EXAMINATION OF OPPORTUNITY FOR COMPOST TO REDUCE SYNTHETIC NITROGEN FERTILISER REQUIREMENTS OF SUGARCANE AND NITROUS OXIDE EMISSIONS

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Abstract

A REPLICATED EXPERIMENT was conducted in sugarcane at Maroochy River (SE Queensland) over three years to assess the potential for partially replacing use of synthetic nitrogen (N) fertiliser with compost and a biological N fixing product. Agronomic indices and nitrous oxide (N_2O) emissions were measured. Banded application of compost above or below the sugarcane trash blanket can partially substitute the use of synthetic fertiliser. Treatments where compost-derived N (mineral N at time of application plus mineralisable N) reduced annual use of synthetic N fertiliser by 35 to 43 kg N/ha, showed identical yields to treatments that received only synthetic fertiliser. However, surface application of compost with reduced N rates was an unattractive agronomic and economic strategy. Use of a biological N fixing product did not show any N effects within the timeframe of this project. There was no consistent significant impact of compost in reducing emissions of N_2O. In fact, emission rates were enhanced by the presence of compost in the 2014–15 crop. Soil data at the time of high daily emissions showed higher levels of nitrate (NO_3^-) N in the row where compost was applied. Conversely ammonium (NH_4^+) N levels were higher than NO_3^-–N in the row where compost was not applied. Avoiding application of N in excess of recommended rates was more effective than partially substituting mineral N fertiliser with compost in minimising N_2O emissions. Beneficial impact of compost on total carbon and N in soil was confined to the row zone and largely the 0–5 cm depth.

Introduction

SEQ Catchments was approached by the Sunshine Coast Regional Council in 2011 to determine any beneficial use in agriculture for segregated and composted municipal green waste so as to minimise carbon tax liabilities associated with methane emissions from landfilled organic waste. A research and development project was prepared for, and subsequently funded under, the Australian Department of Agriculture Forestry and Fisheries Carbon Farming Futures program for Action on the Ground.

The project had the following objectives:

- determine if compost based on municipal green waste can be economically incorporated into crop management programs

- quantify any greenhouse gas abatement advantages of using compost and a biological nitrogen (N) fixing product to reduce nitrous oxide (N_2O) emissions compared to use of synthetic N fertiliser alone
- quantify impact of compost use on soil carbon sequestration and soil N accumulation.

The sugarcane trials involved a replicated experiment and a commercial scale demonstration trial. This paper reports on the replicated experiment in sugarcane which was conducted over 2012–13, 2013–14 and 2014–15 cropping seasons.

Materials and methods

The experiment was established in a first ratoon crop of Q232 on a humic gley soil on the Petersen Farm at Maroochy River (26˚34.5'S, 153˚ 01.4'E) on the Sunshine Coast of Queensland in October 2012. The experiment was designed as a strip split plot design in four replications, with compost to be applied on the row in 15 cm bands by a mechanical spreader. Strips were split firstly by three rates of N (Table 1) and then by a biological N fixing product (TwinN – Mapleton Agri Biotec Pty Ltd, Mapleton, Queensland). Individual plots were six rows x 13m gross. Treatments are detailed in Table 1. The field was surveyed with an EM38 earth conductivity meter to allow allocation of plots and replicates to the most uniform parts of the field. Rainfall data were taken from an automatic weather station at Dunethin Rock, some 800 m SW of the trial site.

Table 1—Treatments applied to the replicated small plot experiment.

Treatments	Allocation
Co=No compost + CK44 @ 400 kg/ha	Strip
C1=Compost @ 13.9 or 30 m^3/ha. No CK44	Strip
N1=Equivalent of compost N, normal P & K (compost or CK44)	Sub-plot
N2=65% Grower N fertiliser, normal P & K (compost or CK44 and urea)	Sub-plot
N3=Grower N rate, normal P & K (compost or CK44 and urea)	Sub-plot
N4=N1 + Twin N	Sub-plot
N5=N2 + Twin N	Sub-plot
N6=N3 + Twin N	Sub-plot

Compost (13.9 m^3/ha) for the first ratoon crop (Table 2) was based on layer chicken manure, sourced from a commercial supplier as the Sunshine Coast Council could not supply suitable material. Product for the second and third ratoon crops (Table 2) was based on municipal green waste composted on a neighbouring farm and augmented with chicken manure or gelatine waste to improve nutrient content (30 m^3/ha). The decline in potassium content of the on-farm products was noted.

Table 2—Nutrient analysis of compost used in 2012, 2013 and 2014.

Nutrient	2012	2013	2014
N %DM	2.1	1.6	2.1
Phosphorus %DM	1.9	1.0	1.0
Potassium %DM	1.5	0.26	0.46
Calcium %DM	7.4	2.9	2.9
Magnesium %DM	0.79	0.39	0.29
Organic C %DM	26	22	27
NH_4–N mg/kg FM	931	399	906
NO_3–N mg/kg FM	2	147	8

The three N rates for first and second ratoon crops (Table 3) were chosen to make the lowest synthetic N rate equivalent to the N considered available from compost. A second N rate at approximately 65% of the recommended commercial N rate to allow activation of TwinN and the third and commercial N rate target was to allow for a cane yield of 110 t/ha (Schroeder *et al.,* 2006) and equated to approximately 150 kg N / ha for the first two crops. Observation of low yield in the N1 and N4 treatments in the first and second ratoon led to an increase in N rates across treatments for the third ratoon crop (Table 3).

