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SUPPORT OF CANE FARMER TRIALS OF ENHANCED EFFICIENCY FERTILISER IN THE CATCHMENTS OF THE GREAT BARRIER REEF

FINAL REPORT 2016/807

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EXECUTIVE SUMMARY

There is growing pressure from community and government for farmers located within the Great Barrier Reef catchments to reduce nutrient losses. Enhanced Efficiency Fertilisers (EEFs) provide an opportunity to improve nitrogen (N) fertiliser uptake by sugarcane cropsby better matching N supply with crop demand. Complementary benefits from improving fertiliser N uptake efficiency are the resultant improvements in nitrogen use efficiency (NUE) and reduced risk of nitrate losses.

The EEF60 project is the most extensive evaluation of EEFs ever to be undertaken in the Australian sugarcane industry and reflects a collaborative partnership between sugarcane growers, CANEGROWERS, Sugar Research Australia, regional productivity services and agricultural economists from the Department of Agriculture and Fisheries. It was designed to test EEFs on 60 sugarcane farms, located between Bundaberg and Mossman, over three harvests. The trials evaluated the performance of EEFs relative to conventional fertilisers by measuring cane and sugar yield, Commercial Cane Sugar (CCS), grower profitability, NUE, crop N content, fertiliser uptake efficiency, post-harvest soil N and water quality (N leaching and runoff).

Two main types of EEFs were tested as part of this project, namely controlled release fertilisers (CRFs) and nitrification inhibitors (NIs). The former release urea-N slowly through a protective polymer coating, while the latter are based on the addition of nitrification inhibitors such as DMPP[1] to urea to stabilise the N in ammonium form. The EEFs were tested at N rates below the sugarcane industry's current nitrogen rate recommendations due to their promoted ability to reduce environmental losses through better matching N availability to crop N uptake over the growing season, and their higher costs in comparison to urea.

Four treatments were kept consistent across 54 of the trial sites representing 128 crops harvested. These included two urea treatments and two EEF treatments. One of the urea treatments had N applied at the current industry recommended N rate (SIX EASY STEPS (6ES)) (Urea 6ES), while the other was 20% below 6ES (Urea -20%). EEF treatments were all applied at N rates 20% below 6ES. The most widely tested EEF treatment was used in all sites and consisted of a blend of 1/3 DMPP with 2/3 CRF (DMPP/CRF -20%). The other was a Wildcard treatment that varied in response to individual grower preference. Growers in the project were given a choice of EEFs to trial with many choosing to test either urea with DMPP (46% of crops harvested) (DMPP -20%) or blends of 20% CRF with 80% urea (42% of crops harvested) (CRF -20%). A few growers also chose the 1/3 DMPP and 2/3 CRF EEF blend but applied at the higher 6ES recommended N rate.

Urea applied at N rates 20% below 6ES produced relatively lower cane yields in medium and high rainfall conditions compared to Urea 6ES, particularly on loam and clay soils when fertiliser was applied late in the season and heavy rainfall was experienced. While it maintained grower profitability, widespread adoption would reduce mill revenue (due to lower cane yield) and have a net negative impact on the industry. While the lower N rate maintained cane yield and achieved higher grower profitability in low rainfall conditions, weather forecasts to predict these situations are inaccurate, which makes N rate decisions based on predicted rainfall risky.

In contrast to urea, EEFs were found to reduce the risk of N losses from rainfall events post fertiliser application, opening an opportunity to deploy reduced N rates. The main EEF treatment trialled was DMPP/CRF -20%. This treatment produced similar cane yield to Urea 6ES in most situations and higher CCS in low rainfall conditions, but higher fertiliser costs (50-60% higher N costs) generally made this blend less profitable to apply except for a few situations such as in sand and loamy soils that experienced high rainfall conditions after late season fertiliser application. Compared to Urea 6ES, this EEF blend improved NUE by 23%, fertiliser uptake efficiency by 24% and post-harvest soil N by 12%, while maintaining crop N content.

