An assessment of controlled release fertilisers in the Australian sugar industry*

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Abstract

Nutrient loss is a significant issue faced by the sugarcane industry in tropical Australia. Controlled release (CR) fertilisers may offer significant opportunities to reduce nutrient losses leading to potential improvements in nutrient efficiencies, productivity gains and improved environmental outcomes. This paper reviews the research undertaken in the Herbert, Burdekin and Mackay cane growing regions of Australia, comparing the Everris® Agrocote® controlled release urea against conventional urea products. Controlled release N significantly increased cane and sugar yield compared to similar rates of urea N in the Burdekin and Herbert. Significant yield responses were measured in seasons with both wet and dry conditions in the first two months following fertiliser application. Due to productivity increases, net returns were increased where between 15% and 40% of the N was supplied in the CR form in the Herbert and Burdekin. Application of fertiliser significantly increased nitrous oxide emissions but there were no significant differences between N sources.

Keywords: ***controlled release fertilisers, Agrocote®, denitrification, nitrogen, sugarcane, urea***

Introduction

The management of nutrient inputs is essential to maintain soil fertility and to optimise and sustain long-term crop yields. Of the nutrients applied, nitrogen is quantitatively most important for cane growth. When nitrogen is added to the soil as an inorganic fertiliser it is generally in the form of urea. Other N sources are available but are generally more expensive.

When urea is added to the soil, microbial activity rapidly converts it to ammonia, after which it may be volatilised or converted to ammonium in contact with water. Nitrifying microbes may convert ammonium-N to nitrate-N.

Nitrate is highly mobile and can be readily lost through leaching (particularly in permeable soils) and /or denitrification under waterlogged conditions when the soil has a reduced level of oxygen.

It is difficult to manage nitrogen inputs in tropical cane growing regions where nutrient losses associated with volatilisation, leaching, runoff and denitrification are regular occurrences (Chapman and Haysom, 1991; Denmead *et al*., Prasertsak *et al*., 2002; Rasiah *et al*., 2003a; Weier *et al*., 1998). It is not uncommon that nitrogen losses can be high during periods of high rainfall and waterlogged conditions in tropical regions of Australia, or through temporary water logging associated with flood irrigation systems used in the Burdekin cane growing region.

Cheesman (2004) reported that on average 16–20kg N/ha was lost due to denitrification processes over one growing season in trials conducted in Mauritius. This paper will report on a denitrification study undertaken in the Herbert region to assess the potential losses that may occur due to denitrification from clay soils in the region.

To date, the management of nitrogen losses has been difficult in tropical, cane farming systems due to urea-based products being the most commonly used nitrogen sources in the Australian sugarcane industry. In the Herbert and Mackay areas, nitrogen applications of up to 160 kgN/ha are confined to a short period between harvest and the onset of the wet season (Di Bella *et al*., 2013). In the Burdekin area, nitrogen applications of up to 200 kgN/ha are usually applied either once or twice in a period between the

harvest and when the crop can no longer be passed over by tractor-drawn application equipment.

Split applications of nitrogenous fertilisers are generally not practiced in Australia due to the increased application costs, the time required to undertake multiple passes due to lack of available labour, and the risk of not being able to access fields after the onset of wet weather. Past research in the Australian sugarcane industry found little or no yield advantages associated with split urea-based fertiliser applications (Kingston *et al*., 2008).

Di Bella *et al*. (2013) reported that controlled release (CR) fertilisers might offer an opportunity to minimise nitrogen losses and increase productivity in cane production systems. Over the last 30 months, trials have been established in the Herbert, Burdekin and the Mackay districts to compare the relative efficiencies of CR and conventional urea.

Materials and methods

Three groups of trials were established to assess the potential of CR urea when compared to conventional urea. The first group of trials were a continuation of the work commenced in 2011 in the Herbert, and reported by Di Bella *et al*. (2013), to measure the relative efficiency of CR N compared to conventional urea; these trials will be referred to as the 'N efficiency trials' throughout this paper. The second group of trials were conducted in the Herbert, Burdekin and Mackay areas to assess the efficiency of CR urea when used in conjunction with conventional urea. The second group of trials will be referred to as the 'CR blended trials'. A third trial was conducted in the Herbert utilising one of the existing sites to assess de-nitrification losses from N applied as Agrocote® CR urea and from conventional urea; this trial will be referred to as the 'Denitrification trial'.