Table 3—Nutrient application to first / second / third ratoon crops as outlined in Table 1.

Treatments		N	P	K
N1	with compost	40 / 43 /35	58 / 100 /103	92 / 33 /68
	Urea 3rd ratoon	62		
	Total	40 / 43 /97	58 / 100 /103	92 /33 /68
N2	with compost	40 / 43 /35	58 /100 /103	92 / 33 /68
	Urea	62 / 62 /112		
	Total	102 / 105 /147	58 /100 /103	92 / 33 /68
N3	with compost	40 /43 /35	58 /100 /103	92 /33 /68
	Urea	115 /115 /162		
	Total	155 /158 /197	58 /100 /103	92 /33 /68
N1	without compost			
	CK 44	34 /34 /34	38 /38 /38	106 /106 /106
N2	without compost			
	CK 44	34 /34 /34	38 /38 /38	106 / 106 /106
	Urea	59 / 59 /112		
	Total	93 /93 /146	38 /38 /38	106 /106 /106
N3	without compost			
	CK 44	34 /34 /34	38 /38 /38	106 /106 /106
	Urea	112 / 112 /162		
	Total	146 / 146 /196	38 /38 /38	106 /106 /106

IncitecPivot Crop King 44 (CK44, 8.5%N, 9.4%P, 26.5%K, 0.8%S) fertiliser, was applied by machine in the non-compost strips. Urea was manually applied to the soil surface for the first ratoon crop on top of compost and trash. For second and third ratoons urea was placed in a slot created by a double disc opener and then manually covered with soil and trash. Compost was applied on top of the trash. TwinN was applied according to manufacturer's instructions and injected to approximately 10 cm behind a coulter disc in the centre of the row area. TwinN was applied soon after at least 10 mm of rain had fallen to ensure moist soil at injection.

Greenhouse gas emissions were measured in the second and third ratoon crops. Gas was trapped in 25 cm diameter PVC cylinders driven 10 cm into the soil and fitted with gas tight lids and sample extraction valves. Cylinders were placed in the cane row (over the fertiliser, compost and Twin N bands), in the centre of the inter-row area and mid-way between these positions (shoulder) in four replications of treatments detailed in Table 4. Cylinder tops were open except during measurement events.

Tops were replaced for one hour prior to sample extraction with a syringe, which then transferred gas to an evacuated vial (Exetainer, Labco Ltd., UK). Samples were analysed for N_2O, CH_4 and CO_2 concentrations as described by Wang *et al.* (2011). Gas samples were taken the day after fertiliser application and then at median intervals of 3–4 days and maximum intervals of 8–10 days across the two crops for periods of about four months. Gas data were scaled to area-based units using the method of Wang *et al.* (2016). Rainfall events were a trigger for sampling.

Soil samples were taken from positions adjacent to the PVC cylinders on three occasions during the second monitoring campaign (16/12/14, 3/2/15 and 27/3/15) to examine mineral N dynamics. Soil was sampled from the row position in 0–10 cm and 10–20 cm intervals and from 0–20 cm only for the other two positions. Soil was also sampled with a core sampler on 21–22/5/15 from the cane row zone for 0–5 and 5–10 cm depths in the compost and no compost treatments in the N3 treatment, to quantify impact of compost application on carbon and total N accession to the soil profile.

Table 4—Treatments for installation of N_20 sampling cylinders.

Treatments without compost	Treatments with compost
N2	N2
N5 +TwinN	N5 + TwinN
N3	N6 + TwinN,

Leaf samples were taken from each plot during months of peak growth (February 2013 and 2015), but in early April 2014 after the crop recovered from severe moisture stress. Yield was determined just prior to commercial harvest by manually cutting and weighing all cane in a 5 m section of the centre two rows of each plot. Six stalks were selected for juice analysis to determine the commercial cane sugar content (CCS).

Data were analysed using an analysis of variance program in the STATISTIX 9.0 software package.

Results

Weather conditions

Monthly rainfall data (Figure 1) show major rainfall for January to April 2013 that was associated with two flooding events to about 50 cm depth across the trial site in January–February. Conversely, the 2013–14 crop was affected by severe moisture stress between November 2013 and February 2014. The 2014–15 crop experienced ideal conditions for growth during the peak growth months of December 2014 to March 2015.

