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Aspects of temporal N management in sugarcane in sub-tropical Queensland

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Abstract The proximity of the Australian sugar industry to the Great Barrier Reef (GBR) has resulted in ongoing concerns about elevated concentrations of the dissolved inorganic nitrogen (DIN) in the near-reef environments due to sugarcane production practices on-farm. Although the nitrogen (N) guidelines within the SIX EASY STEPS nutrient-management program are generally appropriate, scope exists for fine-tuning of N application rates for specific circumstances. In particular, enhanced-efficiency fertilisers (EEFs), such as urea coated with 3,4-dimethylpyrazole phosphate (DMPP-urea) and polymer-coated urea (PC-urea), offer promise potentially to improve nitrogen-use efficiency (NUE) in sugarcane production and reducing DIN losses to the GBR. Temporal N-management strategies using these EEFs were assessed within a randomised complete-block field trial conducted in a sub-tropical environment on a well-drained soil supported by a concurrently run shorter-term pot experiment. There were no significant yield responses to applied N, split applications or use of EEFs in the trial in either the plant or first-ratoon crops. Rainfall measured during these seasons would not have resulted in excessively wet conditions at the trial site and may have contributed to the lack of responses to EEFs. Increased N-uptake by the crop, due to the use of N strategies away from the standard practice (i.e. by using EEFs or split applications of urea), improved NUE values based on crop N, but this did not always translate into any improvements in yield. The highest partial net returns in the plant and first-ratoon crop corresponded to the control treatments. Urea applied at 120 kg N/ha in a single application resulted in the next best partial net returns in both crops. This appeared to be the most appropriate strategy to minimise risk to growers. The cost of EEF fertilisers negatively affected the partial net returns, with DMPP-coated urea being more affordable than the poly-coated urea. The results of the pot experiment that included two sugarcane cultivars supported these outcomes. Further work, across seasons (dry, wet and 'normal'), is needed to evaluate more fully the potential of EEFs for use in specific circumstances.

Key words Sugarcane, temporal nitrogen management, enhanced efficiency fertilisers, climate

INTRODUCTION

The Australian sugar industry is located in several discrete regions within about 2000 km from Mossman in far north Queensland to Grafton in coastal northern New South Wales (Anon. 2018). The eastern boundaries of the northern regions (Far North, Herbert, Burdekin and Central) are flanked by the Coral Sea that includes the Great Barrier Reef (GBR) Lagoon (Anon. 2016). This proximity of the sugar industry to an important World Heritage listed site has resulted in ongoing concerns about the effect of land-based farming activities on the quality of water in the GBR Lagoon (Thorburn *et al.* 2013). In particular, there have been reports of damage to coral due to elevated concentrations of the dissolved inorganic nitrogen (DIN) in the near-reef environments (Kroon *et al.* 2016). The sugar industry has reinforced its commitment to sustainable sugarcane production (profitability partnered with environmental responsibility) through the Smartcane BMP initiative (Anon. 2017a; Kealley and Quirk 2016). This program endorses the SIX EASY STEPS program as the basis for best practice nutrient management (Schroeder *et al.* 2018). Although the nitrogen (N) guidelines within STEP 4 of the SIX EASY STEPS program are generally appropriate for use within the various regions/districts (Schroeder *et al.* 2018), scope exists for fine-tuning of N application rates for specific circumstances as part of STEPS 5 and 6. In particular, enhanced-efficiency fertilisers (EEFs), such as urea coated with 3,4-dimethylpyrazole phosphate (DMPP-urea) and polymer-coated urea (PC-urea), offer promise to improve nitrogen-use efficiency (NUE) in sugarcane production (Verburg *et al.* 2015) and are seen as a possible mechanism for reducing DIN losses to the GBR (Bell and Moody 2015).

The aim of this paper is to report on a multi-facetted (agronomic, economic and environmental) evaluation of the temporal aspects of N management using EEF and split application of urea compared with standard non-enhanced/non-split applications of urea.

METHODOLOGY

The investigation consisted of:

i. A field trial established in 2015 at Welcome Creek near Bundaberg on a well-drained and moderately permeable Red Clay Loam soil (Schroeder *et al*. 2007) of the Otoo series (Donnollan *et al*. 1988).
ii. A pot experiment [using topsoil (0-20 cm) from the field trial site] conducted under semi-controlled conditions to provide supporting information.

