonstrated that the tilled plots had the highest nitrogen status in July, approx. one month prior to planting (Table 3).

The September sampling (20 DAP) revealed that both of the tilled soybean plots had significantly more mineral nitrogen than the fallow treatments and that the treatment with the

triticale planted between the soybean and cane crops had significantly lower mineral nitrogen status than the Soybean DD treatment. By the time of fill-in (86 DAP), all of the soybean plots had significantly more nitrogen than the fallow treatments; and that the difference between the plots that had been sown to the triticale catch crop still had significantly less nitrogen than the other DD treatment.

The elevated soil mineral nitrogen status of the Fallow N145 treatment in January is evidence of the urea applied at fill-in. By March 2014 both of the DD treatments had the highest mineral nitrogen status (Table 3). Interestingly there was no effect of nitrification inhibitor application on the soil nitrate concentration between the tilled soybean plots +/- nitrification application (data not shown).

Table 3—Soil profile mineral nitrogen content (kg N/ha) to 30 cm depth in the bed area only. Values in columns followed by the same letter are not statistically different ($P < 0.05$).

Treatment	July	September	November	January	March
Fallow N0	48.0 ^a	64.3 ^c	24.9 ^c	7.9 ^c	7.6 ^c
Fallow N145	48.0 ^a	85.3 ^{bc}	36.9 ^c	74.1 ^a	12.4 ^{bc}
Soybean Tilled	55.1 ^a	122.9 ^a	79.1 ^{ab}	12.2 ^{bc}	16.1 ^{bc}
Soybean DD	33.0 ^{bc}	104.3 ^{ab}	87.9 ^a	17.3 ^{bc}	21.0 ^a
Soybean + DMPP +Tilled	45.7 ^{ab}	118.4 ^a	93.2 ^a	19.1 ^{bc}	17.7 ^{ab}
Soybean + Triticale DD	29.5 ^c	59.7 ^c	67.0 ^b	29.1 ^b	28.2 ^a
P Value	0.007	0.001	<0.001	<0.001	0.005

There was a trend for more mineral nitrogen in the soybean DD treatment at plant cane harvest (Figure 3), however there was no statistical difference between any of the treatments ($P = 0.598$). Interestingly there was only 2 kg N/ha difference between the two fallow treatments despite the addition of 145 kg N/ha of nitrogenous fertiliser in the Fallow N145 treatment. Similar results have been reported at other trials conducted in the district (Halpin *et al.*, 2013).

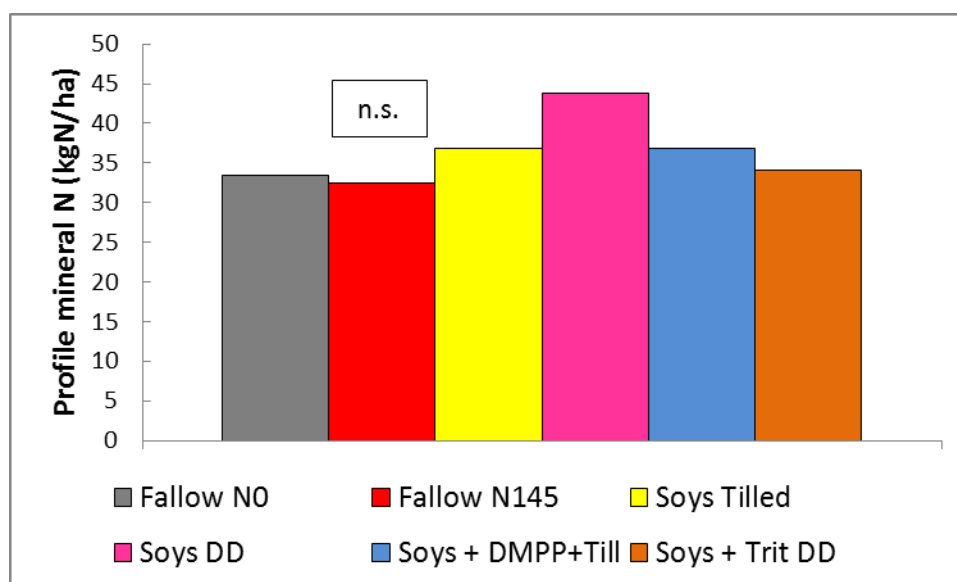


Fig. 3—Soil profile mineral nitrogen content to 100cm (kgN/ha) at plant cane harvest.

Sugarcane crop

Early biomass (86 DAP) in the treatment that had the triticale crop between soybean and sugarcane crops was significantly lower than that of the Fallow N145 treatment (Table 4). This effect was maintained to 190 DAP where the Fallow N145 treatment had accumulated 26% more

dry matter than the Soybean + triticale DD treatment. The fallow N145 treatment was significantly more productive than Fallow N0, Soybean + DMPP and Soybean + triticale DD treatments by 4.6 t/ha, 3.1 t/ha, 5.6 t/ha respectively. The Fallow N145 treatment had the highest number of stalks and crop nitrogen uptake at the 190 DAP assessment. The higher stalk number and nitrogen accumulation reflects the elevated soil mineral nitrogen status in the January sampling (Table 3).