The trials consisted of large replicated commercial strips between 0.3–1.0 hectares in size. A randomised complete block design was used for the 'N efficiency trials', the 'Denitrification trial' and the 'CR blended trials'. Trial results were statistically analysed using ARM9 (Gylling Data Management, Inc.). Means separation was by Fisher's protected LSD at the 0.05 level of significance.

The trials were fertilised using application equipment available on-farm and harvested by a commercial harvester and mill bin weights were recorded for each treatment. Herbert and Mackay trials were harvested green and the Burdekin trial was harvested burnt. Tables 1 and 2 show the soil types, cane varieties and fertiliser application methods. The Herbert and Mackay trials were grown under a rainfed green cane trash blanket farming system, while the Burdekin trial was a cultivated, flood irrigated farming system. As conditions were initially dry, the Braemeadows trial site in the Herbert ('CR blended trials') was irrigated using an overhead water cannon between September and late December.

Controlled release (CR) N, based on a polymer-sulphur coating technology, was supplied by Everris Australia Pty Ltd. The polymer and sulphur coating slow the dissolution and release of urea- N into the soil (Di Bella *et al*., 2013). All CR fertilisers used in all trials are labelled as Agrocote® in Australia.

All sites were soil tested prior to the commencement of trials. Any nutrient deficiencies were addressed for all nutrients other than N according to the Six Easy Steps Guidelines.

Cane yield and CCS were measured in the commercial cane supplied to the mill for the Herbert and Burdekin trials, but in the Mackay trials, small mill samples were taken to determine CCS. Juice CCS samples taken through the large mill sampling process were undertaken in accordance with Queensland mill CCS determination processes (BSES, 1984).

N efficiency trials

Due to the large plot sizes and the difficulty of finding cane blocks large enough, sites were paired according to soil type and two replications were established per paired site. The Hamleigh and Seymour sites (clay soils) were paired, as were the Yuruga and Wharps sites (solodic soils) for N trials (Table 1). A mistake occurred in the calibration of the fertiliser equipment at the Wharps site resulting in a small increase in application rates in the 2013 harvest year.

CR blended trials

The Herbert, Burdekin and Mackay regional trials consisted of large scale plot sizes with three replicates per site; these trials were established in 2012 and harvested in 2013. Three trial sites (Braemeadows, Hawkins Creek and Macknade) were established in the Herbert region, one trial (Airville) in the Burdekin region and one trial in the Mackay region. Table 2 shows the fertilisers that were applied to each trial site.

Denitrification trial

Regular manual gas sampling was undertaken by the HCPSL team from selected treatments at the Hamleigh 'N efficiency trial' site during the 2012–13 season. Nitrous oxide emissions from (0–15

Table 1. Nitrogen fertilisers applied in the Herbert 'N efficiency trials'

Trial site	Soil type	Variety	Plot size (ha)	Urea (kg N/ha)	†Agrocote® (kg N/ha)	Application method
Hamleigh	Clay	Q208	0.6	122, 163	83,119, 160	Surface on row
Seymour	Clay	Q208	0.9	97, 163	97, 124, 160	Surface on row
Yuruga	Solodic	Q208	1.0	80,121, 160	80, 120, 160	Stool split
Wharps	Solodic	Q208	0.5	80, 120, 160 (2012) 106, 143, 182 (2013)	80, 120, 160 (2012) 103,147, 184 (2013)	Stool split

†*Agrocote® applied at 100%*

Table 2. Nitrogen fertilisers applied in the 'CR blended trials'