Selected soil chemical and physical properties of soil samples (0-20cm) collected across the trial site prior to establishing the trial are shown in Table 1. These are also applicable to the soil used in the pot experiment. Prior to establishing the field trial, the site was used for commercial cane production.

***Table 1*.** Selected soil chemical and physical properties of the trial site at Welcome Creek at 0-20 cm depth.

Assay	Units	Value
$pH_{(water)}$	-	5.8
[1] Organic C	%	1.1
[2] ECEC	cmol(+)/kg	3.3
Texture	-	Light clay

[1]Walkley and Black (1934); [2]Effective cation exchange capacity

Field trial

Two rates of N (120 and 160 kg N/ha) were applied to the sugarcane plant crop (PC) as DMPP-urea and PC-urea and compared to urea applied as split applications that also totalled 120 kg N/ha and 160 kg N/ha. A control (zero N) treatment was included. The randomised complete-block design included four replicates. The block was planted on 9 September 2015 (cv. Q183⏀) with di-ammonium phosphate (DAP) fertiliser applied in the planting furrow due to a P requirement indicated by a soil test. The N treatments (that included the N in the DAP) were applied according to the schedule in Table 2. The side-dressings were applied by hand on the shoulder of the cane rows in each plot. Irrigation was applied shortly after the treatment applications. The N treatments to the first-ratoon crop (120 and 160 kg N/ha) were applied as before using DMPP-urea, PC-urea and urea as split applications according to the schedule in Table 3. The cane was irrigated shortly after the treatment applications.

Monthly rainfall data for September 2015 to September 2017 [Bundaberg Aero, 24.91S, 152.32E (Station 39128)] were obtained from the Bureau of Meteorology (BOM) website (http://www.bom.au). Nitrogen uptake by the crop (kg N/ha) was determined from the N%DM of biomass (stalk, and leaves and tops) collected at harvest of the plant and first-ratoon crops. Sugarcane yields (t cane/ha) and sugar yields (t sugar/ha) were determined by weighing hand-harvested cane from two centre rows of each plot using an in-field weigh platform. Six-stalk samples were collected for CCS analysis. The plant crop was harvested on 21-22 September 2016 and the first ratoon on 28 September 2017.

Pot experiment

The pot experiment was conducted in a glasshouse at SRA, Bundaberg. It was established on 2 September 2015. The aim was to understand aspects of N uptake and NUE in young sugarcane plants (cultivars Q200⏀ and Q208⏀) with different temporal N options – urea, DMPP-urea and PC-urea applied at equivalent rates of 0, 75, 150 and 225 kg N/ha. There were four replications within a randomised complete-block design. The intention was to maintain the soils in the pots at field capacity using a semi-automated dripper irrigation system. Any excess water that leached to the saucers was returned to the appropriate pot. The above ground plants were harvested in mid-December 2015. The plant material from each pot was partitioned into stalk, and leaves and tops, and then placed in a drying oven at 65°C. The dry mass was determined. Samples were then prepared and submitted to the laboratory for N analyses.

The field trial and pot experiment data were analysed using Statistix Version 10.0.

Table 2. Nitrogen treatments applied to the plant crop in the N trial at Welcome Creek.

Treatment	Fertiliser formulation applied during side-dressing	N applications (kg N/ha)				Total N applied (kg N/ha)
		Initial as DAP[1] (9 September 2015)	Side-dressings			
			1st (25 Nov 2015)	2nd (30 Dec 2015)	3rd (28 Jan 2016)	
12	Control	40	0	0	0	40
2	Urea	40	40	20	20	120
1	Urea	40	40	40	0	120
6	Urea	40	80	0	0	120
8	DMPP-urea	40	80	0	0	120
10	Poly-urea	40	80	0	0	120
4	Urea	40	80	40	0	160
3	Urea	40	80	20	20	160
11	Urea	40	40	40	40	160
7	Urea	40	120	0	0	160
5	DMPP-urea	40	120	0	0	160
9	Poly-urea	40	120	0	0	160

[1]Initial N application (40 kg N/ha) in each case was as applied at di-ammonium phosphate fertliliser across the block due to the P requirement indicated by the soil test.