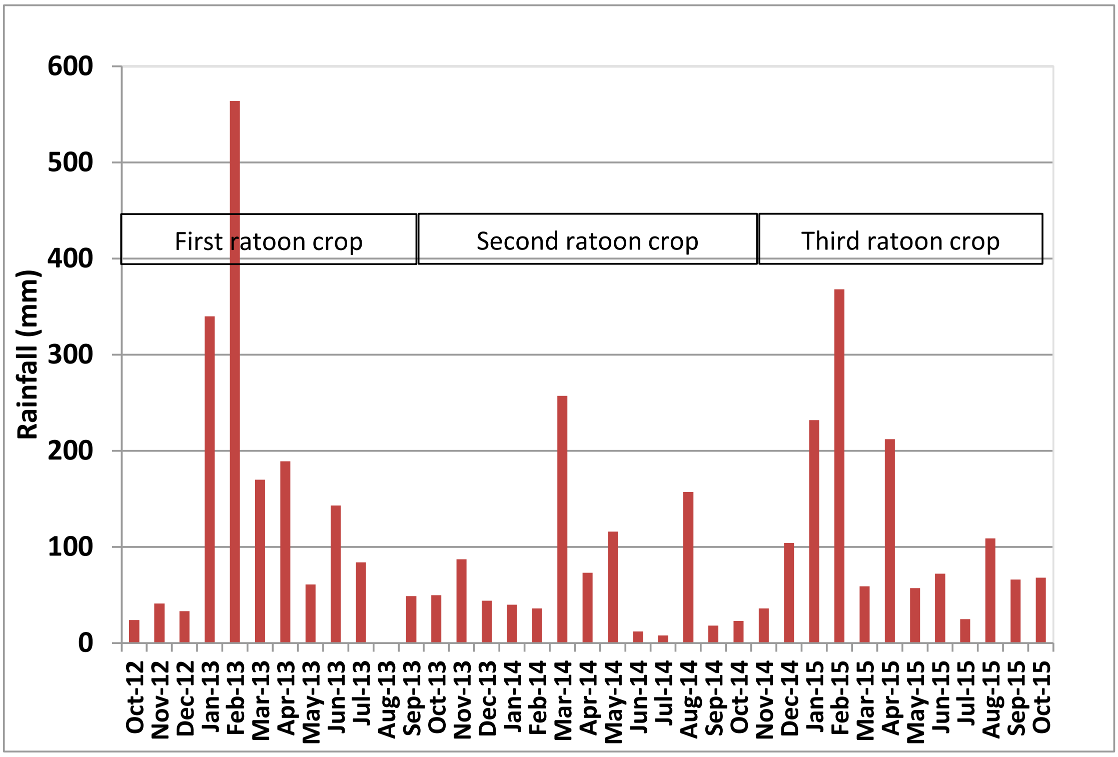

Fig. 1—Monthly rainfall at Dunethin Rock automatic weather station.

Leaf analysis

There was no significant difference between compost and synthetic fertiliser treatments for leaf N levels across the three crops. N levels were sub-optimal for only N1 and N4 treatments in the first ratoon. There was no significant difference (P = 0.001) in N levels between the recommended and 65% N rate. For the second ratoon only the recommended N rate exceeded the critical N rate of 1.8%. Increased N rates for the third ratoon resulted in N level in all treatments exceeding 2%, with a ranking in general accord with N rate. Twin N had no impact on leaf N levels.

By second ratoon, levels of P, Ca, Mg, Cu, Zn and Mn were slightly, but significantly, higher in the treatments which received compost (P = 0.03, 0.04, 0.03, 0.03, 0.001 and 0.04 respectively), and all were plots were well above critical levels. There was no significant effect of compost on P, Cu or Mn levels in leaf tissue in the third ratoon crop.

Leaf K levels in the first ratoon were adequate, however by second ratoon, K values averaged 1.07%, just below the critical value of 1.11%. Third ratoon K values (Table 5) were significantly lower (P = 0.002) with compost, 0.97% compared to 1.28% in the treatments fertilised with synthetic fertiliser.

Table 5—Compost × N rate interaction for K in the third ratoon crop.

Compost treatment	N treatment	K%
No compost	N3	1.35 A
No compost	N2	1.33 AB
No compost	N5	1.30 AB
No compost	N6	1.25 ABC
No compost	N4	1.23 ABCD
No compost	N1	1.20 BCDE
Compost	N4	1.04 CDEF
Compost	N6	1.02 DEFG
Compost	N1	0.99 EFG
Compost	N3	0.93 FG
Compost	N5	0.92 FG
Compost	N2	0.90 G
P		0.002

Values followed by the same letter are not significantly different.

Cane and sugar yield

Compost and Twin N had no significant effect on cane or sugar yield or CCS for the three crops.

The two higher N rates produced significantly more cane and sugar (P = 0.001) than the lowest N rate in the first ratoon crop (Table 6). Cane and sugar yields in the 65% N regime were slightly, but not significantly, lower than the highest N rate. Low overall yield for the first ratoon is most likely a reflection of the flood impact in January–February 2013.

For the second ratoon (Table 6) only the highest N rate without TwinN (N3) had significantly higher cane and sugar yield (P = 0.0027 and 0.0062, respectively) than the lowest N treatment with TwinN (N4). Again while there was a trend to lower yield with the 65% N rate, the difference in cane or sugar yield between the full N and 65% N application treatments was not significant.

