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Can new fertilizer technology facilitate a reduction in fertilizer-N rates and improved water quality without compromising sugar production?

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Abstract Optimizing nitrogen (N) application rates to both sustain high levels of productivity and minimize any impacts on the surrounding ecosystem is challenging, especially under monsoonal wet-season conditions in northern Australia. The inability of existing application strategies and fertilizer-N products to achieve synchrony of mineral N supply with crop demand or prevent rapid formation of nitrate-N (that is vulnerable to loss via gaseous or aqueous loss pathways) increases risks of inefficient N use. A blend of enhanced efficiency fertilizers (EEFs) with different modes of action has the best chance of lowering the risk of N losses and increasing crop-N recovery, providing an opportunity to reduce fertilizer-N rates without increasing the risks of productivity loss. Seven field trials were established from Mackay to the wet tropics, with data from consecutive ratoon crops at sites in Tully, Silkwood and the Burdekin reported here. Yields and indices of N use efficiency were developed for crops receiving urea-N at rates equivalent to that derived from the local SIX EASY STEPS guidelines, or as urea or a blend of EEFs applied at N rates calculated using a block-specific yield target (PZYP) based on mill records. Results showed that yields at all sites responded to the application of urea-N fertilizer, and there were suggestions of a slight productivity drop if rates were lowered to those determined using PZYP at some sites. The apparent crop uptake of urea-N was generally poor (15–30% of applied N) and the agronomic efficiency of fertilizer-N use varied significantly among sites and seasons (2.5–11.4 kg N applied/t additional cane yield). The use of the EEF blend consistently delivered improved fertilizer-N recovery (30–47% of applied N), but the lack of any yield increases at sites other than Silkwood resulted in similar agronomic efficiencies (2.5–7.6 kg N applied/t additional cane yield). The impacts of the EEF blend on runoff and drainage losses at Silkwood were confounded by inadequate closure of the fertilizer trench during stool splitting.

Key words Urea, enhanced efficiency fertilizers, nitrogen, productivity zone yield potential, dissolved inorganic nitrogen

INTRODUCTION

The Australian sugar industry operates in challenging environments, with high rainfall and variable soil types collectively producing difficult conditions in which to efficiently manage a mobile nutrient such as nitrogen (N). In addition, the crop demand for available N to support biomass growth and cane yield accumulation occurs over an extended period (typically 6–8 months – Bell *et al*. 2014). This extended period of crop-N demand increases the risk of loss of labile forms of N via gaseous and aqueous loss pathways, especially if the combination of fertilizer application strategies and soil N transformations result in accumulation of NO_3–N. Simulation studies (Thorburn *et al.* 2017a) have illustrated the quantum and variability of such off-site N losses from conventionally fertilized sugarcane fields in Tully and Mackay over a 7-year climate string. At urea-N application rates of 150 kg N/ha applied to fine and coarse-textured soils, seasonal total N loss from fertilizer and soil N sources by denitrification and leaching was estimated to range from about 15–110 kg N/ha at Mackay and from 35–200 kg N/ha at Tully, with soil type influencing both the quantum of loss and the likely loss pathway. The extent of this variability adds considerable uncertainty to the calculation of an optimal N-fertilizer rate.

There is considerable evidence that at least part of the 'lost' fertilizer-N from sugarcane systems is entering the marine environment in the Great Barrier Reef lagoon, with adverse impacts on water quality and the health of the marine ecosystem (Bell *et al.* 2016; McCloskey *et al.* 2016). There is, therefore, an imperative to reduce the quantum of fertilizer-N loss from cane fields but attempts to do this through a simplistic approach such as reducing N rates in lower yielding fields without changing other aspects of agronomic or fertilizer-N management has been shown to introduce risks to crop productivity (Thorburn *et al.* 2017b, 2018). Similarly, despite recent machinery advances that allow split N applications to be made later in the crop season, there are suggestions that this strategy used with conventional urea alone will still prove relatively ineffective at reducing fertilizer-N requirement and improving NUE (Thorburn *et al.* 2015).

Enhanced efficiency fertilizers (EEF) attempt to modify fertilizer-N release rates or control the rate of N transformations in and around the fertilizer band to better synchronize labile-N availability with crop-N demand. While different strategies have proved more or less effective in varying soil types (Di Bella *et al*. 2017), their effectiveness in increasing cane yield or allowing reduced fertilizer-N rates has been variable (Verburg *et al.* 2017, 2018) and the higher cost of these products/kg N applied has typically resulted in a reduction in profitability, even when applied as blends with conventional urea (Kandulu *et al.* 2017). There has been no work quantifying the impact of EEF use on off-site N losses.