Table 3. Nitrogen treatments applied to the first-ratoon crop in the N trial at Welcome Creek.

Treatment	Fertiliser formulation applied during side-dressing	N applications (kg N/ha) as side-dressings				Total N applied (kg N/ha)
		1st (19 Dec 2016)	2nd (5 Jan 2017)	3rd (25 Jan 2017)	4th (21 Feb 2017)	
12	Control	0	0	0	0	0
2	Urea	40	40	20	20	120
1	Urea	40	40	40	0	120
6	Urea	120	0	0	0	120
8	DMPP-urea	120	0	0	0	120
10	PC-urea	120	0	0	0	120
4	Urea	40	80	40	0	160
3	Urea	40	80	20	20	160
11	Urea	40	40	40	40	160
7	Urea	160	0	0	0	160
5	DMPP-urea	160	0	0	0	160
9	PC-urea	160	0	0	0	160

RESULTS AND DISCUSSION

Rainfall

The monthly and annual rainfall data from the Bundaberg Aero site and the estimated amounts of irrigation applied to the trial site for the period July September 2015 to Oct 2017 are shown in Figure 1. This period included the plant crop from establishment (September 2015) to harvest (October 2016), and the first-ratoon crop from October 2016 to September 2017. The 2015/16 cropping season (October–September) in Bundaberg was wetter (1041 mm of recorded rainfall) than the 734 mm of recorded rainfall during the 2016/17 season. The rainfall patterns during those seasons differed from each other and from the long-term pattern (Figure 1). Both crops were irrigated during the high-growth period (January-March each year), but the first ratoon received 100 mm more than the plant crop. The total rainfall and irrigation for each of the crops were, therefore, not dissimilar and were in line with, or higher than, the long-term mean annual rainfall. Although temporary periods of moisture 'stress' were possible, overall water availability should not have been an overriding factor in crop growth and, therefore, should not have influenced the results of the field trial.

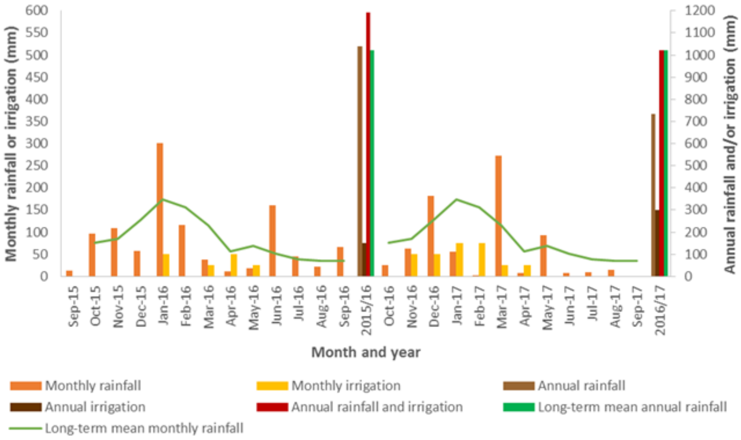

Figure 1. Monthly and annual recorded rainfall from the Bundaberg Aero site and details of irrigation relevant to the field trial at Welcome Creek (September 2015-September 2017).

Field trial

There were no significant differences in sugarcane yields (t cane/ha) and CCS values in either the PC (Table 4) or the first-ratoon crop (Table 5) due to the N treatments. The values were, however, different in the two crops.

In the PC (Table 4), the total N uptake (kg N//ha) varied from 74.8 kg N/ha (urea applied at 120 kg N/ha as three splits of 40 kg N/ha) to 109.4 kg N/ha (PC-urea applied at 120 kg N/ha N following an initial application of urea applied at an equivalent rate of 40 kg N/ha). The N uptake values associated with the other applications were not significantly different from each other. There were no significant differences in NUE (expressed as t cane/kg N applied and t cane/kg crop N) due to the various temporal N strategies. The highest partial net return ($2,249/ha) corresponded to the control treatment (Treatment 12) (Table 4). Urea applied as a single side dressing, 80 kg N/ha after the initial 40 kg N/ha as DAP (Treatment 6), resulted in the next best partial net return ($2,145/ha). DMPP-coated urea applied at 80 kg N/ha after the initial 40 kg N/ha applied at DAP (Treatment 8) was ranked third (partial net return of $2,117/ha). Urea applied at higher rates or split applications resulted in lower partial net returns than the top three treatments. The lowest partial net return ($1,715/ha) was associated with the 160 kg N/ha applied as PC-coated urea (Treatment 9).

