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A three-year assessment of controlled-release and nitrification-inhibiting fertilisers in the Burdekin

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Abstract The application of controlled-release and nitrification-inhibiting fertilisers may help to reduce nitrogen (N) losses from crop-root zones and enable greater plant uptake under some conditions. There have been limited research findings to date on the ability of these fertilisers to maintain production and profitability of sugarcane in field trials at N application rates lower than industry recommendations. This topic is examined drawing upon three years of harvest data (2015–2017) from 12 field trials conducted in the Burdekin. Nine of these sites tested the conventional N rate (220 kg/ha) and rates 40 kgN/ha lower than this conventional rate, for a variety of N forms. These forms were urea, a nitrification-inhibiting fertiliser and a controlled-release, polymer-coated fertiliser (CRF). The other three sites compared each product form at the conventional rate and at a rate 60 kgN/ha lower. Four sites were established on each of the three key soil types (sand, loam or clay). Fertilisers were applied at different times over the season to determine if these factors influence fertiliser efficacy. Sugarcane cultivars also varied among the trial sites. Data were analysed using restricted maximum likelihood (REML) to enable the testing of fixed effects and the allowance for random effects. Results from sites that tested N rates 40 kg/ha lower than conventional rates indicated that soil type, timing of fertiliser application and cultivar influenced the efficacy of the CRF. The CRF treatment with 50% of the N as a poly-coated urea obtained significantly higher cane yield on sandy soil, but no significant differences were identified on loam or clay soils. For fertiliser application timing, the CRF50% treatment achieved significantly higher cane yields than all other treatments, and significantly higher sugar yields than both urea treatments, when applied late in the season. Cultivar also potentially influenced fertiliser efficacy. For Q253⦶, both CRF treatments (25% and 50% blends) obtained significantly higher cane and sugar yields than urea applied at a conventional N rate, but only on loam soil. This was not the case for Q183⦶ on loam soil. Findings from the economic analysis indicate that the profitability of each fertiliser type varied depending on cultivar and soil type. For Q183⦶ for example, CRF50% obtained significantly higher profitability than DMPP on sand, while the opposite was found on clay. The three sites testing N rates 60 kg/ha lower than conventional rate showed that the treatment effects varied depending on the cultivar and soil combinations. Annual rainfalls during the trials were below average, which may have reduced the potential efficacy of these fertilisers relative to conventional urea.

Key words Enhanced-efficiency fertilisers, nitrogen, productivity, profitability, Burdekin

INTRODUCTION

A sizable proportion of the inorganic nitrogen (N) fertiliser being applied to soil is not being taken up by the crop (Bell *et al*. 2015; Chen *et al*. 2008). After urea converts to ammonium and then nitrate it can be lost from the soil-root zone, where it will provide no benefit to the crop and can potentially have detrimental environmental implications. Controlled-release and nitrification-inhibiting fertilisers may help to improve the efficiency of crop-N uptake compared to conventional urea application. Controlled-release fertilisers (CRFs) are designed to match the supply of nitrogen (N) with the crops demand for N in order to enhance uptake, although these release patterns can vary significantly based on environmental considerations such as temperature and moisture (Verburg *et al*.

2016). Nitrification inhibiting fertilisers (NI) slow down nitrification, thus decreasing the loss potential from leaching and denitrification (Alabos *et al.* 2014; Cui *et al*. 2011; Soares *et al.* 2015; Wang *et al.* 2016).

Studies using virtual APSIM simulations for the Tully region (Verburg *et al.* 2018) and in glasshouse experiments in Ingham (DiBella *et al*. 2017) showed that enhanced-efficiency fertilisers (EEFs) can reduce leaching of N, which in turn can lead to improved yield by improving availability of N to the crop throughout the crop growth period. These studies were conducted using CRFs as the total N supply. Kandulu *et al*. (2017) identified that, because CRFs cost twice as much as conventional urea, uptake and adoption is dependent on the ability for growers to maintain yields and profitability. Our work investigates commercial responses to EEFs employing nitrification inhibitors, as well as blends of urea and CRFs that make up either 50% or 25% of the total applied nitrogen component. The reason for this was to determine if total fertiliser costs can be reduced for growers when using these EEFs and thus potentially increase the usage rate of them by growers.

Environmental and biophysical factors (e.g. soil type, temperature, rainfall, irrigation regime, crop cultivar, and time of fertiliser application during the harvest period) are likely to influence the potential benefit provided by these products (Verburg *et al*. 2016). If conditions are conducive to losses during or before crop-N uptake, then these products may help to improve yield potential. However, if not, then the potential benefits that these products provide may go unexploited (e.g. dry years). Consequently, these products may safeguard yield potential rather than guarantee higher yields.