Our study compares the standard approach to fertilizer-N (urea) management currently documented in the SIX EASY STEPS (6ES) framework (Schroeder *et al.* 2014) with one in which fertilizer-N rates are derived from the productivity potential of the individual block/zone (PZYP) and the fertilizer is applied as either urea or the best available blend of EEF products commercially available. The approach is assessed on the basis of productivity, fertilizer NUE and runoff water quality.

METHODS

Field sites and fertilizer application rates

We established seven field sites after the 2016 crop harvest, but results from only the Burdekin, Tully and Silkwood sites are reported in this paper due to the delay in obtaining harvest results from the 2018 crop season at the Freshwater and Mackay locations. All experiments were commenced after harvest of the first or second ratoon in 2016, with selected site details shown in Table 1. There was substantial variation in soil organic carbon (C) among sites (1.0–5.6%C), which normally modifies the recommended fertilizer-N rate in 6ES. However, there are recognized situations where the in-season soil-N mineralisation adjustment (which is based on soil organic-C content) is uncertain (e.g., wet sites occupying low landscape positions and with elevated C, such as the Silkwood site) and we took the opportunity at this site to compare rates with and without adjustment for the soil-N mineralisation.

The experimental design and plot size varied with site. In Silkwood and the Burdekin, plots were large-scale strips six to eight cane rows wide and the length of the cane block, with yield (and in the case of Silkwood, runoff water quality) collected from the entire treated strip. The Burdekin trial contained three replicate strips of each treatment, but due to the extensive water-quality monitoring equipment requirements at Silkwood, treatments were not replicated. At Tully, both sites consisted of smaller plots, replicated experiments in a randomized block design. Plot size was six cane rows wide each 30 m long, and all treatments were replicated four times except for the Nil N plot, which had two new replicate plots in each growing season.

The basis of fertilizer rates was either the District Yield Potential (DYP, currently used to determine the fertilizer-N rates in 6ES) or the Productivity Zone Yield Potential (PZYP, used to determine N rates aligned to a spatially relevant yield target), with those targets shown for each site in Table 1. The PZYP was calculated from the mean yield from block or satellite records over two or more crop cycles, plus 2 times the standard error of that mean. As all sites were established in ratoon crops, plant-crop yields were generally excluded from this calculation, especially where those yields were markedly higher than yields of the ratoons. In situations where large variation in yields occurred between La Niña and normal or drier seasons (e.g. in the wet tropics), separate PZYP targets were calculated to reflect the expected seasonal forecast (i.e. lower PZYP targets in forecast La Niña conditions). Each site hosted a Nil N treatment each year (fertilizer-N was withheld for that growing season), but these plots/strips were rmoved to new plot/strip locations annually. Having the Nil N treatment always located on a plot with a history of fertilizer-N application provided a realistic assessment of the soil N supply which the fertilizer-N application was designed to augment.

Table 1. Details of the experimental sites and fertilizer-N rate treatments.

Location	Soil type	Soil organic C (%)	District yield potential (and 6ES N rate)	Productivity zone yield potential (and N rate)	Discretionary treatment (N rate)	Variety and initial crop stage
Burdekin (Mulgrave region)	Loam over sodic clay (Sodosol)	1.0	180 t/ha (200 kg N/ha)	130 t/ha (150 kg N/ha)	Grower rate urea (170 kg N/ha)	Q240$^{\Phi}$ (1R)
Tully 1 (well drained)	Well-drained silty light clay (Tully series)	1.0	120 t/ha (140 kg N/ha)	130 t/ha (150 kg N/ha)	(i) PZYP without mineralization discount (170 kg N/ha, urea) (ii) Wet season exploratory (120 kg N/ha, EEF)*	Q208$^{\Phi}$ (2R)
Tully 2 (poorly drained)	Poorly drained silty clay loam (Timara series)	2.3	120 t/ha (110 kg N/ha)	130 t/ha (120 kg N/ha)	(i) PZYP without mineralization discount (170 kg N/ha, urea) (ii) Wet season exploratory (90 kg N/ha, EEF)*	Q208$^{\Phi}$ (2R)
Silkwood**	Bulgan series (Hydrosol)	5.6	120 t/ha (160 kg N/ha*)	80 t/ha (100 kg N/ha*)	Long-term Nil N subplot	Q183$^{\Phi}$ (2R)

* Based on adjusting fertilizer-N rates in response to seasonal forecasts (Skocaj 2015).