As in previous crops the allowance for N in compost for the third crop gave equivalent yield to the N supplied from chemical fertiliser. Cane yield was proportional to the N regime, with the N3 and N6 regimes (197 kg N/ha) having significantly higher yield than N2 and N5 regimes (147 kg N/ha). The N1 and N4 regimes (97 kg N/ha) had lowest cane yield. N treatment had no impact on CCS. Sugar yields generally were ranked according to cane yield, with minor differences associated with variation in CCS.

Table 6—Impact of N rate on cane yield (TC/ha), sugar yield (TS/ha) and sugar content (CCS) for three crops.

N treat.	First ratoon			Second ratoon			Third ratoon		
	TC/ha	CCS	TS/ha	TC/ha	CCS	TS/ha	TC/ha	CCS	TS/ha
N3	60.0 A	16.25 A	9.73 A	80.0 A	16.03 A	12.82 A	79.3 A	14.70 A	11.64 AB
N6	60.9 A	15.98 A	9.73 A	71 4 AB	15.68 A	11.17 AB	77.1 A	15.56 A	11.98 A
N2	56.8 A	16.52 A	9.38 A	69 8 AB	16.07 A	11.06 AB	68.5 B	14.42 A	9.87 BC
N5	56.4 A	16.38 A	9.22 A	69.2 AB	15.81 A	11.02 AB	67.5 BC	14.91 A	10.11 ABC
N1	43.9 B	16.42 A	7.21 B	58 6 B	15.61 A	9.14 B	60.1 CD	14.55 A	8.73 C
N4	39.9 B	16.11 A	6.44 B	59.5 B	15.84 A	9.41 B	58.9 D	14.56 A	8.61 C
p	0.001	NS	0.001	0.003	NS	0.006	0.001	NS	0.001

Values followed by the same letter are not significantly different. N.B. N1=N4, N2=N5 and N3=N6 for N rates.

Greenhouse gas emissions

Cumulative N_2O emissions, averaged across sampling positions in treatments, were ranked N3>N2 (Figure 2) in the second ratoon. However only C0_N2 and C0_N3 without compost and Twin N application were significantly different (P=0.05, Figure 2). While addition of compost reduced emissions from the N3 treatments, the effect was not significant. The other treatment effects, i.e. +/– compost and +/– TwinN, were not significant at P = 0.05. Cumulative emissions ranged between 4 and 7 kg N_2O–N/ha.

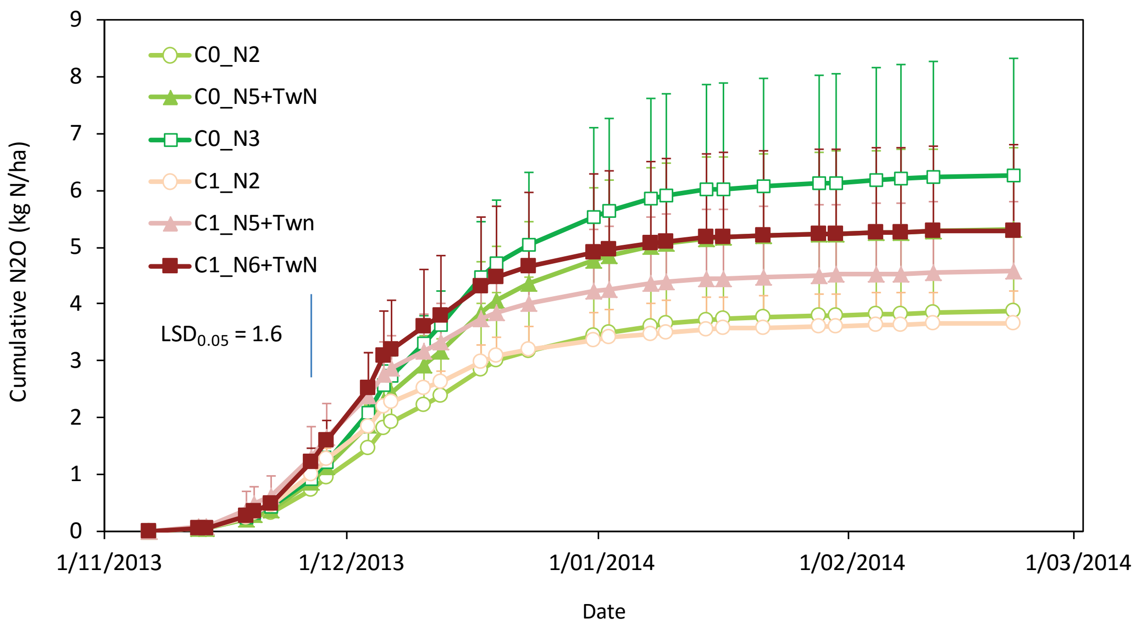

Fig. 2—Cumulative N_2O emissions from selected treatments in the second ratoon crop.

Daily N_2O emissions increased for the first three weeks following fertiliser application (24 November 2014) in the third ratoon. Daily emission rates peaked at 200 – 525 g N_2O–N ha/day (Figure 3). The peak in emissions (22 days after fertilising, DAF) was preceded by several days of rainfall, amounting to 23.8 mm, which most likely provided sufficient soil moisture to increase emissions from nitrification/denitrification.