While there has been research examining the effectiveness of these fertilisers to reduce N losses (Prasertsak *et al.* 2002; Merino *et al.* 2005; Yu *et al.* 2007; Akiyama *et al.* 2010; Chen *et al.* 2010), there has been limited research examining the ability of these fertilisers to influence production on commercial sugarcane farms, particularly in fully irrigated systems. One practical issue for commercial farmers is the higher cost per tonne of these fertilisers, particularly the CRFs. Given their higher cost per tonne, farmers need to be able to either improve yields when applying these fertilisers at the conventional N application rate, or maintain yields at lower than conventional N rates (Thompson *et al*. 2017).

The Burdekin region, located in northern Queensland, covers over 90,000 ha of furrow-irrigated sugarcane cropping. Although the region receives an average of 935 mm of rain per year, Burdekin growers rely almost exclusively on irrigation water supplied from the Burdekin Falls Dam as well as underground resources in the Burdekin Delta area. Due to the accessibility of this water, applied predominantly in furrow irrigation, in conjunction with high solar radiation and productive soils, the Burdekin region produces the highest cane yields in Australia for one-year crops (Sugar Research Australia 2017).

As a result of the accessibility to an abundant supply of irrigation water in the Burdekin, combined with its proximity to the Great Barrier Reef, and the risk of pollutants such as dissolved inorganic nitrogen (DIN) leaving farms and entering freshwater and marine ecosystems, substantial environmental pressure is currently being imposed on the region to improve the quality of water leaving farms (Queensland Government 2018).

The aim of our assessment was to examine the cane yield, sugar production and profitability implications from the use of contrasting commercially available enhanced efficiency fertilisers (EEFs); DMPP being a nitrification inhibitor 3,4-dimmethylpyrazole phosphate, and a polymer-coated urea with a reported 90-day release period (CRF), at lower N rates than suggested by the SIX EASY STEPS methodology on different soil types across the Burdekin (Schroeder *et al.* 2007, 2018b). Our intention was to explore these issues in order to provide guidance to industry, particularly in relation to the impact from reducing inorganic N applications without compromising productivity.

METHODS

Field sites and trial designs

Commencing in 2014, 12 trial sites were established on commercial farms in the Burdekin region to examine the performance of controlled-release and nitrification-inhibiting fertilisers on ratooning sugarcane crops. Sites were selected based on soil texture and consisted of four sandy soil sites, four sites on a loam soil and four sites on clay to cover a range of soil classes relevant to growers in the region. These soil type descriptions were identified through cation exchange capacity (CEC) values based on the SIX EASY STEPS methodology for Burdekin soils, with CEC values of 0–10, 10–20 and 20+ classed as sand, loam and clay, respectively (Schroeder *et al.* 2007). The 12 sites were organised into two groups (A and B) that examined two different sets of treatments. Treatments are summarised in Table 1 along with the fertiliser cost for each treatment. Each treatment within the two groups was replicated three times in a randomised complete-block layout and all treatments maintained their spatial position in all following years.

Group A consisted of nine trial sites: three sand, three loam and three clay sites. At each of the sites, urea fertiliser was applied at the conventional N rate (220 kg N/ha) and was compared to a urea fertiliser applied at a lower rate (180 kg N/ha), urea coated with DMPP, and two fertiliser blends containing urea and polymer-coated urea in different proportions which were all applied at N rates 40 kg lower than the conventional rate (180 kgN/ha). The CRF25% blend had 25% of the N as a polymer coated product, while the CRF50% blend had 50% of the total N coated. Group B consisted of three trial sites: one each of a sand, loam and clay site. This group compared each of the fertiliser products (N forms) Urea, DMPP and the CRF (25%) at the conventional N rate (220 kgN/ha), to a rate 60 kg lower (160 kgN/ha).

To ensure N rate and N form were the main nutritional variables in this assessment, every treatment had 20 kgP/ha, 80 kgK/ha, 33 kg S/ha applied for Group A. Group B had 20 kgP/ha, 80 kgK/ha and 22 kg S/ha applied. This ensured all other nutritional requirements, besides N, were supplied to the crop in non-limiting quantities. All trials ran the length of the field. Electrical conductivity (EC) mapping of the trial sites was conducted by using a Veris 3100 to spatially delineate contrasting soil properties of the surveyed area (Coventry *et al*. 2011). Based on this data, trials were positioned accordingly to minimise the effect of inherent infield soil variation on trial results. All sites were free from alternative forms of N such as groundwater nitrate, historical mill-mud application and recent legume fallows.