The trials identified that DMPP -20% and 20% CRF -20% (Wildcard) treatments performed well, highlighting their potential for broader application in ratoon cane. Both of these EEFs were successful at maintaining production and profitability compared to Urea 6ES, while increasing NUE by 23%, maintaining crop N content and maintaining or increasing fertiliser uptake efficiency and post-harvest soil N. Maintaining production and profitability, along with similar fertiliser input costs, will be key factors for achieving widespread uptake by industry. The substantial increases in NUE (and improvements in fertiliser uptake efficiency) are likely to reduce the risk of nitrate-N losses and improve water quality outcomes. There was a trend for EEFs to produce higher crop yields than Urea 6ES in sandy soils under high rainfall conditions when fertiliser was applied late in the season, although differences were not significantly different. These observations were consistent with past EEF research indicating that the benefits of EEFs are exploited more in high rainfall conditions when the likelihood of N losses are greatest.

The other Wildcard option was the 1/3 DMPP with 2/3 CRF blend applied at the higher 6ES recommended N rate, which was tested at fewer sites. It was not found to increase yield relative to the same EEF blend at the 20% lower

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[1] 3,4-Dimethylpyrazole phosphate

N rate, which made it even less profitable due to the higher fertiliser costs. This option also did not improve NUE relative to Urea 6ES nor result in additional N captured in the crop.

N uptake efficiency demonstrated that although N was applied at 20% less in the EEF treatments, crops were able to obtain similar amounts of N as crops grown in the Urea 6ES treatment. These findings were confirmed by analysis of crop N content, which showed that although less N was applied in the EEF treatments, crops were able to accumulate similar or more N (depending upon treatment) in comparison to the crops grown in the Urea 6ES treatment.

Water quality monitoring was undertaken at four sites in the Wet Tropics and two sites in the Burdekin. The movement of dissolved inorganic nitrogen (DIN) through the soil profile was monitored over the wet season at each of these sites. Analysis of soil water samples collected at depth (1m) from these sites has shown that DIN concentrations were significantly higher in the Urea 6ES treatment compared to the lower rate of urea and the EEF treatments.

The number of trials and consistency in trial design have enabled a wealth of data to be collected and analysed to determine what types, blends and rates of EEF perform better, where they get the optimal results (soil, rainfall and region) and when these products work best (time of application). Given practices are less likely to be widely adopted when there are perceived risks to the longer-term sustainability of cane farming businesses, the ability of this project to integrate the collective impacts of EEF use on production, profitability and NUE is essential to the widespread adoption of these products by industry. These findings will also facilitate the development of recommendations to help guide effective EEF use.

Key Findings

1. Applying urea at N rates 20% below the 6ES recommended rate decreased cane yield in medium and high rainfall conditions. While it maintained grower profitability, the lower yield decreases mill revenue and could reduce industry profitability. The lower urea N rate performed better (e.g. greater net revenue) in low rainfall conditions, however making N rate decisions based on predicted rainfall is currently risky.
2. DMPP treated urea and blends of 20% CRF with 80% urea applied at N rates 20% less than 6ES maintained similar productivity and profitability to urea applied at 6ES.
3. EF blends with a high proportion of CRF (e.g. 1/3 DMPP with 2/3 CRF) applied at N rates 20% lower than 6ES have high fertiliser costs, which generally reduces profitability except in a few situations such as in sand and loamy soils that experience high rainfallconditions after late season fertiliser application. Applying the same EEF blend at the higher 6ES N rate did not increase production and so was even less profitable.
4. Concentrations of N in water sampled 1 metre below the soil surface from the Urea 6ES treatment were found to be significantly greater than from EEFs and urea applied at N rates 20% lower than 6ES.
5. Indicators of NUE, such as crop N content and N uptake efficiency, were improved in comparison to Urea 6ES when EEFs are applied at N rates 20% less than 6ES.
6. Urea treated with DMPP and blends of 20% CRF with 80% urea, both applied at N rates 20% less than 6ES, can be applied at any time during the season without loss of productivity or profitability in comparison to urea applied at the 6ES recommended rate. These strategies delivered higher yields than Urea 6ES in some high rainfall situations, which was consistent with other EEF research. These findings suggest that the EEF option should be the preferred nutrient management strategy when high rainfall is expected.