Trial site	Soil type	Variety	Plot size	Urea-N (kg N/ ha)	Agrocote® (kg N/ha)	Application method
Brae-meadows	Sandy clay	MQ239	0.6	150	125 (15% CR blend) 125 (25% CR blend) 100 (40% CR blend)	Stool split
Hawkins Creek	Clay	Q208	0.6	150	125 (15% CR blend) 125 (25% CR blend) 100 (40% CR blend)	Stool split
Macknade	Sandy clay	Q200	0.5	160 (2012)	121 (25% CR blend) 152 (25% CR blend)	Stool split
Burdekin (Airville)	Sandy loam	Q183 and Q200	0.3	120, 160, 200	200 (25%, 50% and 75% CR blend), 160 (50% CR blend), 120 (50% CR blend).	Incorporate into stool
Mackay	Sandy Loam	Q232	0.7	140, 102	140, 115, 102	Incorporate into stool

cm) × 5 cm diameter intact soil cores were measured after sealing the cores for 24 h in chambers buried in the field with 5–10% v/v acetylene in the chamber headspace. Initially soil cores were taken from inter-row and row (over the fertiliser band) positions, but inter-row sampling was discontinued after 64 days.

Two fertilised treatments were sampled: 122 kg N/ha as urea and 119 kg N/ha as CR urea, both applied to the crop row surface. Crop row ends that had not received N fertiliser were also sampled as a 'nil applied N' treatment. There were two crop strips per treatment (183 m of 6 rows cane on 1.64 m row spacing) and two sample locations were randomly selected per strip (top end and bottom end), giving a total of four replications per treatment at each sampling time.

Gas/soil samples were taken every three to four days for the first 29 days following fertiliser application (25 October 2012), then every seven days until 84 days after fertiliser application. Sampling frequency then extended to 14-day intervals until 166 days after fertiliser application, and finally once per month until sampling ceased 258 days after fertiliser application.

At each gas sampling, gravimetric soil moisture and 1M KCl-extractable ammonium-N and nitrate-N were measured. Soil moisture content was converted to water filled pore space (WFPS) using measured soil bulk density. Resource constraints prevented the measurement of dissolved organic carbon (a major factor impacting on denitrification) and also any ammonia gas loss via volatilisation from the surface-applied fertilisers.

Margin calculations

Net returns were calculated using the Cane Payment Formula (CPF) where the sugar price was set at $420/t and harvesting costs were assumed to be $7.50/tonne of cane harvested. Returns exclude irrigation, chemical and fixed costs.

1. CPF = ((Sugar price * 0.009 * (CCS Relative – 4)) + 0.662)

2. Net Returns ($/ha) = CPF-(Harvesting costs) * t cane/ha – fertiliser costs/ha.

Fertiliser costs were provided by Impact Fertilisers and based on the recommended retail price as of October 2013.

Results

Rainfall

Rainfall patterns in the Herbert valley were significantly drier in 2012–13 compared to the 2011–12 season (Table 3). In particular, only 15 mm of rainfall was recorded in November 2012, immediately following fertiliser application, compared to 151 mm in November 2011. In the 2011–12 season, severe waterlogging was experienced at the Hamleigh, Seymour, Yuruga and Wharps sites soon after fertiliser application (Di Bella *et al*., 2013).

The first significant rainfall event in the 2012–13 season occurred between Christmas Eve and New Year's Eve with localised flooding and waterlogging occurring. Annual rainfall in the Burdekin and Mackay regions were 530 mm and 1961 mm, respectively (Table 3). Like the Herbert, minimal rain fell within the first two months after fertiliser application.

N efficiency trials

The 2012 (Di Bella *et al*., 2013) and 2013 harvested trials show significant promise for the Agrocote® CR urea to manage nitrogen losses and, in some soil types, increase cane and sugar yields.

In the Herbert N efficiency trials, cane yield was significantly ($P \leq 0.05$) increased by CR N on the clay and solodic soils at 120 kg N and 160 kg N/ha in 2012–13 (Figure 1). On the clay soil, 120 kg/ha of CR N achieved the same yield as 160 kg/ha urea-N.