At harvest, all plots were consigned separately and commercial weights (tonnes of cane and tonnes of sugar) were recorded and used for analysis. Commercial cane sugar (CCS) data were also obtained, but not considered independently in this paper. Harvests of the sites occurred in either two or three of the years 2015, 2016 and 2017 covering a range of ratoons (first, second, third or fourth) across the sites for the various years. Most sites grew sugarcane cultivar Q183$^{\Phi}$, with other sites growing cultivars Q208$^{\Phi}$, Q253$^{\Phi}$ or KQ228$^{\Phi}$. Fertiliser applications were mostly made in mid harvest season (August/September) or late harvest season (October/November). All sites had fertiliser applied subsurface, with nine of the 12 sites applied via a stool splitter and three sites were side-dressed.

Table 1. Summary of treatments.

Group A

	Fertiliser product	N rate kg/ha	Fert. cost $/ha**	Abbreviation
T1*	Urea	220	$537	Urea-220
T2	Urea	180	$480	Urea-180
T3	DMPP	180	$534	DMPP-180
T4	CRF25%	180	$608	CRF25%-180
T5	CRF50%	180	$733	CRF50%-180

Group B

	Fertiliser product	N rate kg/ha	Fert. cost $/ha**	Abbreviation
T1*	Urea	220	$537	Urea-220
T6	CRF25%	220	$693	CRF25%-220
T7	DMPP	220	$608	DMPP-220
T8	Urea	160	$451	Urea-160
T9	CRF25%	160	$566	CRF25%-160
T10	DMPP	160	$497	DMPP-160

* Conventional fertiliser treatment.

**Fertiliser prices were collected in 2015–16.

Economic analysis

This research is an extension of that completed by Thompson *et al.* (2017) and provides a complete data set of productivity findings from three harvests. To evaluate the economic performance of each fertiliser treatment, gross margins were calculated using the Farm Economic Analysis Tool (FEAT) by calculating revenue received from the crop and subtracting the variable costs incurred from growing and harvesting the crop. Revenues and costs were calculated from harvest and farm operational data specific to each treatment and used the five-year average (2010–15) net sugar price of $430 per tonne (Queensland Sugar Limited 2015). Fertiliser prices were collected from local Burdekin suppliers.

The cost of the DMPP-coated urea for these trials was higher than urea per tonne. However, the rates at which these fertilisers were applied at were generally lower than conventional practice, which made the 160 and 180 kgN/ha treatments relatively cheaper per hectare (Table 1). The controlled-release fertiliser blends were more expensive than conventional practice per hectare even though they were applied at lower rates in several treatments. The fertiliser costs used for the economic analysis were included in Thompson *et al*. (2017).

Statistical methodology

Data for each group (A and B) were analysed separately using Restricted Maximum Likelihood (REML) to assess the treatment effects. For group A, the design structure was accounted for by including random effects (Trial_Site/Replicate/Plot).Crop_Harvest_Year. Because of the unbalanced nature of the design with respect to ratoon and year and the confounding of various effects with year, a conservative approach to analyses was adopted through accounting for the variability over time by including Crop Harvest Year in the random term (rather than as a fixed effect). Initial analyses were performed to investigate only Soil Type*Treatment effects (where * represents the main effects and the interaction of the terms) in the fixed model as this was the focus of the trial. Subsequent analyses also considered fixed effects of fertiliser timing and cultivar. The non-significant treatment terms were dropped in a backwards elimination process to determine a final model. Group A data were also analysed for each cultivar separately.

As the sites in group B were on three different soil types, the Group B data were initially analysed separately for each soil type. Using REML, the random effects were (Replicate/Plot).Crop_Harvest_Year and the fixed effects tested were N_rate *N_form. This allowed for testing the interaction of N rate and N form, to determine whether the influence of N rate was the same for each N form. If the interaction was not significant (at level $p=0.05$), then the interaction was dropped from the model and only main effects were fitted. Data for the three groupB sites were also analysed in an across sites analysis.

Normality assumptions were checked using normalised residual plots and data were $\log_e$ transformed (ln) where necessary. Pairwise comparisons were made using Fisher's protected least significant difference (lsd) method (Fisher 1935). If means differed by more than the lsd, they were considered significantly different at $p<0.05$. Back-transformed means were presented for those values that required transformation. If the overall effect was not significant, sed's (standard error of difference between means) were quoted instead of lsd's to give an indication of error. All analyses were conducted using Genstat v19 statistical software (VSN International 2017).

RESULTS

Burdekin annual rainfall in the first two years of the trial (2014/15 417 mm and 2015/16 484 mm) was around half the 10-year average (926 mm), while the third year of the trial (2016/17 910 mm) was just below average. Figure 1 shows the monthly rainfall data for the three years of the trial. Rainfall was often below average between August and December, the critical time for early ratoon establishment following harvesting.