Collectively, these findings suggest that the use of DMPP and blends of 20% CRF with 80% urea at N rates 20% less than recommended by the 6ES method should be promoted to growers as an additional option to their existing nutrient management strategy. The results indicate adoption of this strategy would have no impact on productivity and profitability but would improve NUE and water quality. To capitalise on the intrinsic benefits of EEFs (e.g. NUE, water quality), the EEF option could be promoted as the preferred nutrient management strategy when high rainfall is expected, which is associated with certain weather outlooks, and late in the season when rainfall associated with the wet season is more likely.

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1 INTRODUCTION

The EEF60 project was designed to test Enhanced Efficiency Fertilisers (EEFs) on commercial farms to identify opportunities to increase nitrogen use efficiency (NUE) and reduce nitrogen (N) losses by better matching N supply with crop demand. The project was a collaborative partnership between sugarcane growers, CANEGROWERS, Sugar Research Australia, regional productivity services, agricultural economists from the Department of Agriculture and Fisheries, Queensland and the Australian Government.

The project included approximately 60 replicated commercial scale field trials, conducted over three seasons. This included 30 in the Wet Tropics, 15 in the Burdekin, 10 in the Mackay-Whitsunday's region and five in the Bundaberg region (Figure 1). The objective was to capture '180 years' of trial data.

The large number of trials were designed to evaluate the performance of EEFs relative to conventional N fertilisers in terms of cane and sugar yield per hectare (TCH and TSH), commercial cane sugar (CCS) and NUE, with the aim of identifying circumstances in which growers can apply EEFs and maintain profitability. At six sites, four in the Wet Tropics and two in the Burdekin, water quality monitoring equipment was used to compare N losses between treatments via run-off and deep drainage.

This project was overseen by a technical working group which consisted of staff from Sugar Research Australia, CANEGROWERS, the Department of Agriculture, Water and the Environment, CSIRO, Department of Environment and Science, University of Queensland and the Department of Agriculture and Fisheries, Queensland. The technical working group provided guidance to the project team to ensure that the research was conducted in a scientifically sound manner.

The replicated strip trials were located on commercial farms across the catchments of the Great Barrier Reef. Sites were located from Mossman in the far north to Bundaberg in southern Queensland.

Major soil types in each region were represented in the project. Sites were selected after considering several factors such as block size, shape, soil uniformity, irrigation systems employed and pest control measures. Consideration was also given to yield history of the blocks.