All treatments with compost addition had higher peaks in daily N_2O emissions from 250 to 525 g N_2O–N ha/day, compared to 215 – 275 g N_2O–N ha/day for treatments without compost. All treatments reduced to similar daily emissions in the following two weeks. From February 2015 onwards, emissions were small (<25 g N_2O–N ha/day) and large rainfall events did not initiate major emission flushes, possibly due to limited N availability at that time (Figures 7a–b).

Over the 112-day sampling campaign in the third ratoon, cumulative N_2O–N losses ranged from 7.5 kg N/ha to 12 kg N/ha. At the 147 kg N/ha fertiliser rate (N2 and N5), N_2O emissions were not significantly affected by compost or TwinN application (Figure 4). There was no significant difference in cumulative emissions between N fertiliser rates when there was no addition of compost and Twin N (Figure 5). In contrast, with compost and TwinN application, there was a 60% increase (P<0.05) in N_2O emissions when N application rates were increased from 147 kg N/ha (N2 or N5) to 197 kg N/ha (N6) (Figure 6). Note soil data (Figure 7a) from 16 December 2014 showed higher nitrate N levels in the fertiliser zone under compost than where compost was not applied.

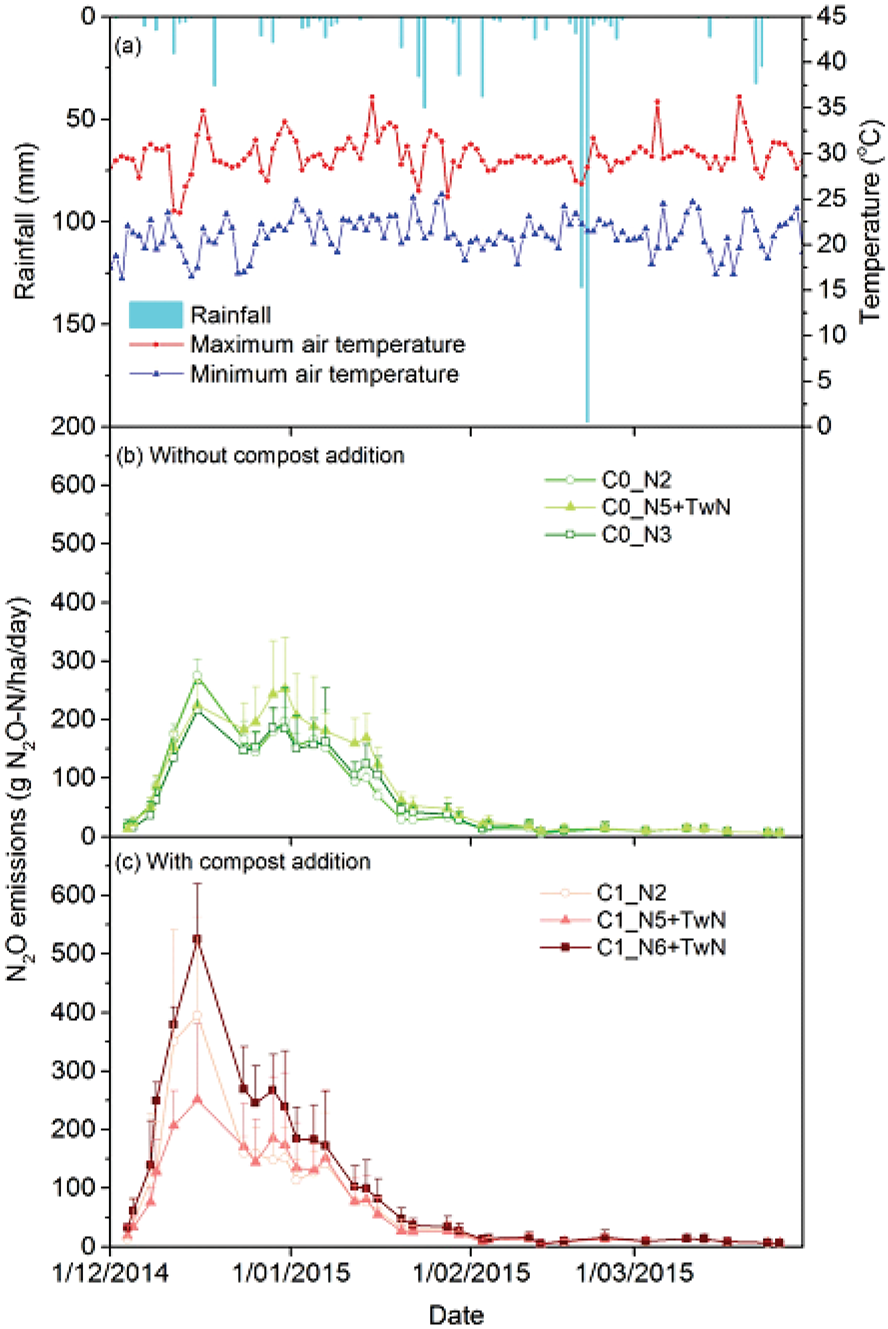

Fig. 3—(a) Daily rainfall and air temperature in relation to N_2O emission dynamics; (b) for treatments without compost addition and (c) with compost addition in the third ratoon.