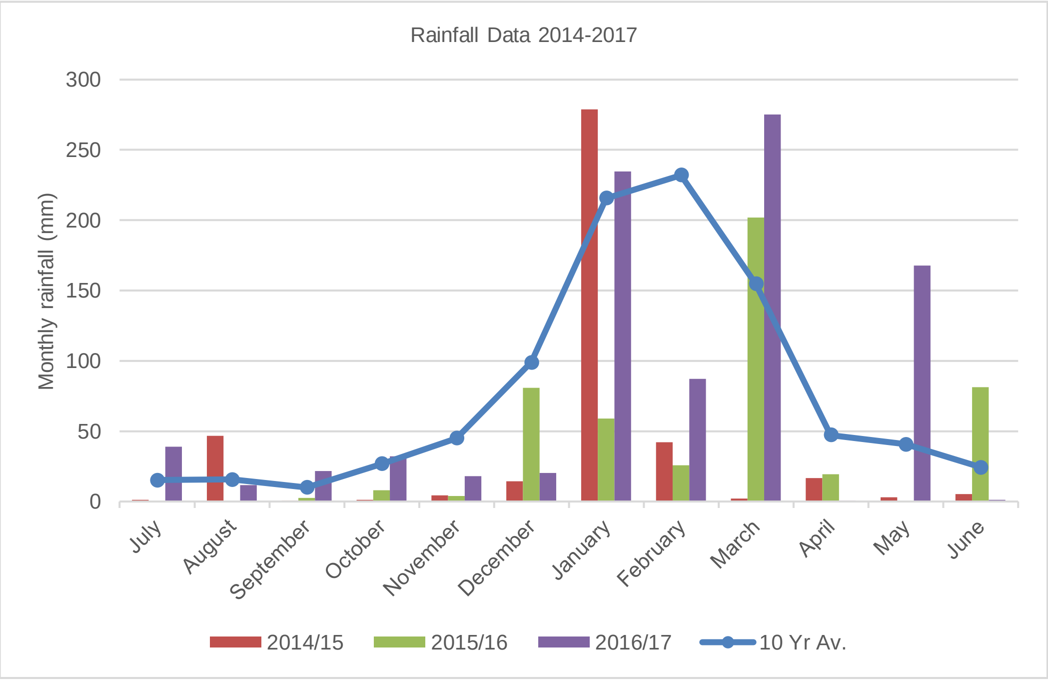

Figure 1. Monthly rainfall data 2014–2017.

Group A results

Statistical analysis of the three-year dataset examined treatment, soil type and fertiliser timing main effects as well as the interactions of all of these measures. As a comparison of these analyses, Table 2 shows the p-values for main effects and interactions for cane yield, sugar yield and gross margin data from Group A. The three-way interaction was not significant ($p>0.05$) for either of the three measures, thus it was not included.

The interaction effects between treatment and soil type as well as treatment and fertiliser timing were significant for cane and transformed sugar yield. This indicates that the relative performance of the EEF treatments (or the standard urea treatments) varied between soil types (sand, loam and clay) and timing of fertiliser application (early-mid and late) for these variables. In contrast, for the gross margin data, only main effects, not interactions, were significant. Treatment, soil type and fertiliser timing main effects each influenced the gross margin significantly.

Table 2. P-values for main effects and interactions - cane yield, sugar yield and gross margin, all cultivars.

	Cane yield	Ln Sugar yield	Gross margin
Treatment	0.087	0.153	0.006**
Soil type	0.235	0.153	0.031*
Fertiliser timing	0.706	0.522	0.047*
Treatment x Soil type interaction	0.049*	0.031*	0.232
Treatment x Fertiliser timing interaction	0.007**	0.026*	0.133

* $p<0.05$ **$p<0.01$

The interaction effects identified instances where there may be an opportunity to use EEFs in the Burdekin region. Table 3 presents the mean cane yield, back-transformed sugar yield and gross margin results for each treatment and soil-type combination. Mean gross margin values do not have subscript letters as the interaction was not significant. Due to the replication varying within the treatment combinations, the lsd and sed values differed for the various pairwise treatment combinations. Thus, the lsd and sed values in Table 3 will not seem exact – the values used are to give an average indication of the relevant lsd or sed value.

Pairwise comparisons identified that on sandy soils the CRF50%-180 produced significantly higher cane yield than all other treatments. No significant differences among treatments were identified on loam and clay soils. A similar trend was identified with log transformed sugar yield on sandy soils, except the CRF50%-180 did not produce significantly higher ln sugar than conventional practice (Urea-220). For gross margin, no significant interaction between treatment and soil type was identified.