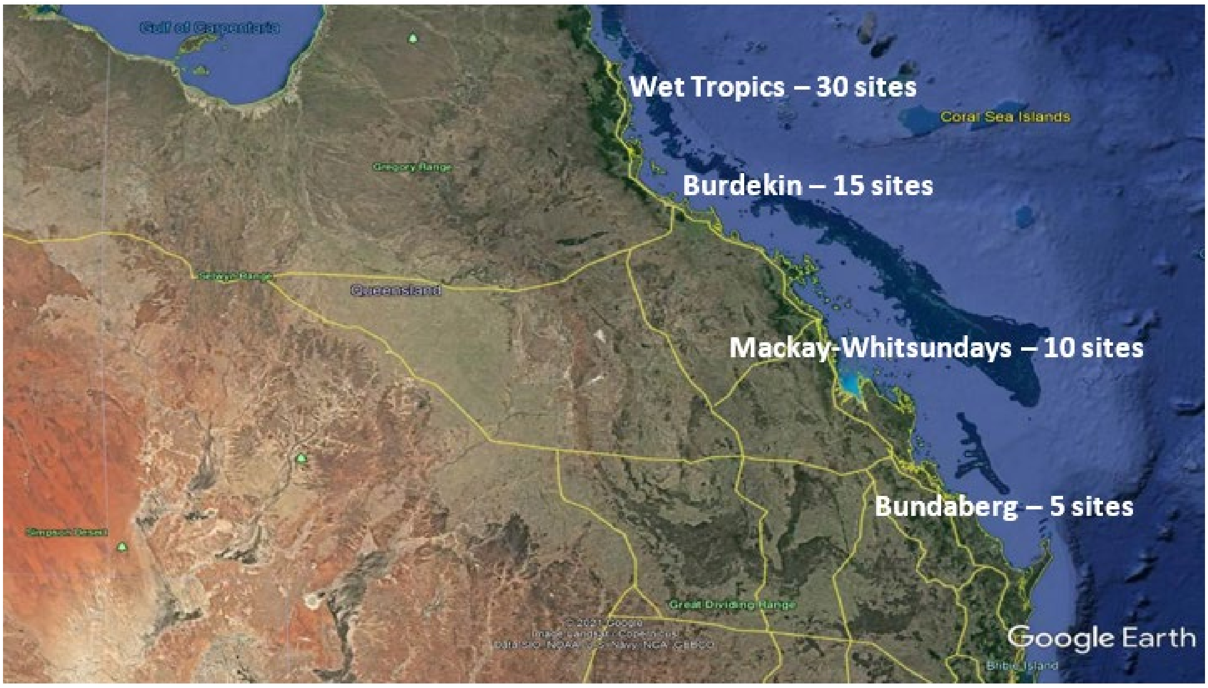

Figure 1: EEF60 site locations across Queensland.

2 BACKGROUND

Community and government have placed increasing pressure on farmers located in the Great Barrier Reef (GBR) catchments to reduce nutrient losses from farms due to linkages between water quality and the health of the reef (The State of Queensland, 2013). New fertiliser technology such as EEFs may be an opportunity to improve the efficiency of fertiliser uptake by sugarcane crops and reduce N losses by better matching N supply with crop demand. The EEF60 project was designed to evaluate the production, profitability, and water quality implications from applying EEFs in place of urea.

The objective of the project was to evaluate EEF performance at 60 trial sites using a replicated strip trial designed to compare the production and profitability implications from using EEFs against that from conventional urea-based fertiliser products applied according to the current industry recommendations (SIX EASY STEPS (6ES) guidelines). The EEFs were tested at N rates below 6ES guidelines due to their higher unit costs (see section 5) when compared to urea and their purported ability to reduce N losses by better matching N supply to crop demand over the growing season. Trials were established on commercial sugarcane farms in all major sugarcane growing regions located adjacent to the Great Barrier Reef.

Two main types of EEFs were tested as part of this project. These were controlled release fertilisers (CRFs) which release N slowly through a polymer coating, and nitrification inhibitors (NIs) which are added to urea to stabilise the N in ammonium form to reduce losses. Both products aim to reduce the amount of nitrate in the soil profile whilst maintaining adequate supply to meet crop demand.

Field trials conducted in the Burdekin with NIs and CRFs (Dowie et al. 2019), suggest that there are opportunities to utilise EEFs at reduced rates whilst maintaining productivity and profitability. It was also reported that there were significant interactions between treatments, soil types and the time of application which impacted cane and sugar yield

A glasshouse experiment conducted in the Herbert (Di Bella et al. 2017) compared fertiliser N lost in drainage and as nitrous oxide for conventional urea, CRFs and NIs. CRFs and NIs were found to be effective at reducing N losses in comparison to conventional urea. Other studies, including Verburg et al. 2018, have been undertaken to examine the effectiveness of EEFs for improving NUE.

3 METHOD

3.1 Strip trial site establishment

At the beginning of the project, protocols were developed by SRA and agreed upon by the Technical Working Group. These protocols provided guidelines on research activities which were undertaken (refer to Appendix 3).

Sites were initially identified through contacts made using the knowledge of local productivity services, CANEGROWERS and SRA staff. Once sites were identified a site inspection was undertaken with the grower to determine if the site was a prospective candidate for the trials.