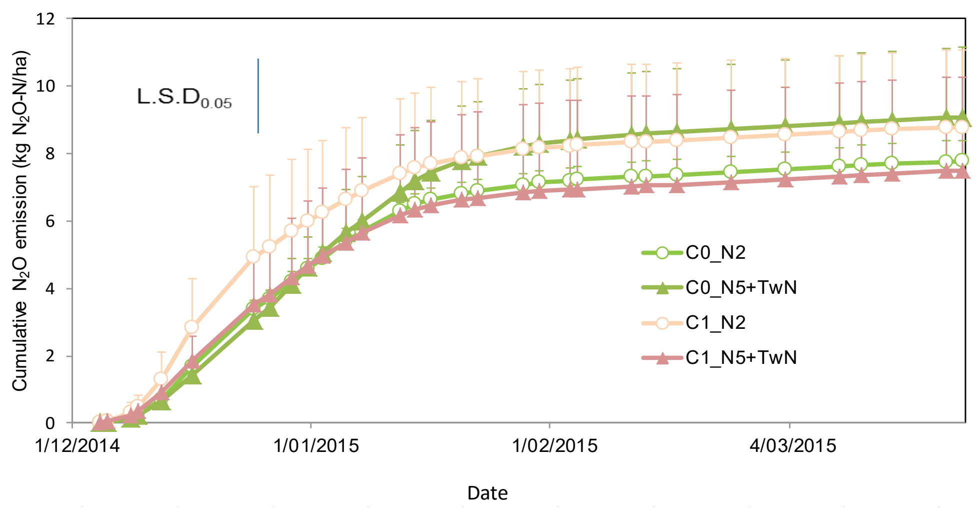

Fig. 4—Effects of compost and Twin N application on cumulative N_2O emissions for the 147 kgN/ha rate (N2 and N5) in the third ratoon.

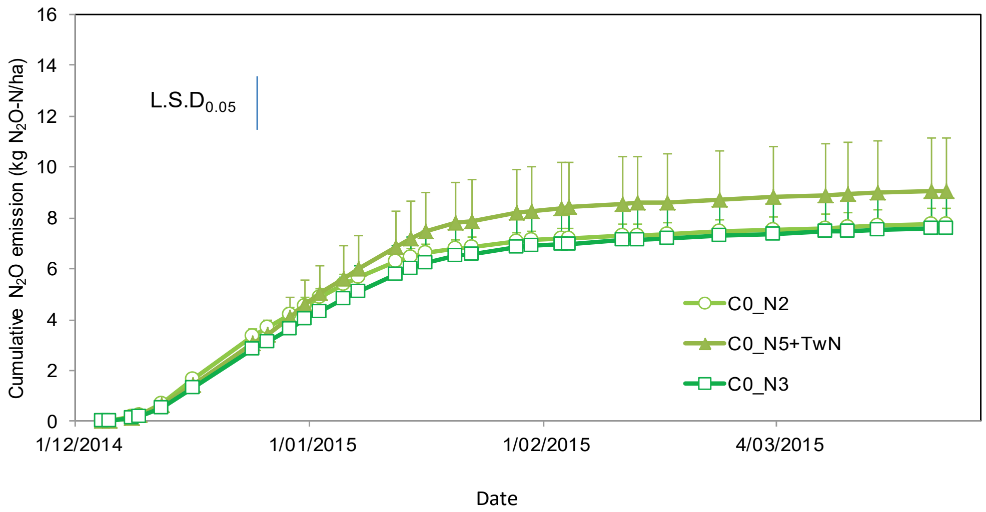

Fig. 5—Effects of Twin N application and N fertiliser rate without compost addition on cumulative N_2O emissions in the third ratoon.

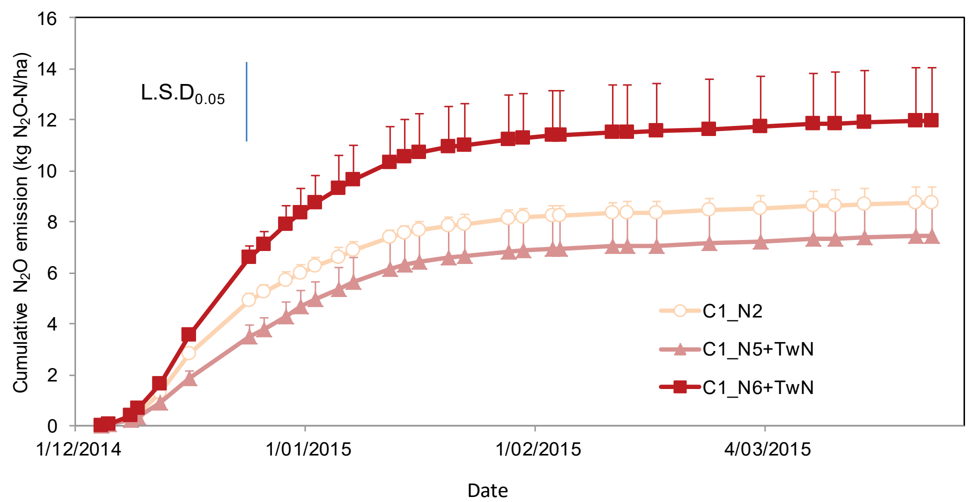

Fig. 6—Effects of TwinN application and N fertiliser rate with compost addition on cumulative N_2O emissions in the third ratoon.