** The mineralization index on this high-C Hydrosol overestimates background N mineralization; the 6ES rates, therefore, do not include the mineralization rate discount, and were applied as urea or the EEF blend

Crop harvest and fertilizer application were conducted as in the grower's normal practice at each location, although in both years at all sites there were no crops harvested in the first round. This was considered desirable, as it was expected that the best chance to assess the risks of reduced N rates and the efficacy of EEFs would be under conditions where fertilizer-N losses were more likely to occur (i.e. where the onset of the monsoonal wet season occurred before the crop had finished the majority of biomass-N accumulation).

Fertilizer-N sources

The same fertilizer-N sources were used at each site. The fertilizer-N standard was taken as granular urea, which was applied during the month following harvest of the preceding ratoon. This was compared to an EEF blend consisting of one-third of the urea coated with the nitrification inhibitor 3,4-dimethylpyrazole phosphate (DMPP, marketed commercially as Entec®) and two-thirds the polymer-coated urea with a reported 90-day release period (product of Everris Pty Ltd and marketed as Agromaster Tropical®). This blend was chosen as the best possible combination of products that would protect fertilizer-N from risk of loss – initially by retaining the N in the NH_4–N form, and subsequently by slowing the release of urea-N into the soil solution.

Both products were applied using either stool-split (Burdekin and Silkwood) or subsurface side-dress (Tully) fertilizer applicators, although at Silkwood in particular, the stool-split applicators did not always effectively close the fertilizer trench and cover the fertilizer band with soil. This suboptimal application strategy contributed to some confounding of the benefits of EEF use in some seasons due to greater loss risks to both the atmosphere and in runoff.

Fertilizer-N recovery, crop yield and indices of fertilizer-N use efficiency

Fresh and dry biomass and crop-N content were determined from hand-cut biomass samples collected from 7–10 months after fertilizer application, on the assumption that at this stage, the crop-N content would be at a maximum, and most relevant to the yield-determining processes (Bell *et al*. 2015). Crop-N was partitioned between leaf/cabbage/dead leaf and stalks at that time. In situations where biomass sampling was conducted a little earlier than desirable (e.g. due to an impending cyclone), fewer whole-stalk samples were again collected for dry matter and N concentration immediately prior to harvest (to determine the partitioning of N between harvested and non-harvested portions of the crop), and stalk-N concentration from the final harvest was used in combination with cane yields to estimate crop-N removal.

Yields were determined by commercial harvest in the case of the large strip plots, with the bins collected from each strip weighed and CCS determined at the mill. In the case of the small plot trials at Tully, yields were determined from small-plot hand harvesting and CCS was determined by near infrared spectroscopy (Berding *et al.* 2003).

Two indices of N use efficiency were calculated from these data, using calculations adapted from Ladha *et al.* (2005):

- *Agronomic efficiency of fertilizer-N use* ($AgronEff_N$) = Fertilizer-N rate/($Yield_{N1}$ – $Yield_{N0}$) = kg fertilizer-N required to produce an additional tonne of cane yield. In this calculation, $Yield_{N1}$ is the cane yield at fertilizer rate N_1, while $Yield_{N0}$ is the yield with no N applied.
- *Nitrogen uptake efficiency (NUpE)* = (Crop-N1 – Crop-N0)/Fertilizer-N rate = the additional crop-N uptake/kg fertilizer-N applied. In this calculation, N1 is the biomass-N content for N rate 1, while N0 is the biomass-N content with no applied N fertilizer.

Runoff and drainage losses of N

Surface water runoff and drainage below the root zone (1 m depth) were monitored in four of the fertilizer rate treatments at Silkwood in both seasons, excluding the Nil N treatment, in addition to strategic sampling in the farm drain around the block. Surface water samples were collected by automated samplers, with each water sample representing an integrated composite of runoff from each individual runoff event (event mean concentration). Runoff samples were analysed for sediment, total nitrogen, urea, ammonium-N, and nitrate-N. Drainage samples were collected from five lysimeter barrels in each of the treatments with runoff monitoring (totalling 20 barrels) on a weekly to monthly basis, depending on rainfall. Drainage samples were analysed for nitrate-N and ammonium-N concentrations.