***Table 3*.** Mean cane yields, sugar yields and gross margins – treatment x soil type interaction, all cultivars*.

Treatment	Cane yield, t/ha			Back-transformed sugar yield, t/ha			Gross margin, $/ha		
	Clay	Loam	Sand	Clay	Loam	Sand	Clay	Loam	Sand
Urea-220	140 bd	124 abc	119 b	19.7 bcd	16.9 abcd	16.6 bcd	3220	2370	2140
Urea-180	138 abc	126 abc	114 a	19.6 bcd	17.3 abcd	15.8 a	3289	2506	2021
DMPP-180	140 bd	125 abc	117 ab	20.0 ce	17.2 abcd	16.0 ab	3341	2411	1984
CRF25%-180	140 bd	124 abc	117 ab	19.9 ce	17.0 abcd	16.4 abc	3237	2317	2010
CRF50%-180	141 bd	126 abc	125 cd	20.0 ce	17.2 abcd	17.2 de	3124	2270	1994
	lsd within the same:						sed within the same:		
	Treatment: 24.31						Treatment: 421.90		
	Soil type: 3.95						Soil type: 82.53		

*Figures within a column followed by the same letter are not significantly different ($p=0.05$) (on the transformed scale for sugar yield).

Table 4 presents the mean cane yield, back-transformed sugar yield and gross margin results for each treatment and fertiliser application time. Due to the replication varying within the treatment combinations, the lsd and sed values differed for the various pairwise treatment combinations. Thus, the lsd and sed values in Table 4 will not seem exact – the values used are to give an average indication of the relevant lsd or sed value. Cane yield values have been rounded to the nearest tonne/ha, thus subscript letters indicating differences may seem to conflict with the quoted lsd value. For the early-mid application time, the Urea-220 rate had significantly higher cane yields than the reduced-N rate treatments of DMPP-180 and CRF25%-180. The results were quite different for the late application, where the CRF50%-180 had significantly higher cane yields than all the other treatments.

The Urea-220 treatment produced significantly higher ln sugar yield than the DMPP-180 treatment for the early-mid application time. The CRF50%-180 had significantly higher ln sugar yield than both of the urea treatments when applied late in the year. No significant treatment by fertiliser timing interaction was identified for the gross margin.

***Table 4*.** Mean cane yields, back-transformed sugar yields and gross margins – treatment x fertiliser timing interaction, all cultivars*.

Treatment	Cane yield, t/ha		Back-transformed sugar yield, t/ha		Gross margin, $/ha	
	Early-mid	Late	Early-mid	Late	Early-mid	Late
Urea-220	128 cd	128 ac	18.5 bd	16.9 ab	3001	2148
Urea-180	126 abc	127 ac	18.2 abc	16.8 ab	3019	2206
DMPP-180	124 ab	130 ac	17.9 ac	17.3 abc	2895	2261
CRF25%-180	125 ab	129 ac	18.1 abc	17.3 abc	2867	2169
CRF50%-180	126 abc	134 bd	18.3 abc	17.8 cd	2810	2114
	lsd within the same:				sed within the same:	
	Treatment: 19.5				Treatment: 352.4	
	Timing: 3.2				Soil type: 67.8	

*Figures within a column followed by the same letter are not significantly different (p=0.05) (on the transformed scale for sugar yield).

Table 5 presents the mean gross margin results for the treatment main effect. Soil type and fertiliser timing main effects were significantly different but were not influenced by the EEFs. Across all trial sites, soil types and fertiliser timings (and cultivars), the CRF50%-180 produced a significantly lower gross margin than the two Urea treatments as well as the DMPP treatment. The two urea treatments and the DMPP were not significantly different from each other.

***Table 5*.** Mean gross margins – treatment main effect, all cultivars*.

Treatment	Gross margin, $/ha
Urea-220	2587 bc
Urea-180	2621 c
DMPP-180	2567 bc
CRF25%-180	2513 ab
CRF50%-180	2457 a
lsd	93

*Figures followed by the same letter are not significantly different (p=0.05).

Results from different cane cultivars

Four cane cultivars were grown across the nine trial sites in group A – Q183$^{\Phi}$, KQ228$^{\Phi}$, Q253$^{\Phi}$ and Q208$^{\Phi}$. Q183$^{\Phi}$ was grown on six trial sites and had two trials on each of the three soil types (sand, loam and clay) and was fertilised at both times (early-mid and late). The other cultivars were only grown on one trial site each with a single soil type and fertiliser application time. Consequently, in the individual cultivar analyses, interactions between product and soil type and product and fertiliser timing could only be investigated for Q183$^{\Phi}$. The interaction between treatment and soil type was significant for ln cane yield ($p = 0.004$), ln sugar yield ($p = 0.002$) and gross margin (0.031). This indicates that the relative performance of the EEF and/or other treatments varied among soil types. The interaction between treatment and fertiliser timing was not significant for all three variables ($p > 0.05$).

Table 6 presents the back-transformed means for both cane yield and sugar yield for each treatment on each soil type for Q183$^{\Phi}$ only. Similarly, to the analysis of all cane cultivars, the CRF50%-180 performed well on sandy soils. No significant differences between treatments were identified on loam and clay soils. On sandy soil, the CRF50%-180 treatment produced significantly higher ln cane yield than the Urea-180 and DMPP-180 treatments. It also obtained significantly higher ln sugar yield than all other treatments except the Urea-220. In contrast, the DMPP-180 attained significantly lower ln cane and ln sugar yield than all other treatments apart from the Urea-180.