Soil N dynamics during the third ratoon crop

Because of the absence of any trends or significant impacts of TwinN on agronomic data, soil sample results were statistically analysed as a balanced data set comparing the N2, N5 and N3 regimes with and without compost to investigate effects on soil N dynamics. There was never a significant N treatment effect on nitrate N (NO_3^-–N) or ammonium N (NH_4^+–N) at any position across the three sampling periods, thus averaged treatment data are reported.

Examination of the 0–20 cm mineral N data for 22 DAF showed a highly significant interaction (P = 0.001) between compost treatments and sampling position for both NO_3^-–N and NH_4^+–N. The compost treatment showed much higher NO_3^-–N levels in the row than in the absence of compost (Figure 7a), while the converse applied for NH_4^+–N (Figure7b). Similar data (not shown) applied to the 0–10 cm assays. These data support the higher N_2O emissions from the compost treatments in December 2014 (Figure 3).

The position effect of compost treatment for mineral N level was significant only for the row sampling position. The effect of compost on NO_3^-–N levels was significant only for the row (Figure 7a). NH_4^+–N levels in the row were significantly higher without compost and greater than the other positions for both compost treatments (Figure 7b).

Mineral N levels in all sampling positions declined in the 0–20 cm zone by 71 DAF. NO_3^-–N levels in the row were significantly higher than for other positions, with levels in the compost-added treatment still higher, but not significantly so, than without compost (Figure 7a). NH_4^+–N levels were significantly higher for the row position only in the absence of compost (Figure 7b).

The decline in mineral N levels continued to the sampling on 123 DAF, confirming previous observations (Wood *et al.,* 1996 and Kingston *et al.,* 2008) that N uptake by sugarcane was substantially completed between 100 and 180 days of crop age and that residual mineral soil nitrogen levels were low. Effects of compost and sampling position had generally disappeared.

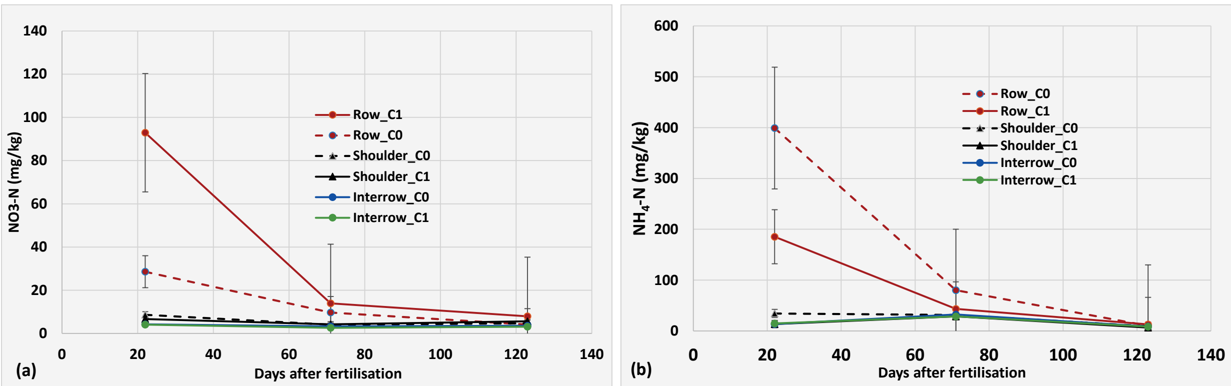

Fig. 7—(a) NO_3–N and (b) NH_4–N levels for 0–20 cm depth at row, shoulder and inter-row positions averaged across N2, N3 and N5 treatments.

Sequestration of carbon

Total carbon and N data revealed significant (P = 0.001 to 0.02) effects for compost, sampling position and sampling depth for both assays. There were significant interaction effects for compost x position, position x depth and the three factor interaction.

There was no significant difference in total C and N levels between depths and positions in the absence of compost (Figure 8a–b). Total C and N were significantly higher in the 0–5 cm than 5–10 cm depths for both row and shoulder positions where compost was applied. Comparison of C and N means for compost treatments within positions and depths showed compost application significantly increased both C and N levels at both depths in the row, but only 0–5 cm for the shoulder.

These results show that compost clearly increased C and N levels in the application row zone, and that while effects were largest in the 0–5 cm zone, there was also improved C and N fertility in the 5–10 cm depth, although compost was only applied on top of the trash and not incorporated. The benefits of compost on C and N fertility were less obvious in the shoulder zone for either depth.