Suitable sites were mapped for electrical conductivity (EC) (Veris 3100 or similar device). These maps were used to provide a general guide to changes in soil type and salinity/sodicity across blocks (Figure 2). This information was used to develop comprehensive soil sampling strategies. Potential trial sites were broken up into zones and soil was sampled according to the results of the EC survey.

Soil samples were collected to a depth of 1 m in each zone, with sub-samples from 0-20 cm, 20-40 cm, 40-60 cm, 60-80 cm and 80-100 cm depths being collected and analysed for nutrient status. The results of the analysis from each zone for the 0-20 cm samples were assessed using the 6ES method to determine baseline nutrient requirements across trial sites.

Soil samples from all sites were analysed for the percentage sand, silt and clay in the top 20cm of the soil profile for all sites. A texture triangle (Hunt, N., & Gilkes, R. 1992) was then used to classify the soil according to texture, i.e. sandy loam. In order to undertake statistical analysis, texture classifications were simplified to three main categories of Sand, Clay and Loam using the texture triangle for guidance.

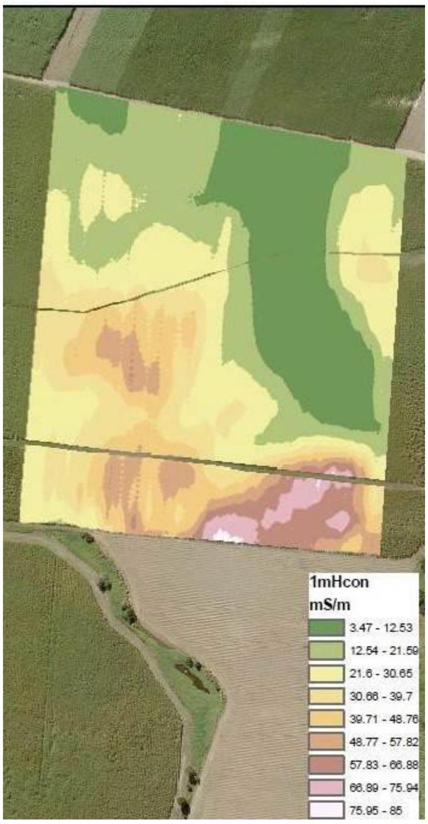

Figure 2: A 'soil' map generated from electrical conductivity measurements.

Most trial sites were established in first ratoon crops with fertiliser applied 4-6 weeks post- harvest (Figure 3). In most cases, the farmers fertiliser boxes were used to apply products following calibration to the desired rate. SRA's stool splitter / side dresser box was also utilised for sites in the Burdekin region. For each treatment fertiliser boxes were recalibrated to apply the desired rate of product.

Figure 3: SRA fertiliser box used to establish trial sites in the Burdekin.

Over the period of the project, factors such as crop establishment, irrigation management, and pests and disease management were monitored.

Trials were conducted at commercial scale using large, replicated strips. Two forms of EEFs based on urea were used in the trials – Controlled Release Fertilisers (CRFs) and Nitrification Inhibitors (NIs).

Treatments included:

1. Nitrogen at the SIX EASY STEPS® (6ES) rate applied as Urea (Urea 6ES).
2. Nitrogen at 20% less than the 6ES rate applied as Urea (Urea -20%).
3. Nitrogen at 20% less than the 6ES rate applied as a blended product which consisted of 33% nitrification inhibitor treated urea and 67% controlled release fertiliser (DMPP/CRF -20%).
4. Nitrogen at 20% less than the 6ES rate applied as either CRF (20% CRF -20%), nitrification inhibitor (DMPP -20%), or other product (Other) which was decided based on grower or regional interest, referred to as the 'Wildcard'.
5. Small plot areas (6 rows x 20 m) with 0 N were included to allow calculation of how much background N was available from the soil.

These treatments were replicated (3 replicates) and randomised at each site.