Table 4—Treatment effect on dry matter production and nitrogen accumulation 86 and 190 DAP and stalk count 190 DAP. Values in columns with the same letter are not statistically different ($P < 0.05$).

Treatment	Dry matter production 86 DAP (t/ha)	N uptake 86 DAP (kg N/ha)	Dry matter production 190 DAP (t/ha)	Stalks/ha 190 DAP	N uptake 190 DAP (kg N/ha)
Fallow N0	1.4 ^{abc}	22.0 ^{bc}	22.3 ^{bc}	100,274 ^b	122.4 ^c
Fallow N145	1.5 ^a	25.4 ^a	26.9 ^a	116,121 ^a	175.3 ^a
Soybean Tilled	1.3 ^{bc}	21.2 ^{bc}	24.7 ^{ab}	101,640 ^b	148.2 ^b
Soybean DD	1.2 ^{bc}	20.2 ^{bc}	24.4 ^{ab}	101,640 ^b	150.9 ^b
Soybean + DMPP +Tilled	1.4 ^{ab}	23.4 ^{ab}	23.8 ^{bc}	103,552 ^b	151.0 ^b
Soybean + Triticale DD	1.2 ^c	19.6 ^c	21.3 ^c	98,634 ^b	128.5 ^c
P Value	0.04	0.017	0.041	0.024	<0.001

The Fallow N145 treatment yielded higher than all other treatments. It produced 8.4% more cane than the next best treatment, the Soybean Tilled treatment (Table 5). There was no statistical difference in cane productivity between the other treatments. There was a trend for the Fallow N145 to have the highest sugar yield but this was not statistically different to any other treatment. Similarly crop gross margin analysis demonstrated no statistical difference in profitability.

The difference in gross margin between the Fallow N0 and N145 was \$332/ha and, with a fertiliser cost of \$180, a return on investment of 1.8.

The Fallow N145 treatment accumulated only an extra 44 kg N/ha in the above-ground biomass compared to the N0 treatment, representing a fertiliser nitrogen use efficiency of only 31%, similar to that reported by others (Bell *et al.*, 2010; Halpin *et al.*, 2013).

Table 5—Treatment effect on final cane yield, CCS, sugar production, nitrogen uptake, stalks/ha and crop gross margin of the plant cane crop. Values in columns followed by the same letter are not statistically different ($P < 0.05$).

Treatment	Cane yield (t/ha)	CCS	Sugar production (t/ha)	N uptake (kgN/ha)	Stalks/ha	Gross margin (\$/ha)
Fallow N0	122.8 ^b	17.6	21.6	140.7	94 086 ^{bc}	3268
Fallow N145	135.2 ^a	17.0	23.0	184.7	105 323 ^a	3600
Soybean Tilled	124.7 ^b	17.0	21.3	172.4	98 452 ^{ab}	3113
Soybean DD	121.8 ^b	17.0	20.7	165.6	92 076 ^{bc}	3230
Soybean + DMPP +Tilled	120.0 ^b	17.7	21.3	170.0	91 257 ^{bc}	3236
Soybean + Triticale DD	117 ^b	17.0	19.9	150.7	85 974 ^c	3054
P value	0.01	0.608	0.100	0.063	0.004	0.404

Cane yield was strongly correlated with stalk number (Figure 4). Others (Bell and Garside, 2005; Garside *et al.*, 2000) have suggested that nitrogen supply is primarily responsible for tiller retention.

Regression analysis between the mid-season stalk number and soil profile nitrogen demonstrated that the soil N status for January was significantly correlated with mid-season stalk number ($P=0.017$) however the r^2 was low at 0.234.

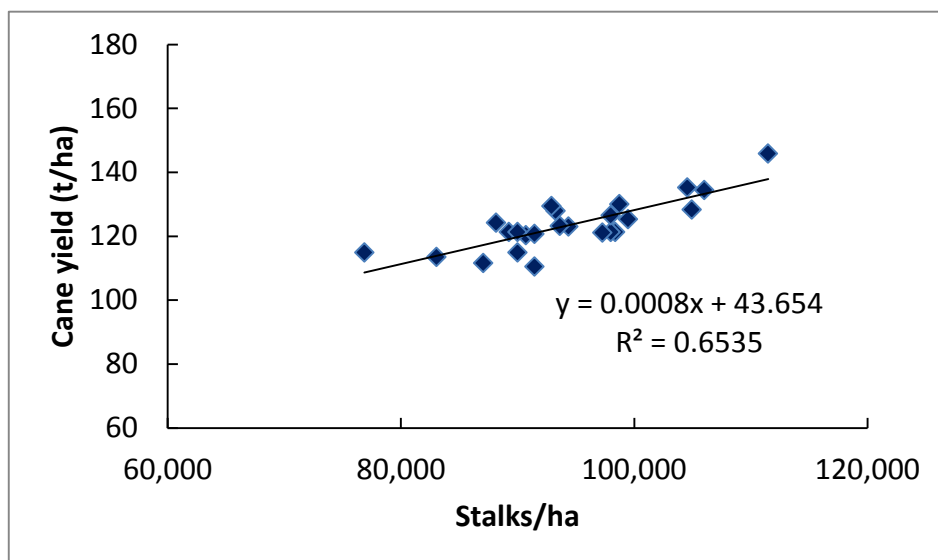


Fig. 4—Correlation between stalks/ha and cane yield.