The gross margin results indicated similar results in sandy soil but also identified significant differences on clay and loam soils. On sandy soil, the CRF50%-180, as well as the Urea-220, produced a significantly higher gross margin (profitability) than the DMPP-180. In contrast, on clay soil DMPP-180 obtained a significantly higher gross margin than the CRF50%-180 but showed no advantage compared to the remaining treatments. On loam soil, the Urea-180 attained a significantly higher gross margin than both of the CRF treatments.

***Table 6*.** Mean cane yields, sugar yields and gross margins – treatment x soil type interaction, Q183$^{\Phi}$ only*.

Treatment	Back-transformed cane yield, t/ha			Back-transformed sugar yield, t/ha			Gross margin, $/ha		
	Clay	Loam	Sand	Clay	Loam	Sand	Clay	Loam	Sand
Urea-220	130 bc	114 abc	106 bc	19.2 bc	16.2 abc	15.8 bc	3123 ef	2193 a-f	2177 cdef
Urea-180	127 abc	117 abc	101 ab	18.9 abc	16.6 abc	14.9 ab	3169 ef	2336 bef	2073 a-e
DMPP-180	128 bc	115 abc	96 a	19.3 bc	16.4 abc	14.3 a	3242 f	2219 a-f	1888 ab
CRF25%-180	129 bc	111 abc	104 bc	19.2 bc	15.9 abc	15.7 b	3114 def	2046 ac	2109 a-e
CRF50%-180	129 bc	114 abc	111 c	19.2 bc	16.2 abc	16.8 c	2995 a-e	2050 acd	2219 cdef
Lsd within the same:									
Treatment								195.8	
Soil type								113.2	

*Figures within a column followed by the same letter are not significantly different (p=0.05) (on the transformed scale for yields).

KQ228$^{\Phi}$, Q253$^{\Phi}$ and Q208$^{\Phi}$ were each grown on one of the trial sites. Given each of these trials had a particular soil type and fertiliser was applied at a particular time, it is not possible to explore the interaction between treatment and soil type or treatment and fertiliser application time. Instead, only the treatment main effect could be identified (Table 7).

For the trial with Q253$^{\Phi}$, which was a loam soil and fertilised late, a significant treatment effect was identified for cane yield (p=0.047) and sugar yield (p=0.035). Both CRF blends were found to have significantly higher cane and sugar yield than the Urea-220. The CRF25%-180 also had significantly higher sugar yield than DMPP-180.

The trial with KQ228$^{\Phi}$, on a sandy soil and fertilised early-mid, showed significant treatment effects on gross margin (p=0.024, Table 7) but not on cane or sugar yield (means not presented).

Trials with Q208$^{\Phi}$ with sand and clay also showed no significant treatment effects (p>0.05) for cane yield and sugar yield, while there was significant difference (p<0.001) in gross margin for the treatments on sand but not clay (p>0.05) (means not presented).

Table 7. Mean* cane yields, sugar yields and gross margins for significant treatment effects for Q253$^{\Phi}$ and KQ228$^{\Phi}$.

Treatment	Q253$^{\Phi}$		KQ228$^{\Phi}$
	Cane yield, t/ha	Sugar yield, t/ha	Gross margin, $/ha
Urea-220	136 a	17.6 a	2432 b
Urea-180	138 ab	17.9 abc	2242 ab
DMPP-180	138 ab	17.8 ab	2126 a
CRF25%-180	141 b	18.4 c	2229 ab
CRF50%-180	140 b	18.3 bc	2078 a
p	0.047	0.035	0.024
lsd	3.9	0.56	213.1

*Figures within a column followed by the same letter are not significantly different (p=0.05).

Group B results

Group B consisted of three trial sites with each site having a different soil type and cultivar with fertiliser applied either mid or late in the season. The three combinations were: 1. Sand, Q208$^{\Phi}$, Mid; 2. Loam, KQ228$^{\Phi}$, Mid; 3. Clay, Q183$^{\Phi}$, Late. All three sites had each N form (Urea, DMPP and CRF25%) applied at 220 and 160kg N/ha. This trial design enabled a factorial analysis to be undertaken where the N form and N rate effects could be analysed independently.

Table 8 presents the p-values for the N form, N rate and interaction effect on cane yield, sugar yield and gross margin for each trial site as well as across all three trial sites. A significant interaction between N form and N rate was identified on the clay soil site for cane yield, sugar yield and gross margin, but not on the trials with the other soil types. Given there were no significant interactions between N form and N rate on the sand or loam soils, the main effects only (N form, N rate) were then considered.