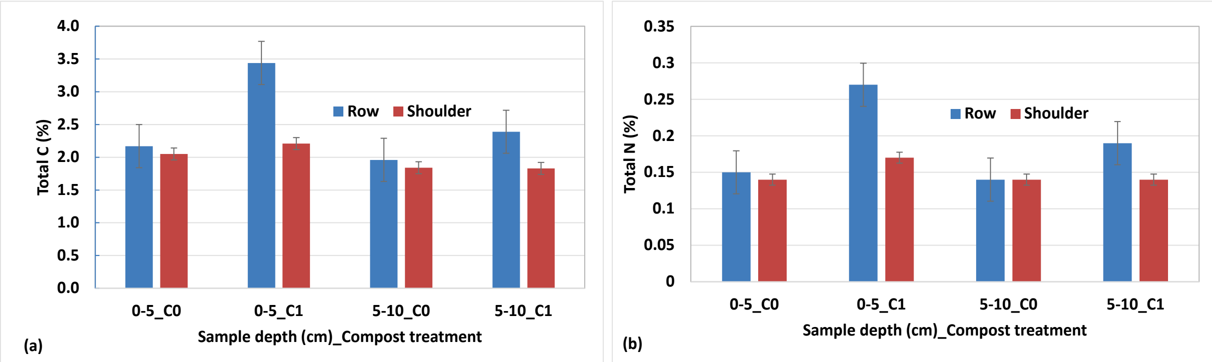

Fig. 8—(a) Total carbon% and (b) Total N% for 0–5 and 5–10 cm depths at row and shoulder positions for the N3 treatment.

Economic analysis

Reliable data for cost of production of compost for the cane trials was not available. Contemporary commercial data (Ideal Compost and SA Composters) was averaged to provide an ex-works cost of \$52.50/m^3. This number was considered relevant for compost produced on farm so as not to include a transport component. The price was further discounted by 25% to take out the commercial profit factor to arrive at a pre-spreading price of \$39.40/m^3. This resulted in a cost of \$1182 /ha, before spreading of 30 m^3/ha of compost (with farm produced quality for second and third ratoon applications). The cost of all chemical fertilisers for the highest N treatment (N3 and N6) was \$533 /ha for first and second ratoon and \$615 /ha for the third ratoon.

Thus in the absence of any yield responses to surface application of compost this strategy is not justified on economic considerations for replacement of a small component of the total N requirement of sugarcane.

Discussion and conclusions

Equivalence of the estimated N availability from compost and that in fertiliser was demonstrated in leaf N levels and absence of cane yield differences between compost treatments. Compost application allowed a 23% reduction in chemical fertiliser input for the recommended N fertiliser input of 150 kgN/ha. No effects of Twin N were measured on any parameter in the experiment.

Low potassium in farm-produced compost led to sub-optimal tissue K levels for the third ratoon crop. This highlighted the need for good quality control to allow production of relevant composts and to provide timely data for the required nutrient augmentation.

Seasonal conditions had a strong impact on cane yield and N use efficiency. Flooding of the first ratoon crop had a greater adverse impact on yield and response to N than did the early water stress for the second ratoon. Third ratoon yield was not substantially different to the second ratoon, even with increased N rates.

N_2O–N emissions of 4–7 and 7.5–12.0 kg N_2O–N/ha in 2013–14 and 2014–15, respectively, were similar to those reported by Wang *et al.* (2014) (11.4–18.2 kg N_2O–N/ha for 0–140 kg N/ha) and Wang *et al.* (2015) (5.6–6.45 kg N_2O–N/ha from a bare fallow system followed by 145 kg N/ha). Allen *et al.* (2008) showed N_2O emission of 2.6, 3.6 and 6.6 kg N_2O–N/ha for 0, 100 and 200 kg N/ha, respectively. Observed N losses through N_2O were below the current default emission factor (EF) of 1.25%, and certainly below the proposed future EF for sugarcane of 1.99%.

Reducing N rate (150 to100 kg N/ha and 197 to147 kg N/ha for second and third ratoon crops, respectively) was more effective in reducing N_2O emissions than was use of compost. Increased emissions in the presence of compost in the third ratoon was supported by measurement of higher levels of NO_3^-–N in the fertilised zone of the row where compost was applied.

This result may be a combination of increased nitrification from greater biological activity in the compost zone, combined with a labile carbon source resulting in more denitrification after rainfall.

Comparison of compost quality data 2013 and 2014 and emissions in the second and third ratoon crop suggests that the quality of organic soil amendments may be another factor affecting emissions. This is supported by data obtained in sandy and clay soil near Broadwater (Biala, 2012). The higher retention of mineral N as NH_4^+–N in the fertilised zone in the absence of compost up to 71 DAF suggested quite slow rates of nitrification.

The humic gley soil had high levels of carbon (Schroeder *et al.,* 2006) even in the absence of compost. Three years of compost application boosted carbon levels in the 0–5 cm zone of the row from 2.05 to 3.34%, a very high level that would favour denitrification.

Compost effects were largely confined to the row zone and mainly the 0–5 cm depth. There was a small increase in C and N levels in the 5–10 cm depth for the row despite the fact that compost was applied on top of the cane trash and not incorporated.

Economic analysis showed that annual use of surface-applied compost could not be justified in a green cane production system on a soil with moderate natural fertility.

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