Table 3. Monthly and total rainfall (mm) at Ingham (station 32078), Ayr (station 33002) and Mackay (station 33023) during the trial period

Location	Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Ingham	2011–12	74	151	254	322	630	939	101	148	75	113	22	14	2844
Ingham	2012–13	53	15	285	626	433	208	101	117	24	33	7	9	1858
Ayr	2012–13	0	8	33	266	91	65	39	25	1	1	0	1	530
Mackay	2012–13	32	22	307	261	428	440	261	161	13	26	1	9	1961

Table 4. Yield, CCS and net returns from the Burdekin trial

Treatment	N rate (kg/ha)	Cane yield (t/ha)	CCS	Sugar yield (t/ha)	Net return ($/ha)
100% Urea	200	122.49 c	14.82 a	18.12 c	$ 3,920.63
25% Agrocote, 75% urea	200	134.94 ab	15.13 a	20.38 a	$ 4,380.75
50% Agrocote, 50% urea	200	134.25 ab	14.30 a	19.17 abc	$ 3,765.83
75% Agrocote, 25% urea	200	140.13 a	14.29 a	19.94 ab	$ 3,788.87
100% Urea	160	125.32 bc	14.96 a	18.74 bc	$ 4,135.87
50% Agrocote, 50% urea	160	128.97 abc	14.63 a	18.86 abc	$ 3867.46
100% Urea	120	123.55 bc	14.80 a	18.23 c	$ 4048.79
50% Agrocote, 50% urea	120	104.22 d	14.65 a	15.22 d	$ 3157.08

Means followed by the same letter do not differ significantly (P≤0.05)

Figure 1. Effect of Agrocote® (●), Urea (●, dashed) and N rate on cane yield grown on clay (A) and solodic (B) soils in 2012–13. Error bar is Fisher's protected LSD 5%

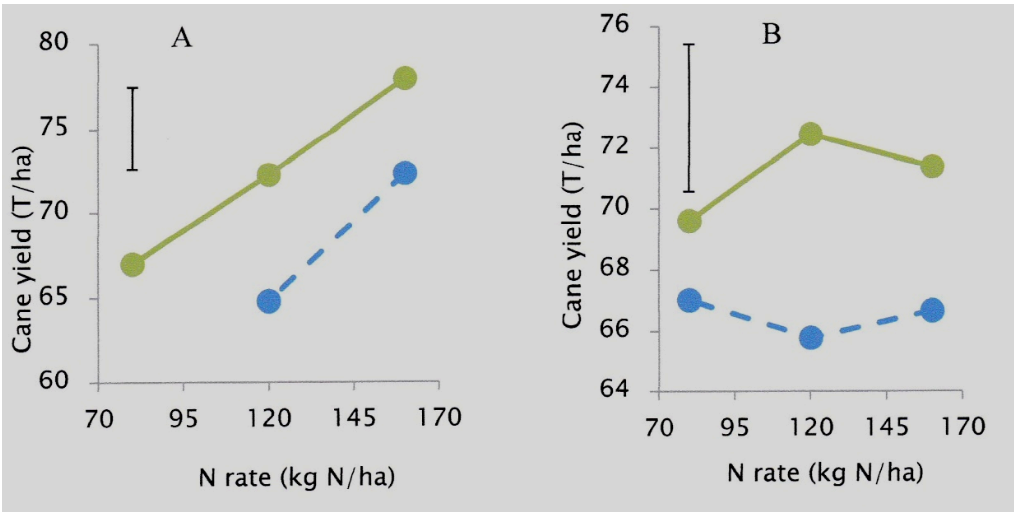


Table 5. Yield, CCS and net returns at the Macknade site

Fertiliser	N rate (kg N/ha)	Cane yield (t/ha)	CCS	Sugar yield (t/ha)	Net return ($/ha)
Urea	153	76.09	15.98	12.16	$ 2,834.60
Agrocote 25%, urea 75%	152	79.37	16.00	12.68	$ 2,934.01
Agrocote 25%, urea 75%	121	79.50	16.00	12.71	$ 2,963.97

No significant differences between any treatments for CCS, cane or sugar yield (P≤0.05)

There was no significant yield response to urea-N on the solodic soil, whereas there was a significant yield response to CR N when compared to urea-N, indicating that N loss from the urea treatment was substantial. Cane yield with 80 kg CR N/ha was not significantly different to 160 kg urea-N/ha on the solodic soil, indicating that the CR N treatment at this site had a higher N use efficiency (yield per unit N applied). These trial results were similar to those reported previously in the Herbert Valley (Di Bella *et al*., 2013).