In the first-ratoon crop (Table 5), the total N uptake was lowest in the control (87.9 kg N/ha). This was significantly lower that the total N uptake associated with Treatments 8, 4, 11, 5 and 9 (DMPP-urea applied at an equivalent rate of 120 kg N/ha, urea applied in three split application at equivalent rates of 40, 80 and 40 kg N/ha, urea applied at an equivalent rate of 160 kg N/ha in four equal splits of 40 kg N/ha each, DMPP-urea applied at an equivalent rate of 160 kg N/ha, and PC-urea applied at an equivalent rate of 160 kg N/ha, respectively). As with the plant crop, there were no significant differences in yield due to the temporal N strategies. However, significantly different NUE values occurred and generally reflected the significantly different N uptake values (Table 5). The highest partial net return ($3,135/ha) corresponded to the control treatment (Treatment 12) (Table 5). Urea applied as a single side dressing at 120 kg N/ha (Treatment 6) resulted in the next best partial net return ($2,979/ha). DMPP-coated urea applied at 120 kg N/ha (Treatment 8) was ranked third (partial net return of $2,937/ha). Urea applied at higher rates or split applications resulted in lower partial net returns than the top three treatments. The lowest partial net return ($2,471/ha) was associated with the 160 kg N/ha applied at PC-coated urea (Treatment 9).

Table 4. Total N uptake and NUE (based on biomass determined immediately prior to harvest), and cane yield (t cane/ha), CCS, partial net returns (PNR) and PNR rankings for the plant crop at the Bundaberg site.

Treatment	Side-dressing fertiliser formulation	N applications (kg N/ha)			Fertiliser cost ($/kg N)		Total N uptake	Yield		NUE		Partial net returns	
		Initial	Side-dressings	Total N applied	Initial	Split formulation	(kg N/ha)	(tc/ha)	CCS	(tc/kg N applied)	(tc/kg crop N)	($/ha)	Ranking
12	Control	40	0	40	1.30	1.30	82.4^{A,B}	80.6^{A}	15.7^{A}	2.02^{A}	0.98^{A}	2,249	1
2	Urea	40	40	120	1.30	1.30	84.5^{A,B}	79.7^{A}	15.6^{A}	0.66^{B}	0.94^{A}	2,065	6
1	Urea	40	40	120	1.30	1.30	74.8^{B}	75.7^{A}	15.3^{A}	0.63^{B}	1.02^{A}	2,105	4
6	Urea	40	80	120	1.30	1.30	82.0^{A,B}	78.9^{A}	15.5^{A}	0.66^{B}	0.98^{A}	2,145	2
8	DMPP-urea[1]	40	80	120	1.30	1.65	84.1^{A,B}	80.1^{A}	15.2^{A}	0.67^{B}	0.97^{A}	2,117	3
10	PC-urea[2]	40	80	120	1.30	4.15	93.2^{A,B}	75.7^{A}	15.4^{A}	0.63^{B}	0.82^{A}	1,917	11
4	Urea	40	80	160	1.30	1.30	84.4^{A,B}	77.5^{A}	15.1^{A}	0.48^{B}	0.92^{A}	2,053	7
3	Urea	40	80	160	1.30	1.30	89.0^{A,B}	77.3^{A}	15.5^{A}	0.48^{B}	0.87^{A}	2,013	9,10
11	Urea	40	40	160	1.30	1.30	103.0^{A,B}	84.4^{A}	15.9^{A}	0.53^{B}	0.83^{A}	2,013	9,10
7	Urea	40	120	160	1.30	1.30	85.8^{A,B}	77.2^{A}	15.4^{A}	0.48^{B}	0.91^{A}	2,093	5
5	DMPP-urea[1]	40	120	160	1.30	1.65	97.7^{A,B}	80.8^{A}	15.7^{A}	0.51^{B}	0.83^{A}	2,051	8
9	PC-urea[2]	40	120	160	1.30	4.15	109.4^{A}	90.5^{A}	15.5^{A}	0.57^{B}	0.83^{A}	1,715	12
	Mean						89.2	79.9	15.5	0.69	0.91		
	SE						6.3	5.5	0.2	0.06	0.31	n/a	
	P						0.02	0.79	0.31	0.00	0.06		
	Tukey's HSD$^{0.05}$						31.4	ns	ns	0.31	ns		