The results showed there were differences between the N rate response for each of cane and sugar yield on loam soils, but no significant differences in gross margin for this soil type. For the sand soil type, there were no significant interaction or main effects for each of cane yield, sugar yield or gross margin.

There were no significant interaction or main effects for N rate and N form when all the properties were considered in the one analysis for either of the three measures. There were significant differences between N rate for cane and sugar yield, but not for gross margin. Thus, means are only presented for main effects.

***Table 8*.** P values for mean cane yields, sugar yields and gross margins – N form, N rate and interaction.

Trial	Soil	Parameter	N form	N rate	N form and N rate interaction
		Cane yield (t/ha)	0.400	0.033*	0.44
1	Sand	Sugar yield (t/ha)	0.328	0.129	0.309
		Gross margin ($/ha)	0.204	0.244	0.124
		Cane yield (t/ha)	0.103	<0.001***	0.173
2	Loam	Sugar yield (t/ha)	0.291	0.021*	0.18
		Gross margin ($/ha)	0.394	0.876	0.236
		Cane yield (t/ha)	0.468	0.018*	0.010*
3	Clay	Sugar yield (t/ha)	0.814	0.106	0.005**
		Gross margin ($/ha)	0.107	0.539	0.002**
		Cane yield (t/ha)	0.255	<0.001***	0.110
	Across all 3 sites	Sugar yield (t/ha)	0.327	0.005**	0.084
		Gross margin ($/ha)	0.331	0.628	0.327

* p<0.05 ** p<0.01 ***p<0.001

Table 9 presents the significant N rate effects for cane yield and ln sugar yield across all three trial sites, as well the individual sand and loam sites. Across all three sites, the conventional N rate produced significantly higher cane and ln sugar yield than the reduced N rate that was 60 kg N/ha below the conventional rate. This difference (across all sites) was similar to the individual soil analyses, except for sugar yield on sand.

***Table 9*.** Mean cane yields and back-transformed sugar yields across all three trial sites – N rate effect*.

N rate (kg/ha)	Sand		Loam		Across all three sites	
	Cane yield, t/ha	Sugar yield, t/ha	Cane yield, t/ha	Sugar yield, t/ha	Cane yield, t/ha	Back-transformed sugar yield, t/ha
220	142.0 a	19.8	87.4 a	12.7 a	107.2 a	15.4 a
160	135.8 b	19.3	82.3 b	12.2 b	102.4 b	14.9 b
p	0.033		<0.001	0.021	<0.001	0.005
sed	2.7	0.32	1.28	0.23	1.1	

*Figures within a column followed by the same letter are not significantly different (p=0.05).

Table 10 presents the significant N form and rate interaction for the clay soil trial. The CRF25%-220 resulted in a significantly lower gross margin than all of the other conventional N rate and reduced N rate treatments (60 kg/ha less) including the same N form applied at the reduced N rate (CRF25%-160).

***Table 10*.** Mean cane yields, back-transformed sugar yields and gross margins for clay site – N form effect*.

N Form	Cane yield, t/ha		Sugar yield, t/ha		Gross margin, $/ha	
	N rate (kg/ha)		N rate (kg/ha)		N rate (kg/ha)	
	160	220	160	220	160	220
Urea	87.7 a	95.0 b	14.1 a	15.3 c	2343 b	2546 b
DMPP	88.6 a	93.5 b	14.3 ab	15.0 bc	2349 b	2393 b
CRF25%	90.9 ab	88.2 a	14.9 abc	14.1 a	2463 b	2107 a
lsd	4.5		0.82		210	

*Figures within a column followed by the same letter are not significantly different (p=0.05).

DISCUSSION

Our aim was to investigate the ability of EEFs to maintain production and profitability at N application rates lower than industry guidelines. The objective was not only to determine whether EEFs at lower rates were a viable option in a fully furrow irrigated environment, but also investigate the interactions between products, rates, soil type, application timing as well as potential cultivar responses. Understanding these interactions will guide growers in deciding what product and rate will present gains in production and profitability based on circumstances relevant to their situation.

The results from 12 replicated trials in the Burdekin region over three years identified that there are certainly opportunities to apply EEFs at reduced N rates in the Burdekin while maintaining production and profitability. Additionally, our results showed that there were also significant interactions between treatments and soil type, as well as interactions based on treatment and application time throughout the year, that led to significant differences in cane yield and sugar yield.

On sandy soils (CEC <10), results showed that the CRF-180 blends, in which 50% of the total N was supplied as a controlled-release polymer-coated urea produced significantly higher yields of cane than all other treatments including the Urea-220 (Table 3). The 25% CRF blend showed a lower yield response suggesting that the higher ratio of CRF in the blend was responsible for improved commercial yield by retaining N in the system for longer and allowing more effective supply for crop growth. There were no differences in gross margin between any of the treatments, suggesting the higher CRF proportions maintained profitability on this soil type. In contrast to the sandy soils, there were no effects of either N rate or EEF product on either Burdekin loam (CEC 10-20) or clay (CEC 20+) soils for cane or sugar yields.