3.2 Harvest data capture and interpretation

Over the duration of the project, cane yield and CCS results were supplied by the local sugar mills in each region following the harvest of each trial site (Figure 4). Sugar yield was calculated from these values. The results were analysed to identify if there were any differences in cane and sugar yields which could be attributed to the use of EEFs at N application rates lower than those recommended by the 6ES method.

Figure 4: Harvest of EEF60 trial site.

3.3 Nitrogen use efficiency indicators

Indicators of NUE can be calculated to better understand N dynamics within sugarcane farming systems. Together with productivity, profitability, and environmental data, these can inform nutrient management practices. A simple indicator of NUE which is referred to as Partial Factor Productivity of N is calculated using tonnes of cane/kg of applied N. This can be easily calculated using yield data and fertiliser records. Other methods require sampling and processing (Figure 5) of plant samples to estimate crop size and N accumulation. This process was undertaken at all EEF60 trial sites when crops reached nine months of age. Previous work (Connellan & Deutschenbaur, 2016) demonstrated that biomass and N accumulation in sugarcane peaks by nine months and hence is a suitable time to investigate NUE indicators. Index for Efficiency of Fertiliser N Recovery (NUptEfert) was calculated using estimates of crop N in each treatment along with estimates of crop N in the small areas which did not receive any applied N. NUptEfert is used as an indicator of the efficiency of capture of fertiliser N by the crop.

$$\text{NUpEfert} = \underline{\textit{Total N uptake}_{\textit{fertilised}} - \textit{Total N uptake}_{\textit{0N}}\ \textit{N rate}}$$

Total crop N accumulated in above ground biomass (kg N/ha) was also calculated and compared across treatments, sites, and years.

Figure 5: Collecting and processing biomass samples in the Burdekin.

3.4 Residual soil mineral nitrogen post-harvest

Soil mineral nitrogen concentration (the sum of concentrations of nitrate nitrogen and ammonium nitrogen) in the top 20 cm of the soilprofile was assessed within 1 to 2 days following harvest (Figure 6).

Mineral N (kg/ha) = Concentration (mg/kg) x sampling depth (cm) x bulk density (g/cm^3) x 0.1

An assumed bulk density value of 1.2 was used for all samples to calculate mineral N content in all regions. Detailed protocols for post-harvest soil sampling are included in Appendix 3.

Figure 6: Post-harvest soil sampling in the Burdekin.

3.5 Nitrate nitrogen concentrations in irrigation water Burdekin and Central Regions

Irrigation water in the Delta area of the Burdekin is supplied predominantly from bores which intercept the local groundwater system. However, some growers also utilise channel water. Water used in the Burdekin River Irrigation Area (BRIA) is predominantly surface water supplied via an irrigation network (Figure 7). In the Central region supplementary irrigation was applied predominantly via water cannons and centre pivots.

Over the duration of the project water samples were collected at random intervals from bores or supply channels which were used to irrigate trial sites. Water samples were tested for the presence of dissolved mineral N, with the mean dissolved inorganic nitrogen (DIN) concentrations found each season in water samples presented in the results.

Figure 7: Irrigation in the BRIA region of the Burdekin.

3.6 Water quality monitoring

At four sites in the Wet Tropics and two in the Burdekin, water quality monitoring equipment was installed to monitor DIN concentrations in run-off and leachate. To monitor run-off volume, four SanDimas flumes (Figure 8) were installed at each site, with one deployed in each treatment of a replicate which had the most suitable topography for capturing samples. Each flume contained an Odyssey logger to monitor flow though the flume and a KP sampler (Mark II) to capture water samples for analysis. The KP samplers were triggered via a float switch (turned on when water is present in the furrow) and captured water samples every 20 minutes when triggered. Water samples were collected as soon as possible following a run-off event and in some cases during a run-off event. Samples were then filtered and analysed for NH_4-N and NO_x-N concentrations, with results summed to calculate total DIN concentration.