RESULTS AND DISCUSSION

Cane yield response to N rate and fertilizer form

There were statistically significant cane yield, CCS and sugar yield responses to fertilizer-N application at all sites in both years (data not shown), with cane yields without fertilizer-N in 2017 representing 45–60% (mean 53%) of yields of treatments receiving the recommended 6ES fertilizer rate applied as urea, and a slightly higher 53–80% (mean 66%) of the yields from the same benchmark treatment in 2018. However, at sites where statistical comparisons could be made between the core treatments shown in Table 2 (i.e., excluding Silkwood), there was no significant response to either N rate or the use of EEFs in terms of cane or sugar yields and CCS. There was, however, an interesting trend for 6–8% higher yields with the EEF blend compared to urea at the PZYP N rate across both seasons in the Burdekin, with the yields in the EEF treatment receiving 150 kg N/ha effectively identical to those receiving 200 kg N/ha as urea.

Whilst not able to be compared statistically, yields at Silkwood in the 2017 season responded strongly to increased N rates as urea (cane yields with 160 kg N/ha were 31% higher than those with 100 kg N/ha), and at the 160 kg N/ha rate, increased by a further 23% when the N was applied as the EEF blend. However, while the maximum yield with urea-N was similar in the 2018 crop (47.5 t/ha in 2018 versus 49.6 t/ha in 2017), there was no apparent yield response to urea-N rates above 100 kg N/ha. By comparison, in strips where N was supplied as the EEF blend, yields increased by 22% as the N rate increased from 100 kg N/ha to 160 kg N/ha, and at the 160 kg N/ha rate the EEF treatment produced 16% higher yields than the equivalent rate of urea.

Accumulation of N by the cane crop

Biomass sampling at 7–10 months after fertilizing was assumed to approximate the time of maximum crop-N uptake (Bell *et al.* 2015; Moody and Connellan 2018), and data from across all sites was initially pooled in an analysis of the relationship between crop-N content and final cane yield (Fig. 1). This analysis suggested distinctly different relationships for the crops grown at Silkwood versus the crops grown at the Burdekin or Tully sites. In both datasets, there was a linear relationship between crop-N content and cane yield up to crop-N contents of about 100 kg N/ha, after which there was little or no further increase in cane yields despite greater N accumulation. However, for the same crop-N content, the yields at Silkwood were always 50–60 t/ha less than crops at the other sites, and the crops at those sites were much more efficient at using additional N accumulation to produce increased cane yield. To illustrate this, crops containing <100 kg N/ha at both Tully sites and the Burdekin required an additional 0.81 kg N in above ground biomass to produce an additional tonne of cane yield, while crops at Silkwood needed 1.93 kg biomass-N to produce an additional tonne of cane yield. Collectively, these data suggest that while crops at Silkwood were responsive to N application, other limitations to yield at that site (e.g., waterlogging) were playing a much greater role in determining crop yields.

Table 2. Effect of fertilizer rate and product on cane yield (t/ha), CCS and sugar yield (t/ha) for the 2017 and 2018 crop harvests*.

Location	Season	Cane	CCS	Sugar	Cane	CCS	Sugar	Cane	CCS	Sugar	Cane	CCS	Sugar
		200N, urea			150N, urea			150N, EEF			170N, urea		
Burdekin	2017	121.8	15.0	18.2	115.2	15.5	17.8	122.7	15.	18.5	115.5	15.3	17.7
	2018	115.3	17.2	19.8	106.5	16.7	18.7	115.6	16.6	19.1	112.8	17.3	19.4
Tully 1		150N, urea			150N, EEF			170N, urea			120N, EEF		
	2017	122.4	14.5	17.8	125.1	14.7	18.1	125.4	14.9	18.3	112.1	14.7	16.5
	2018	100.0	15.0	15.0	104.3	14.7	15.4	106.6	15.1	16.1	104.8	14.8	15.5
Tully 2		120N, urea			120N, EEF			170N, urea			90N, EEF		
	2017	98.3	14.5	14.3	90.2	14.1	12.7	100.9	14.6	14.7	91.9	14.7	13.5
	2018	100.6	14.9	14.7	105.3	15.3	16.1	111.1	14.7	16.3	91.2	14.9	13.6
Silkwood**		100N EEF blend			100N urea			160N EEF blend			160N urea		
	2017	–	–	–	37.8	11.9	5.11	61.1	11.9	5.96	49.6	11.9	7.27
	2018	45.4	14.6	6.6	43.9	14.6	6.4	55.3	14.3	7.9	47.5	14.6	6.8

*Statistical testing for treatment effects showed no statistically significant differences (ns) for any parameter in either crop season at Burdekin, Tully 1 or Tully 2 sites. Treatments at Silkwood were applied as unreplicated strips, so statistical comparisons cannot be made

**Fertilizer-N rates were based on the 6ES DYP rate, with or without the soil-N mineralization adjustment, for urea and EEF blends.