Timing of fertiliser application throughout the harvest period for ratooning also showed differences (Table 4). Irrespective of soil type, results showed that the Urea-220 treatments applied in the early-mid part of the Burdekin harvest season (Early July to late September) produced higher cane yield compared to the DMPP-180 and CRF25%-180 treatments. It is important to note that there were no significant differences between any of the 180N treatments indicating the EEFs showed no yield benefit in this investigation in the early-mid timeframe.

This time of the year traditionally has low rainfall (Figure 1), so the risk of losses from leaching or denitrification resulting from severe waterlogging are not as relevant as later in the year due to the wet season, whilst later in the year the risk of N losses may be increased. Conversely, applications later in the year (October onwards) with higher proportions of the controlled release polymer coated blends (i.e. CRF50%-180) produced more cane than all other treatments and produced more sugar than any of the urea treatments. This suggests that the 4-month controlled-release product applied later in the season maintained gradual N release throughout the wet season and ensured N was available for the crop to take up.

Although not all trials grew the same cultivar, many contained Q183[A] which allowed analysis of effects without possible confounding from cultivar differences (Table 6). Similar trends were identified compared to the 'all cultivar' analysis in relation to treatment x soil type effect. Although there were no differences in gross margin in the combined cultivar analysis, the DMPP-180 did provide a better gross margin return on the clay sites compared to the CRF50%-180 when considering Q183$^{\phi}$ alone, but the DMPP treatment performed similarly to the urea treatments and the lower ratio blend of CRF.

On loam soils planted to Q183$^{\phi}$, there was no significant difference between cane and sugar yields. The CRF treatments were more expensive per tonne, so the Urea-180 treatment gave better returns to the grower compared to the CRF treatments.

On sandy soils, the CRFs in Q183$^{\phi}$ performed better than the DMPP in both cane and sugar yield. The CRF-50% gave the best sugar yield in the 180N group and although it yielded an extra tonne of sugar per hectare than the Urea-220 treatments, the statistical analysis deemed these two treatments as not significantly different to each other. Gross margin analysis showed that both the Urea-220 and CRF50%-180 gave better returns to the grower compared to the DMPP product on sandy soils in the Q183$^{\phi}$ investigation.

The results of the analysis of Q183$^{\phi}$ in clay and loam soil types showed that no EEF treatments outperformed the standard Urea treatments in tonnes of cane produced at both 220N and 180N. This was also the case for sugar yield on clays and loams. On the sandy soils however, the CRF50%-180 showed improved tonnes of sugar produced compared to the Urea-180, but it did not perform better than the Urea-220. As a consequence, gross margin results showed no advantage of EEFs over Urea across the individual soil types for Q183$^{\phi}$.

Q253$^{\phi}$, which has been shown to be a more N-efficient cane (Connellan and Deutschenbaur 2016), performed differently to Q183$^{\phi}$. This cultivar may have preferred the controlled N release pattern of the CRFs over the higher rates of urea application on a loam soil (Table 7). While the Q253$^{\phi}$ data set is limited, this type of result highlights the potential of cultivar differences in response to N release patterns and warrants further investigation.

The objective of the Group B investigation was to determine if the higher rates of EEFs led to improved production and profitability whilst also determining the effect of these products at lower rates than used in the Group A analysis.

Although there were similar yields between the 220 N rate and the 180N rate in the Group A results, our data shows that reducing nitrogen application further to 160 kg/ha restricted yield potential. However, there was no interaction between N form at either of these rates. Our results also demonstrate that applying EEFs at the higher N rate showed no production advantage, albeit under conditions that were drier than average thus experiencing large N losses would be less likely.

SUMMARY

We drew upon three years of harvest data from 12 Burdekin trial sites to evaluate whether EEFs can maintain or improve yields whilst ensuring profitability is sustained to encourage adoption. It has highlighted opportunities to most effectively harness productivity benefits and maintain profitability of EEFs in a furrow irrigated environment, clearly highlighting the importance of soil type in making an EEF choice.

Results showed that different soil textures are linked to different EEF performance whilst application timing and possibly cultivar considerations will also need to be factored into the decision support process.

Specific findings were that higher proportions of CRFs were required to maintain yield potential and reduce N loss through effective N supply throughout the crop growth cycle on sandy soils. These CRFs also performed relatively better in late-ratoon application from October onwards close to the wet season. Our results highlighted that higher rates of EEFs do not necessarily lead to improved production or profitability and also suggested that cultivar interactions may also be important.

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