CR blended trials

Controlled release N significantly (P ≤ 0.05) increased cane and sugar yields at the 200 kg/ha N rate compared with urea-N at the Burdekin trial site. Cane yield was increased at 200 kg N/ha, in blends containing 25%, 50% and 75% CR N (Table 4). At 200 kg N/ha there was a strong correlation (r2=0.88) between the proportion of CR N in the blend and cane yield. Compared to 200 kg/ha urea, N blends containing 25% and 75% CR-N significantly (P ≤ 0.05) increased sugar yield (Table 4). The highest grower margins were obtained using a blend of 25% CR N and 75% urea-N; net margins increased by $460 /ha above that achieved with urea-N. At the lowest N rate (120 kg N/ha), yields were significantly reduced with 50% CR N. Low N rates combined with controlled N delivery early in the season may have delivered insufficient N to the crop. Early vigour and N availability are important factors in yield development.

Specific blends with controlled release N produced the highest grower margins at both the Burdekin (Table 4), Macknade (Table

Table 6. Yield, CCS and net returns at the Braemeadows site					
Fertiliser	**N rate (kg N/ha)**	**Cane yield (t/ha)**	**CCS**	**Sugar yield (t/ha)**	**Net return ($/ha)**
Urea	150	94.31	11.85	11.17	$ 2,067.43
Agrocote 15%, urea 85%	125	95.58	12.05	11.50	$ 2,140.63
Agrocote 25%, urea 75%	125	93.32	11.85	11.14	$ 2,063.45
Agrocote 40%, urea 60%	100	94.82	12.05	11.42	$ 2,140.63
No significant differences between any treatments for CCS, cane or sugar yield (P≤0.05)					

Table 7. Yield and CCS at the Mackay trial site				
Treatments	**Total N (kg/ha)**	**Cane yield (t/ha)**	**CCS**	**Sugar yield (t/ha)**
Urea S	140	86.8 a	15.0 a	13.0 a
UreaS + Agrocote (50% CR N)	140	85.6 a	15.5 a	13.2 a
UreaS + Agrocote (50% CR N)	115	82.0 a	15.3 a	12.6 a
UreaS	102	83.5 a	15.5 a	12.9 a
UreaS + Agrocote (50% CR N)	102	83.4 a	15.3 a	12.8 a
Means followed by the same letter do not significantly differ (P≤0.05)				

5), and Braemeadows (Table 6) sites.