Assumptions: Sugar price = $370/ts; harvesting and levies = $10/tc; fertiliser costs: urea = $1.30/kg N, DMPP- urea = $1.65/kg N and PC-urea = $4.15/kg N; additional cost of applying each split application = $40/ha. ^{A,B} Mean values accompanied by the same letter in a column are "not significantly" different.

Table 5. Total N uptake and NUE (based on biomass determined immediately prior to harvest), and cane yield (t cane/ha), CCS, partial net returns (PNR) and PNR rankings for the first-ratoon crop at the Bundaberg site.

Treatment	Side-dressing fertiliser formulation	N applications (kg N/ha)			Fertiliser cost ($/kg N)		Total N uptake	Yield		NUE		Partial net returns	
		Initial	Total side-dressings	Total N applied	Initial	Split formulation	(kg N/ha)	(tc/ha)	CCS	(tc/kg N applied)	(tc/kg crop N)	($/ha)	Ranking
12	Control	0	0	0	1.30	1.30	87.9^{B}	75.7^{A}	18.2^{A}	n/a	0.88^{A}	3,135	1
2	Urea	40	80	120	1.30	1.30	111.1^{A,B}	74.4^{A}	18.2^{A}	0.62^{A,B,C}	0.68^{A,B}	2,859	7
1	Urea	40	80	120	1.30	1.30	115.9^{A,B}	86.5^{A}	18.5^{A}	0.72^{A}	0.75^{A,B}	2,899	5
6	Urea	120	0	120	1.30	1.30	112.6^{A,B}	82.2^{A}	18.3^{A}	0.68^{A,B}	0.73^{A,B}	2,979	2
8	DMPP-urea[1]	120	0	120	1.65	n/a	131.3^{A}	82.1^{A}	18.2^{A}	0.69^{A,B}	0.63^{B}	2,937	3
10	PC-urea[2]	120	0	120	4.15	n/a	123.3^{A,B}	86.2^{A}	18.3^{A}	0.72^{A}	0.71^{A,B}	2,637	11
4	Urea	40	120	160	1.30	1.30	133.7^{A}	87.1^{A}	17.8^{A}	0.54^{B,C}	0.66^{B}	2,847	8
3	Urea	40	120	160	1.30	1.30	120.3^{A,B}	86.7^{A}	17.9^{A}	0.54^{B,C}	0.73^{A,B}	2,807	9,10
11	Urea	40	120	160	1.30	1.30	127.4^{A}	82.6^{A}	18.2^{A}	0.52^{C}	0.65^{B}	2,807	9,10
7	Urea	160	0	160	1.30	1.30	117.5^{A,B}	80.3^{A}	18.5^{A}	0.50^{C}	0.68^{A,B}	2,927	4
5	DMPP-urea[1]	160	0	160	1.65	n/a	134.6^{A}	84.2^{A}	18.2^{A}	0.53^{C}	0.64^{B}	2,871	6
9	PC-urea[2]	160	0	160	4.15	n/a	130.9^{A}	85.6^{A}	18.0^{A}	0.54^{B,C}	0.66^{B}	2,471	12
	Mean						120.5	82.8	18.2	0.71	0.70		
	SE						7.5	4.7	0.2	0.05	0.04	n/a	
	P						0.006	0.64	0.17	0.0001	0.009		
	Tukey's HSD$^{0.05}$						37.3	ns	ns	0.16	0.20		

Assumptions: Sugar price = $370/ts; harvesting and levies = $10/tc; fertiliser costs: urea = $1.30/kg N, DMPP- urea = $1.65/kg N and PC-urea = $4.15/kg N; additional cost of applying each split application = $40/ha. ^{A,B,C} Mean values accompanied by the same letter in a column are "not significantly" different.