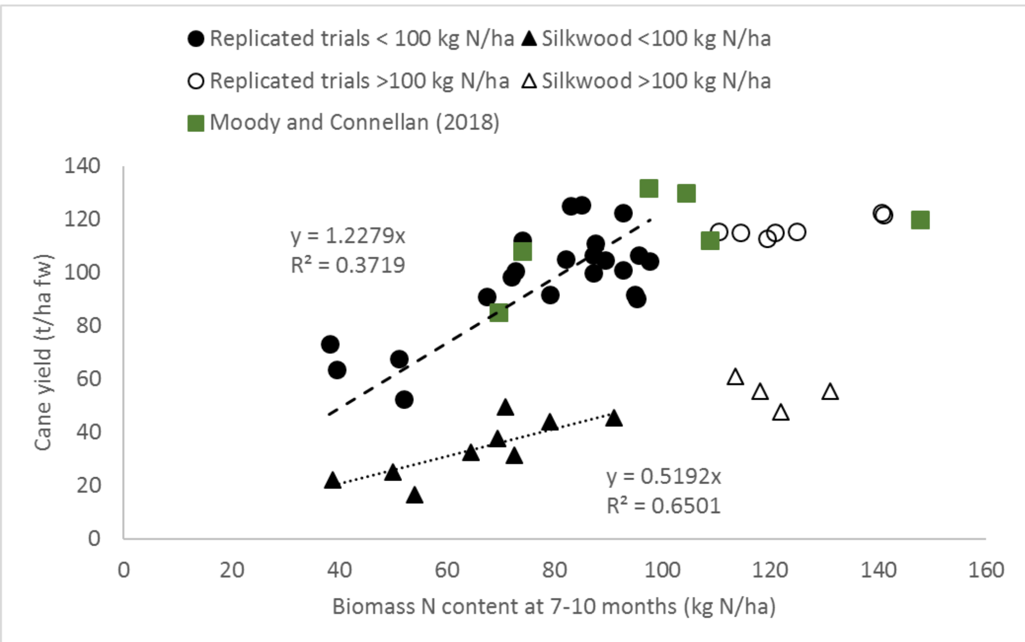

Figure 1. Relationship between biomass-N content of sugarcane crops in all experiments in 2017 and 2018 and cane yields harvested in that growing season. Data have been pooled for the Burdekin and both Tully replicated experiments and contrasted with data from the Silkwood strip trial. Individual trial data from the Burdekin (Moody and Connellan 2018) are shown on this figure for sites where cane yields were <140 t/ha.

It is interesting to note the similarity between the findings from the Tully and Burdekin sites from this study, and those reported by Moody and Connellan (2018) for sites in the Burdekin. The trial data points from Moody and Connellan (2018) for crop yields <140t/ha (slightly above the best recoded in our Tully and Burdekin trials) have been added to Figure 1, and there is clear overlap between these data sets. The pooled data continue to suggest that above-ground N content >100–110 kg N/ha did not necessarily result in higher cane yields, and when a pooled regression was fitted to all data (excluding Silkwood) for crop-N <110 kg N/ha the slope was effectively unchanged ($y = 1.2297x$; $R^2 = 0.44$), as was the calculated 0.81 kg biomass-N/t cane requirement. Moody and Connellan (2018) have suggested an additional 15% of the measured above ground biomass N is sequestered below ground in the stool and shallow roots of the cane crop, and so applying this adjustment, the combined data would suggest the crop needs to acquire 0.94 kg N to produce each t of cane yield.

Efficiency of recovery and use of fertilizer-N

The size of the cane yield response to applied N and the efficiency with which that applied fertilizer was used to produce additional cane yield ($AgronEff_N$) are shown for the 2017 and 2018 harvests at all sites in Table 2. Consistent with the lack of statistically significant differences in cane yields (Table 2), there was a similar agronomic response to applied N in terms of additional cane produced (Table 3), although the size of that response varied between seasons in the Burdekin (e.g. an average 55 t/ha yield increase in 2017 versus 21 t/ha in 2018) and to a lesser extent at the well-drained Tully site (an average 48 t/ha yield increase in 2017 versus 36 t/ha in 2018). The reasons for these trends were quite different, with the reduced N response in 2018 in the Burdekin due to a higher yield without applied N (92 t/ha versus 64 t/ha in 2017), while at the well-drained Tully site the yields without N were similar in both seasons (73 versus 68 t/ha), but the average yield with applied N was substantially lower in 2018 (103 t/ha) than in 2017 (121 t/ha) (Table 2).