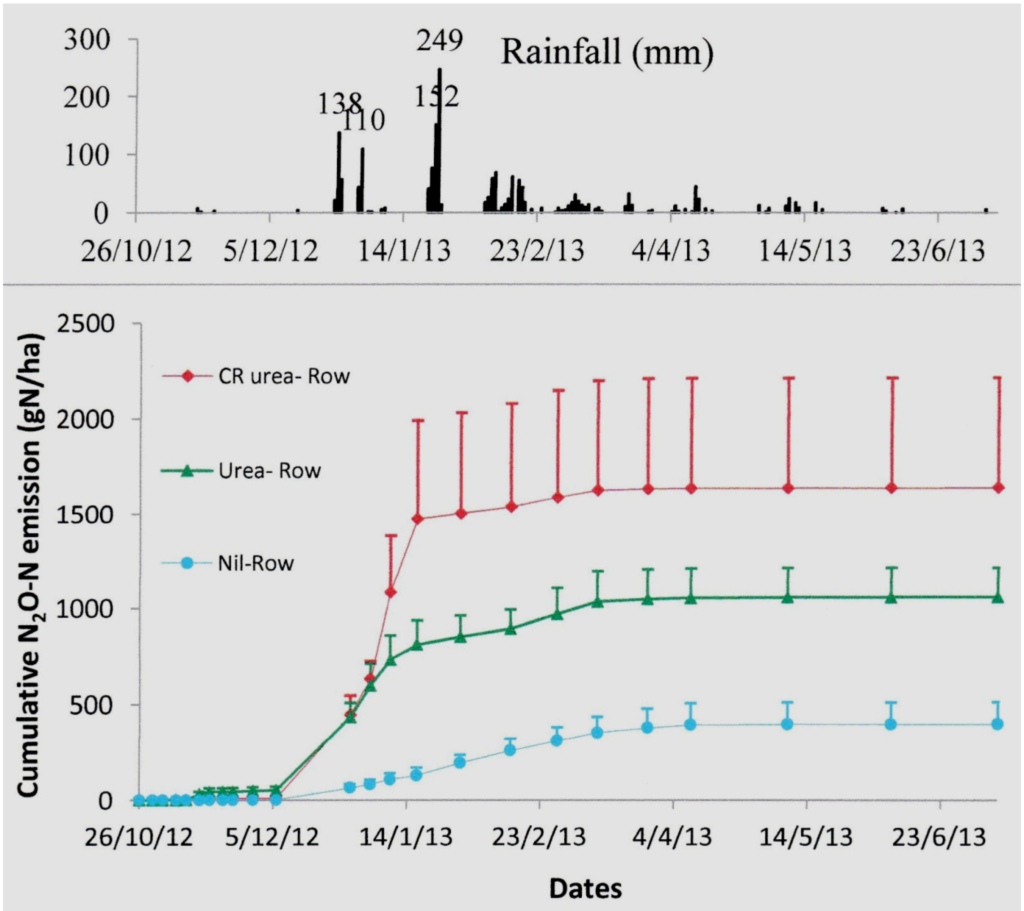
In the Burdekin the 25% controlled release N had the highest gross margin (Table 4), being $460/ha higher than the 100% urea treatment. At Macknade, a blend containing 25% controlled release N increased margins by $129 / ha and $99 /ha compared to urea at application rates of 120 and 150 kg N/ ha, respectively (Table 5). At the Braemeadows site, blends containing 15% and 40% controlled release N increased margins by $97 /ha and $73 /ha, respectively (Table 6).

There were no significant differences in cane or sugar yield at the Mackay trial site (Table 7). The trial site was not nitrogen responsive within the range of N fertilisers applied.

Denitrification trial

Rate and cumulative amount of denitrification

Figure 2. Rainfall and cumulative nitrous oxide emissions from row positions at the Hamleigh site. Treatments of urea and controlled release urea (CR urea) were applied at 120 kg N/ha while no N was applied to the Nil treatment. Bars are standard errors of the means on each sampling occasion



Nitrous oxide (N_2O) gas emissions from the row calculated on a soil core weight basis ranged up to 2.18 mg N/kg soil/day from CR urea, up to 0.46 mg N/kg soil/day from urea, and up to 0.17 mg N/kg soil/day from the unfertilised treatment. Nitrous oxide (N_2O) gas emissions from the interrows during the 64 days of monitoring were reasonably constant across all treatments and always less than 0.02 mg N/kg soil/day. Cumulative emissions calculated on an area basis (0–10 cm soil depth and measured soil bulk density in the row of 1.10 Mg/m3) for the period were approximately 1644 g N/ha from CR urea, 1061 g N/ha from urea, and 403 g N/ ha from the unfertilised row (Figure 2).

There were no significant (P≤0.05) differences between N_2O emissions from urea and CR urea on any occasion. However, from 5 December 2012 onwards, emissions from the nil N row were significantly lower than those from the fertilised treatments. Note that the N_2O emission values are not the absolute amount of N lost by denitrification; conversion of these values to kg N/ha requires calibration of the field methodology against a reference method using 15N and this work will be undertaken in 2014. However, the emission values can be used to compare the relativity of N losses between treatments.