Pot experiment

The yield of millable stalk, and leaves and tops harvested from the pot experiment are shown in Tables 6 and 7, respectively. Significant responses to applied N occurred in both cases, but without significant differences due to the use of the different fertiliser formulations (urea, DMPP-urea or PC-urea). Mean yields of millable stalks, and leaves and tops varied according to cultivar (Q200⏀ and Q208⏀). Significant differences in the amount of N in stalks, leaves and tops, and roots occurred due to N applied (Tables 8, 9 and 10 respectively), there were no significant effects due to the fertiliser formulation used. The total N uptake in the whole plants (stalks, leaves and tops, and roots) of cultivar Q200⏀ at a treatment rate of 150 kg N/ha minus the N-uptake at zero N applied allowed the percentage N in the different plant parts to be calculated. We found that 18% of the applied N was in the stalks, 34% of the applied N was in the leaves and tops, and 20% of the applied N was in the roots. In total, 28% of the 150 kg N/ha application (42 kg N/ha) could not be accounted for in this way. This amount of N was either held within the soil reserves or lost by denitrification. Leaching losses were unlikely as leachates were returned to the pots on a routine basis. Similar trends were obtained for cultivar Q208⏀.

The NUE indicators based on N application rates, mean stalk yields and N content of the stalks are shown in Table 11. Nitrogen use efficiency (t cane/kg N applied) ranged from 0.69 (at 75 kg N/ha) to 0.31 (at 225 kg N/ha). As expected, the Agron EffFert (kg N/additional t cane/ha) increased with increased rates of N applied. The NUpEfert (additional kg uptake/kg fertiliser N applied) was more or less stable at 18-19% at the 150-225 kg N/ha application rates.

***Table 6**.* Effect of N fertiliser formulation, rate of N applied and cultivar on the yield of millable stalks in the pot experiment.

Cultivar	Fertiliser formulation	Yield of millable stalks (t cane/ha)				
		N applied (kg/ha)				Mean
		0	75	150	225	
Q200⏀	Urea	21.5	63.3	66.9	70.5	55.5^{A}
	DMPP-urea	16.5	43.6	59.5	68.7	47.1^{A}
	PC-urea	24.9	49.4	48.9	72.0	48.8^{A}
	Mean	21.0^{C}	52.1^{B}	58.4^{AB}	70.4^{A}	[3]50.4^{X}
Tukey HSD$^{0.05}$: Product = ns (P=0.09); N = 12.2 (P< 0.001); Prod x N = ns (P=0.26)						
Q208⏀	Urea	10.8	34.9	60.5	72.6	44.7^{A}
	DMPP-urea	9.3	41.5	56.5	80.5	46.9^{A}
	PC-urea	9.9	33.3	48.8	69.1	40.3^{A}
	Mean	10.0^{D}	36.5^{C}	55.3^{B}	74.1^{A}	[3]44.0^{Y}
Tukey HSD$^{0.05}$: Product = ns (P=0.18); N = 11.1 (P<0.001); Prod x N = ns (P=0.75)						

[1]DMPP-coated urea; [2]Poly-coated urea; [A,B,C,D,X,Y] Mean values accompanied by the same letter in a group are "not significantly" different; [3]Mean yield of millable stalks for the two cultivars are significantly different (P<0.01)

***Table 7**.* Effect of N fertiliser formulation, rate of N applied and cultivar on the yield of leaves and tops in the pot experiment.