The crop had accumulated most of its nitrogen by April. For example the crop total biomass was 24.9 t/ha in April and had accumulated 146.1 kg N/ha; by harvest in September total biomass had nearly doubled to 48.4 t/ha yet only accumulated another 17.9 kg N/ha to have 164 kg N/ha.

Expressing crop nitrogen accumulation between sampling dates as kg N/ha/day demonstrates that the crop accumulated the most nitrogen between fill-in and April (Figure 5).

This is a similar finding to that of Wood *et al.* (1996) where N accumulation in biomass ceased 198 DAP.

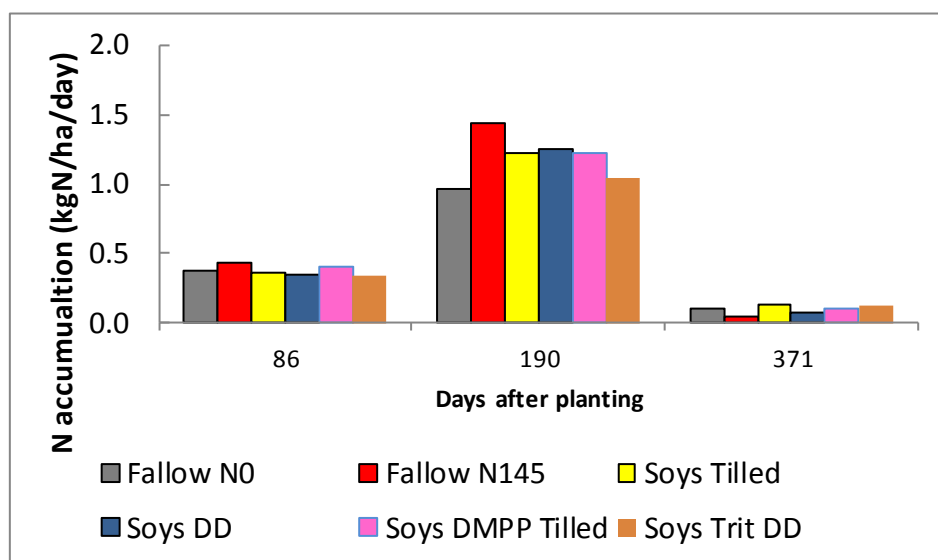


Fig. 5—Treatment effect on daily nitrogen accumulation.

The plant parasitic nematode assessment demonstrated a trend of fewer lesion nematodes in the direct drill treatments. However, that effect was not statistically significant.

All nematode species were well below in-crop 'moderate' thresholds (SRA 2014) (data not shown), indicating that they had little to no impact on the measured yields.

Conclusion

This experiment has demonstrated that the implementation of reduced tillage management techniques as used in the Soybean DD treatment not only reduced N₂O emissions (Wang *et al.*, 2015) but also produced similar cane and sugar yields to the soybean plots that were conventionally tilled.

While the Fallow N145 treatment produced the highest cane yield, its sugar yield was not significantly better than any other treatment. While the soybean rotation didn't significantly improve productivity of the subsequent cane crop compared to the bare fallow, it has to be kept in mind that the soybean crop produced a gross margin of \$1015/ha (data not shown) thus increasing farm profitability. Moreover, this study has further highlighted poor nitrogen use efficiency with the Fallow N145 treatment only accumulating another 44 kgN/ha compared to the Fallow N0 plots that received no nitrogenous fertiliser.

The productivity and high crop N uptake (140.7 kg N/ha–Table 5) of the Fallow N0 treatment was surprising given the low organic carbon level of this site (1.10%). This would suggest that the 'Six-Easy-Steps' discount for soil N mineralisation from this soil is conservative and needs to be re-visited so that the contribution of soil N can be more realistically accounted for.

The use of fertilisation strategy based on six-easy-steps where only 25 kg N/ha was applied to the cane crop following a soybean crop demonstrates that significant nitrogenous fertiliser reductions can be made in the plant cane crop without adversely affecting yield. However further refinement is required as the stalk retention data would suggest that we under-supplied N in the soybean treatments.

Supplying adequate nitrogen to meet productivity requirements without causing environmental harm remains a challenge for the Australian sugar industry.

Furthermore, this study has highlighted a way forward to enable grain legume cropping in the sugarcane farming system to capture all of the soil health/environmental benefits without exacerbating N₂O emissions from Australian sugarcane soils.

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