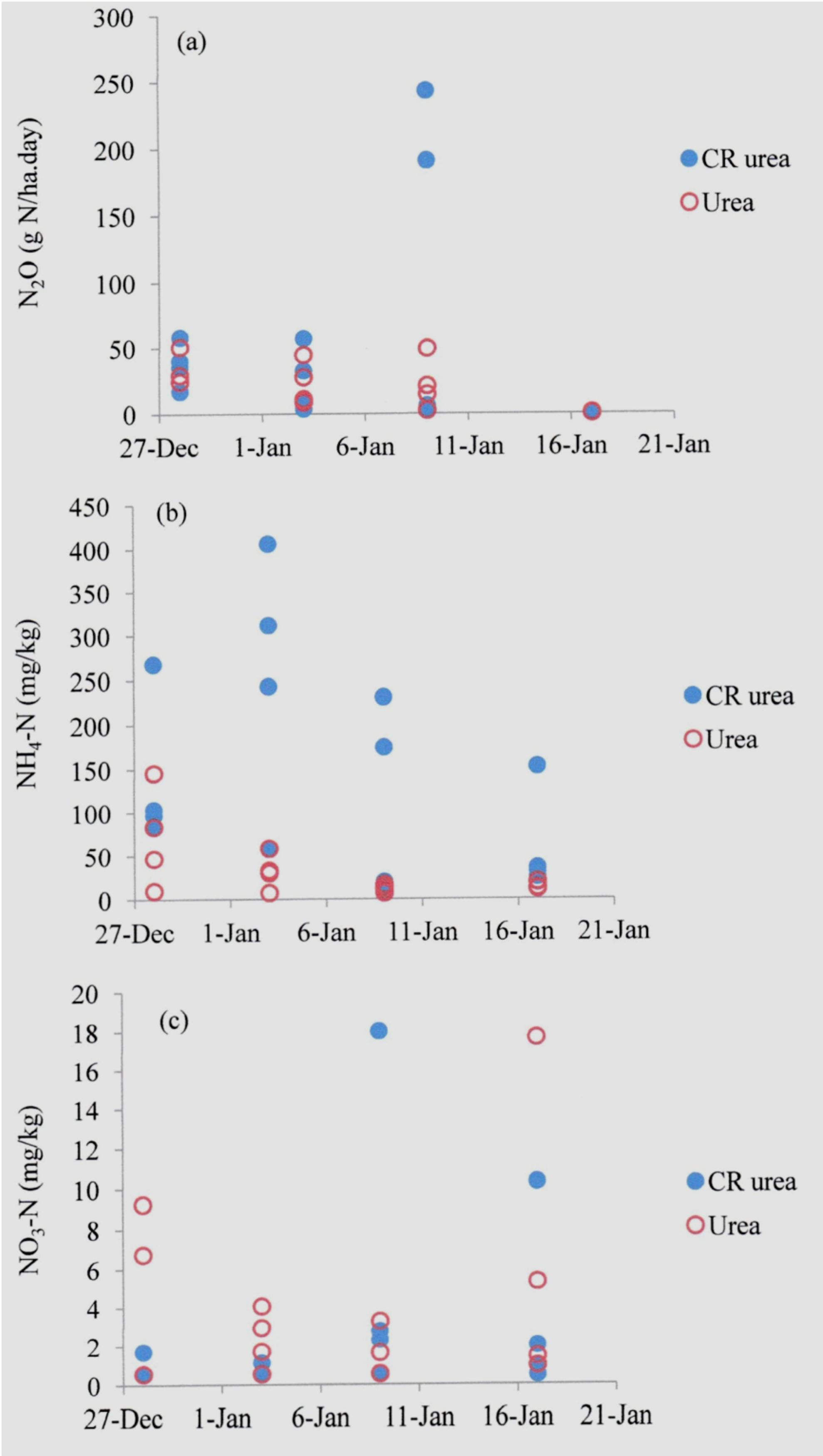
There was limited initial denitrification from both N sources following application to the soil which was drier than field capacity. However, after the first significant rainfall events (>20 mm per event) in late December (about 60 days after fertiliser application), a major flush of denitrification occurred (Figure 2). This was followed by a much smaller flush due to further significant rainfall events in late January. Despite prolonged rainfall in late February, there was only a very limited response in terms of further denitrification.