Cultivar	Fertiliser formulation	Yield of leaves and tops (t/ha)				
		N applied (kg/ha)				Mean
		0	75	150	225	
Q200⏀	Urea	5.6	11.0	14.3	15.3	11.5^{A}
	DMPP-urea	5.3	11.0	13.2	16.4	11.5^{A}
	PC-urea	5.3	10.4	13.1	15.5	11.1^{A}
	Mean	5.4	10.8	13.5	15.7	[3]11.3^{X}
Tukey HSD$^{0.05}$: Product = ns (P=0.25); N = (P< 0.001); Prod x N = ns (P=0.32)						
Q208⏀	Urea	3.9	8.5	11.0	14.0	9.4^{A}
	DMPP-urea	3.5	8.5	11.2	13.1	9.1^{A}
	PC-urea	3.7	8.1	10.0	13.1	8.7^{A}
	Mean	3.7^{D}	8.3^{C}	10.7^{B}	13.4^{A}	[3]9.0^{Y}
Tukey HSD$^{0.05}$: Product = ns (P=0.16); N = 1.1 (P<0.001); Prod x N = ns (P=081)						

[1]DMPP-coated urea; [2]Poly-coated urea; [A,B,C,D,X,Y] Mean values accompanied by the same letter in a group are "not significantly" different; [3]Mean yield of leaves and tops for the two cultivars are significantly different (P<0.01).

Table 8. Effect of N fertiliser formulation, rate of N applied and cultivar on the amount of N in stalks.

Cultivar	Fertiliser formulation	N in stalks (kg N/ha)				
		N applied (kg/ha)				Mean
		0	75	150	225	
Q200$^{\Phi}$	Urea	11.9	40.5	44.4	52.1	37.2^{A}
	DMPP-coated urea	9.7	25.2	36.5	52.2	30.9^{A}
	Poly-coated urea	13.7	29.7	34.9	51.7	32.5^{A}
	Mean	11.8^{C}	31.8^{B}	38.6^{B}	52.0^{A}	[1]33.5^{X}
Tukey HSD$^{0.05}$: Product = ns (P=0.08); N = (P< 0.001); Prod x N = ns (P=0.44)						
Q208$^{\Phi}$	Urea	7.0	20.6	38.3	50.1	29.0^{A}
	DMPP-coated urea	5.7	25.7	36.9	53.8	30.5^{A}
	Poly-coated urea	6.2	20.3	31.0	45.6	25.8^{A}
	Mean	6.3^{D}	22.2^{C}	35.4^{B}	49.8^{A}	[1]28.4^{Y}
Tukey HSD$^{0.05}$: Product = ns (P=0.19); N = 8.1 (P<0.001); Prod x N = ns (P=0.84)						

[1]Mean yield: millable stalks for the two cultivars are significantly different (P<0.01); ^{A,B,C,D,X,Y} Mean values accompanied by the same letter in a group are "not significantly" different.

Table 9. Effect of N fertiliser formulation, rate of N applied and cultivar on the amount of N in leaves and tops.

Cultivar	Fertiliser formulation	N in leaves and tops (kg N/ha)				
		N applied (kg/ha)				Mean
		0	75	150	225	
Q200$^{\Phi}$	Urea	27.0	57.5	80.4	98.4	65.8^{A}
	DMPP-coated urea	25.8	56.8	77.7	100.0	65.1^{A}
	Poly-coated urea	27.7	56.4	75.8	97.0	64.2^{A}
	Mean	26.9^{D}	56.9^{C}	78.0^{B}	98.5^{A}	[1]65.1^{X}
Tukey HSD$^{0.05}$: Product = ns (P=0.74); N = 6.5 (P< 0.001); Prod x N = ns (P=0.96)						
Q208$^{\Phi}$	Urea	20.0	42.0	70.8	89.8	55.7
	DMPP-coated urea	19.4	52.8	68.5	93.2	58.5
	Poly-coated urea	19.5	45.0	62.2	92.1	54.7
	Mean	19.6^{D}	46.6^{C}	67.2^{B}	91.7^{A}	[1]56.3^{Y}
Tukey HSD$^{0.05}$: Product = ns (P=0.40); N = 8.9 (P<0.001); Prod x N = ns (P=0.58)						

[1]Mean yield of leaves and tops for the two cultivars are significantly different (P<0.01); ^{A,B,C,D,X,Y} Mean values accompanied by the same letter in a group are "not significantly" different.

Table 10. Effect of N fertiliser formulation, rate of N applied and cultivar on the amount of N in roots.