Table 3. Agronomic responses in cane yields and crop-N uptake from the fertilized treatments at each site. Data are used to derive indices of $AgronEff_N$ and NUpE for the different fertilizer-N treatments.

Location	Year	Agronomic response to fertilizer-N t cane/ha (kg N applied/t extra cane yield)					Apparent fertilizer-N uptake kg fertilizer-N/ha (% applied N)				
Burdekin		200N, urea	150N, urea	150N, EEF	170N, urea	*LSD (0.05)*	200N, urea	150N, urea	150N, EEF	170N, urea	*LSD (0.05)*
	2017	58.1 (3.4)	51.6 (2.9)	59.0 (2.5)	51.8 (3.3)	*ns (0.5)*	52.5 (26%)	26.1 (17%)	52.2 (35%)	22.0 (13%)	*27.3 (0.19)*
	2018	23.5 (10.0)	14.7 (11.4)	23.8 (7.6)	21.0 (14.1)	*ns (ns)*	41.8 (21%)	16.6 (11%)	45.7 (31%)	40.2 (24%)	*19.3 (11.9)*
Tully, well drained		150N, urea	150N, EEF	170N, urea	120N, EEF	*LSD (0.05)*	150N, urea	150N, EEF	170N, urea	120N, EEF	*LSD (0.05)*
	2017	49.3 (3.0)	52.0 (2.9)	52.3 (3.3)	39.0 (3.1)	*ns (ns)*	54.5 (36%)	44.8 (30%)	46.8 (28%)	35.8 (30%)	*ns (ns)*
	2018	32.5 (4.6)	36.8 (4.1)	39.1 (4.4)	37.3 (3.2)	*ns (ns)*	36.2 (24%)	46.6 (31%)	36.2 (21%)	38.4 (32%)	*ns (ns)*
Tully, poorly drained		120N, urea	120N, EEF	170N, urea	90N, EEF	*LSD (0.05)*	120N, urea	120N, EEF	170N, urea	90N, EEF	*LSD (0.05)*
	2017	45.7 (2.6)	37.6 (3.2)	48.3 (3.5)	39.3 (2.3)	*ns (ns)*	20.0 (17%)	43.2 (36%)	40.7 (24%)	42.8 (48%)	*18.4 (16.3)*
	2018	36.9 (3.6)	41.6 (2.8)	47.4 (3.5)	27.5 (3.2)	*ns (ns)*	33.2 (28%)	42.5 (35%)	48.0 (28%)	27.8 (31%)	*ns (ns)*
Silkwood		100N EEF blend	100N urea	160N EEF blend	160N urea		100N EEF blend	100N urea	160N EEF blend	160N urea	
	2017	–	15.7 (6.4)	39.0 (4.1)	27.5 (5.8)	*na*	–	30.5 (31%)	74.6 (47%)	31.9 (20%)	*na*
	2018	20.2 (5.0)	18.7 (5.4)	30.1 (5.3)	22.3 (7.2)	*na*	41.0 (41%)	29.0 (29%)	68.0 (43%)	72.0 (45%)	*na*

Given the similarity in cane yields between fertilizer treatments at each site, differences in $AgronEff_N$ among treatments (only significant in the Burdekin site in 2017) were due primarily to N rate (i.e. similar yield responses from lower N rates). However, there did seem to be situations where this reduced rate effect on $AgronEff_N$ was at least countered, if not reversed, by a constrained crop yield response when N rate was below the optimum. For example, reducing the urea N rate from 160 kg N/ha to 100 kg N/ha at Silkwood in 2017 (a 37.5% reduction) was accompanied by 43% reduction in the cane yield response to applied N and a slight increase in $AgronEff_N$. Similarly, the reduction in EEF N rates from 150 to 120 kg N/ha (20%) in the well-drained site at Tully in 2017, and from 120 to 90 kg N/ha (25%) at the poorly drained site in 2018, resulted in reductions in the cane yield response to applied N of 25% and 34%, respectively and slight increases in $AgronEff_N$. There was substantial variation in $AgronEff_N$ between seasons and among sites, with the $AgronEff_N$ ranging from a relatively efficient 2.5–3.0 kg N applied/tonne additional cane produced (in the Burdekin and the poorly-drained Tully site in 2017) to a relatively inefficient 6.0–7.0 (Silkwood) to 11.0–14.1 (Burdekin 2018) kg N/additional tonne of cane produced. These site and seasonal differences in $AgronEff_N$ did not appear to be related to site differences in fertilizer-N application rates, or to the amount of fertilizer-N recovered by crops (Table 3).