Trends in cumulative denitrification from both urea and CR urea were similar until 3 January, then denitrification from CR urea continued at a higher rate until 17 January whereas denitrification from urea was lower (though not significant at P≤0.05) during the same period. From 17 January until 12 March, both treatments showed limited denitrification and there was minimal denitrification after that date. Denitrification in the untreated row mirrored these trends.

Factors affecting denitrification rate

There was no relationship between N_2O emissions and WFPS (data not presented) during the period 28

Figure 3. N_2O emissions (a) and corresponding ammonium-N (b) and nitrate-N concentrations (c) over time for CR urea and urea treatments at the Hamleigh site



December 2012 to 17 January 2013, but during this period, WFPS always exceeded 65% so conditions were conducive to denitrification. There were no clear relationships between either soil ammonium-N or nitrate-N and N_2O emissions although there was an indication that high concentrations of either form of mineral N were sometimes associated with high emissions (Figure 3). It was apparent that ammonium-N concentrations in the CR urea treatment were generally higher than the urea treatment (Figure 3b), and this suggests the potential for denitrification and/or N_2O emissions from nitrification may have been high at these times.

Discussion

Two years of research trials in the Herbert Valley have shown significant increases in productivity and N-efficiency (t cane/ kg N applied) with CR N compared to urea (see Di Bella *et al*., 2013). Improvements in N-efficiency have been measured in seasons with both wet and dry conditions in the first two months following fertiliser application, and on heavy clay and solodic soils. In 2013, significant increases in efficiency were also measured on a flood-irrigated Burdekin-delta soil. Results from these trials indicate that not only was there an improvement in N-use efficiency, but there is also the potential to reduce N rates applied to the field without compromising productivity.

Due to the higher cost of controlled release N compared to urea, application of straight (100%) controlled release N fertiliser is unlikely to be viable. However blends, containing 15% to 40% controlled release N (80% N release over four months) with urea, significantly increased net margins in the Burdekin and Herbert sites, with increased net margins of up to \$460 /ha (measured in the Burdekin).

Blends with conventional urea may also improve early season growth, particularly in drier seasons. For example, sugarcane at the Wharps site appeared to show a more immediate growth response to conventional urea in the dry growing conditions, even though by harvest cane yield was significantly ($P \leq 0.05$) increased by CR N on the solodic soil (being the mean of the Wharps and Yuruga sites) at both the 120 kg N and 160 kg N/ha rate. Nitrogen is required by the crop early in the season, and therefore a blend of CR N with some uncoated N may increase early-season growth compared to CR N alone.

Nitrous oxide is a greenhouse gas and a by-product of the denitrification process. Results from the Hamleigh trial highlight the significance of the opening wet season rainfall events to denitrification.

When the N fertilisers were applied in October, the soil was drier than field capacity and there were no measurable N_2O emissions. However, following rainfall events in late December, a flush of denitrification occurred. By the onset of the wet season in late-January, emissions had dropped to negligible levels, presumably because of the low levels of soil nitrate present at the time.

Although the N_2O emissions from CR urea were not significantly higher than those from urea, the higher apparent trend suggests that more research needs to be done to better align mineral N release with crop demand.

Conditions during the wet season in terms of water-filled pore space in the soil are conducive to denitrification, so mineral-N supply needs to be in close accord with crop requirements.

An indication from this work is that technologies that increase inorganic N levels in the soil (e.g. by slowing N release rate or reducing leaching or runoff losses, Figure 3b) may be unlikely to reduce nitrous oxide emissions (Figure 2).

Significant N is removed from the sugarcane farming system in harvested cane and crop residues. Thus, by increasing N-use efficiency (productivity per unit N applied) growers can reduce environmental losses because more N is taken up by the crop and converted to cane.

Future projects should measure N loss via deep drainage, runoff, denitrification, and, in the case of surface applied fertilisers, volatilisation, from fields treated with CR N so a whole N budget can be obtained.

Although N-use efficiency was increased by using CR N, and environmental losses likely reduced, the major N-loss pathways that are affected by CR N have not been identified. This work is essential to determine whether the use of CR N will improve water quality and reduce impacts on the Great Barrier Reef.

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