Cultivar	Fertiliser formulation	N in roots (kg N/ha)				
		N applied (kg/ha)				Mean
		0	75	150	225	
Q200$^{\Phi}$	Urea	13.2	34.0	41.4	45.0	33.4^{A}
	DMPP-coated urea	10.8	27.4	40.3	51.5	32.5^{A}
	Poly-coated urea	9.0	27.5	42.9	46.8	31.5^{A}
	Mean	11.0^{D}	29.6^{C}	41.5^{B}	47.8^{A}	[1]32.5^{X}
Tukey HSD$^{0.05}$: Product = ns (P=0.51); N = 5.0 (P< 0.001); Prod x N = ns (P=0.11)						
Q208$^{\Phi}$	Urea	6.6	25.5	41.6	47.6	30.3^{A}
	DMPP-coated urea	6.0	29.2	35.5	50.0	30.2^{A}
	Poly-coated urea	6.2	24.6	32.6	47.6	27.8^{A}
	Mean	6.3^{D}	26.4^{C}	36.6^{B}	48.4^{A}	[1]29.4^{Y}
Tukey HSD$^{0.05}$: Product = ns (P=0.55); N = 8.2 (P<0.001); Prod x N = ns (P=0.80)						

[1]Mean yield of roots for the two cultivars are significantly different (P<0.01); ^{A,B,C,D,X,Y}Mean values accompanied by the same letter in a group are "not significantly" different.

Table 11. N application rates, mean cane stalk yields and calculated N-use efficiency factors associated with cane grown in the pot experiment for cultivars Q200$^{\Phi}$ and Q208$^{\Phi}$.

Yield and efficiency factors	Sugarcane cultivar							
	Q200$^{\Phi}$				Q208$^{\Phi}$			
	Treatments (kg N/ha)							
	0	75	150	225	0	75	150	225
Yield (tonnes cane/ha)	21.0	52.1	58.4	70.4	10.0	36.5	55.3	74.1
Tonnes cane/N applied	-	0.69	0.39	0.31	-	0.49	0.37	0.33
kg N applied/tonne cane	-	1.44	2.57	3.20	-	2.05	2.71	3.04
Agron Eff_{Fert} (kg N/additional TCH)	-	2.41	4.01	4.55	-	2.83	3.31	3.51
NUtE (TCH/kg crop N)[1]	1.78	1.64	1.51	1.35	1.59	1.64	1.56	1.49
Crop N uptake (kg N/ha)[1]	11.8	31.8	38.6	52.0	6.3	22.2	35.4	49.8
Fertiliser N uptake (kg/ha)	-	20.0	26.8	40.2	-	15.9	29.1	43.5
NUpEfert (additional kg uptake/kg fert applied) (%)	-	26.7	17.9	17.9	-	21.2	19.4	19.3

CONCLUSIONS

The rainfall measured during the seasons September 2015 to October 2017 was not characterised by rainfall that would have resulted in excessively wet conditions at the trial site. This may have been a major factor contributing to the lack of yield responses to EEFs as previously reported at other sites by Di Bella *et al.* (2014) and Wang *et al.* (2014). Increased N-uptake by the crop, due to the use of N strategies away from the standard practice (i.e. by using EEFs or split applications of urea), improved NUE values that were based on crop N, but this did not always translate into any improvements in yield. These results were supported by the outcomes of the pot experiment. Although the two cultivars (included in the pot experiment) gave rise to significantly different yields across the rates of N applied, there was a common lack of response to EEFs when losses through leaching were not a factor.

The highest partial net returns in the plant and first-ratoon crop in the field trials corresponded to the control treatments. Urea applied at 120 kg N/ha in a single application resulted in the next best partial net returns in both crops. This appeared to be the most appropriate strategy to minimise risk to growers. The cost of EEF fertilisers negatively affected the partial net returns, with DMPP-coated urea being more affordable than the poly-coated urea.

Further work, across seasons (dry, wet and 'normal'), is needed to evaluate more fully the potential of EEFs for use in specific circumstances. However, given the likely variability in response to these products, suppliers of a locally available brand of DMPP-coated urea have developed a decision-support tree for determining when the product has the best chances of reducing N losses. The industry is also working to develop a decision tool that predicts where these products will be of most benefit. An adoption-focused project involving EEFs in 60 strip trials located in districts from Bundaberg northwards commenced in 2017 (Anon. 2017b). Results from these trials will help inform decision support tools.

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