The average apparent fertilizer-N uptake by crops ranged from 36–53 kg N/ha, with only small differences (<10 kg N/ha, and often much less) between seasons at each site (Table 3). The greatest apparent N recovery was at the Silkwood site (an average NUpE of 36% of applied N), which was consistent with what appeared to be very low N availability and consequent strong fertilizer-N responses recorded at that site (Tables 2 and 3). Within sites, the NUpE of the EEF blend was often significantly greater than that for the equivalent rate as urea, with the instances where this occurred most commonly representing situations where waterlogging and high N-loss situations would be expected (e.g. the flood-irrigated Burdekin site, the poorly drained Tully site, and Silkwood in the 2017 season).

The contrasting NUpE of urea-N at the Silkwood site provides an interesting insight into the importance of the timing and quantity of rain (and hence the potential for fertilizer-N loss) in the period following fertilizer application. In the 2017 crop, N was applied in early December 2016, and in the following 3 months there was a total of 1570 mm of rainfall, with over 710 mm falling in January 2017. By contrast, much less total rainfall (960 mm) fell in the 3 months following the late November fertilizer application in the 2018 crop, with the first large falls and major runoff not occurring until 2 months after fertilizer application. The higher rainfall and greater N loss risk for urea experienced in the 2017 crop was consistent with the poor N recovery in the 160N urea treatment (NUpE of only 20%), with both urea treatments only able to provide about 30 kg/ha of crop-N. In the 2018 crop, the relatively drier period after fertilizer application allowed much greater crop-N recovery in the 160 kg N-urea treatment and NUpE as high as 45%.

Despite this clear demonstration of the vulnerability of urea-N to environmental losses in the contrasting seasonal conditions at Silkwood, the NUpE of the EEF blend at 160 kg N/ha was relatively unaffected at 43% and 47% in 2017 and 2018, respectively. The lower rate of the EEF blend also provided NUpE benefits relative to urea in the 2018 crop – the only time that contrast was present. This consistency of EEF blend performance in terms of fertilizer NUpE was also evident across both seasons in the Burdekin and similarly at both sites at Tully, with the exception of the inexplicably poor performance of the 90 kg N/ha rate in the poorly drained site at Tully in 2018.

Water-quality implications from reduced N rates and EEF use

The combination of crop yields that were often unresponsive to increasing N rate, and apparent crop recovery of applied N that was similar across most of the N rates tested (with some notable exceptions), suggests that the amount of remnant fertilizer-N vulnerable to environmental losses should fall with falling N rates. Similarly, the consistently greater NUpE recorded for EEFs in higher loss situations (Table 3) suggests that losses from the EEF blend would be expected to be less than for conventional urea. Our data from the Silkwood site for the 2018 crop season (Fig. 2) were only partly consistent with these hypotheses. The combined DIN loss from runoff and drainage for the 100 kg N/ha application rate was only 25% of the loss recorded at 160 kg N/ha (i.e., 5.1 kg DIN/ha compared with 20.0 kg DIN/ha), and at the 100 kg N/ha application rate, the EEF blend produced only 42% of the combined losses from the same rate as urea. However, there was a clear anomaly that occurred in the EEF treatment applied at 160 kg N/ha, due to unexpectedly large runoff DIN losses.

Sequential soil sampling showed that significantly higher mineral N concentrations were maintained in the fertilized topsoil layers in the EEF160 treatment, compared to the equivalent rate of urea N, for a period from 50–150 days after fertilizer application (data not shown). While this behaviour was consistent with the objectives of having a controlled-release N fertilizer that released N in synchrony with crop-N demand, the reason for the elevated runoff losses that occurred over this period was consistent with high NO_3-N concentrations in topsoil layers. While this may have been associated with high water tables and limited N redistribution into deeper layers at this site, it was also consistent with inappropriate placement of the fertilizer in the soil profile. At the time of fertilizer application in November 2017 there was visible evidence of a failure to close the slot after the stool split fertilizer application. As a consequence, the more gradual release of mineral N from the controlled release granules provided a continual renewal of soil mineral N in a position that was vulnerable to runoff loss in each subsequent rainfall event.

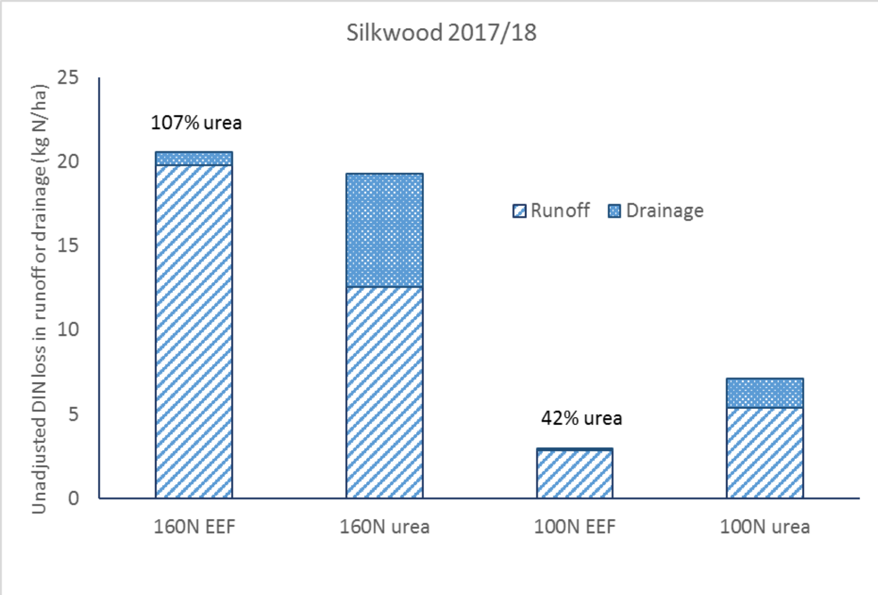

Figure 2. Measured losses of dissolved inorganic Nitrogen (DIN) in runoff and deep drainage at the Silkwood site for the third-ratoon crop harvested in the 2018. Values represent total DIN losses and cannot solely be attributed to fertilizer application, as the Nil N treatment was not able to be monitored to determine background DIN loads.

It is interesting to note that the higher DIN runoff losses from the 160N EEF treatment were almost totally compensated for by elevated drainage losses from the equivalent rate of urea. This would have been consistent with rapid mineralization and generation of nitrate-N in the urea treatment, which was rapidly moved (in runoff or deep drainage) from the vulnerable topsoil layers. Collectively, these data illustrate the critical importance of appropriate N application strategies, in addition to choice of appropriate rates and products, if N-use efficiency and water quality are to be improved.

SUMMARY AND CONCLUSIONS

This paper reports the first results from a subset of the sites established in the National Environmental Science Program and will be the precursor to the more extensive assessment of the performance of combinations of reduced N rates and use of new N fertilizer technology in the Reef Trust 4/EEF60 program. However, while these results are at an early stage of the trial program, they do illustrate important factors that need to be considered in any rationalization of fertilizer-N management in the sugar industry.

Firstly, for crops ratooning after second or final harvesting rounds, the apparent NUpE of applied urea N is poor (typically <30%, and sometimes <20%). Fortuitous combinations of delayed or low intensity rainfall for an extended period after fertilizing can sometimes moderate losses and result in improved NUpE, but it would be impossible to predict these occurrences with sufficient certainty to influence a fertilizer decision.

Secondly, a blend of EEF fertilizer products is providing higher NUpE and a more consistent supply of available N to the sugarcane crop than occurs with urea. This improved NUpE is only rarely reflected in greater crop yields relative to the same rate of urea, although when these situations occur (typically in conditions conducive to large fertilizer-N losses), the yield benefits may be substantial.

Thirdly, the combination of EEF fertilizers and lower fertilizer-N rates offer real potential for reducing the loss of DIN in runoff and drainage. However, this will not happen (and in fact runoff losses may be exacerbated) unless fertilizer is placed well below the soil surface and there is adequate closure of the fertilizer slot to minimize off-site losses. There have already been discussions about the need to ensure effective soil cover of both fertilizers and pesticides applied in-crop, and there is tillage equipment currently being evaluated that should reduce the risks of losses in such situations. However, the extent of inadequate fertilizer trench closure has not been determined, and there would appear to an urgent need to conduct regional surveys after the main fertilization periods to quantify the extent of this problem.

Finally, the research has not been running for long enough to make any firm conclusions about fertilizer rates. There are suggestions that reducing rates to match PZYP in either low or higher yielding situations will be a greater productivity risk when the fertilizer used is urea, but that switching to a blend of EEF products will mitigate that risk somewhat by improving the NUpE and ensuring greater crop-N contents. There is an emerging relationship between crop-N content at 7–10 months and final cane yield that may prove to be a useful guide to the quantum of N required in different productivity zones. The challenge is to maximize the chances of the crop acquiring the N it needs, and the best opportunity to do this lies with rapidly improving EEF technology.

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