To capture soil leachate samples, a ceramic pore water sampler was installed at both ends of each plot (strip) (24 ceramic pore water samplers per site). Samplers were buried at 1 m below ground level, directly below the plant row and placed under vacuum with water samples extracted from the soil and delivered to a bottle on the surface via a tube (Figure 9). Water samples were collected on a weekly basis, filtered and then analysed for NH_4-N and NO_x-N concentrations, with results summed to calculate total DIN concentration.

Figure 8: San Dimas flume.

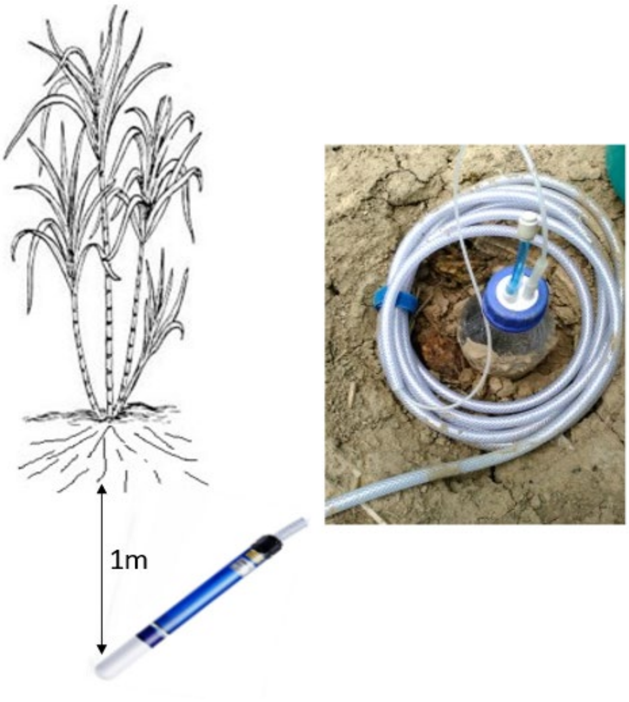

Figure 9: Ceramic pore water sampler and delivery bottle.

3.7 Economic analysis

An important requirement of the economic analysis was to account for all variables that influence the profitability (grower) of each fertiliser treatment including grower revenue, fertiliser costs, harvesting costs and levies. Grower revenue was calculated at the plot (replicate) level by multiplying cane yield by the cane payment formula[2], using relative CCS and the five-year average net sugar price[3] of $421/t to determine grower revenue per tonne of cane. Plot level calculations enabled variability to be considered using statistical analysis. Cane yields and relative CCS values were obtained from mill data.

Fertiliser costs were calculated from the average price paid for each product over the courseof the trial where available[4] (2017-20). Application costs[5] were also subtracted along with the cost of other nutrients apart from N (e.g. Phosphorus, Potassium and Sulphur). Average harvesting costs were sourced from contractors in each region. The analysis assumes that allother variable growing expenses (irrigation, pest control, etc.) remain the same for each fertiliser treatment. Higher net revenue indicates a higher economic benefit.

To quantify the grower economic benefit, this report applies a method that has been used consistently in past research to calculate the net revenue (or ‘partial net return’[6]) from applying different N rates:

Net revenue = gross revenue – fertiliser cost (including application) – harvesting costs – levies (all calculated per hectare).

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[2] Cane payment formula = sugar price x 0.009 x (CCS – 4) + mill constant. The mill constant applicable to each mill area was used. The Mackay formula recently changed due to new mill ownership and now aligns with other regions.

[3] $421 was the five-year average net sugar price for the QSL harvest pool between 2013 and 2017.

[4] Some fertilisers were not applied in some years (e.g. N90 and N80 were not applied in 2017 and N180 was not applied in 2018 and 2019).

[5] For granular fertilisers, fuel, oil, repairs and maintenance plus labour were accounted for assuming application by growers. Costs varied depending on application method (e.g. surface/subsurface). Application costs were generally included in the cost of liquid fertilisers.

[6] For example, Connellan, Thompson, Moody and Arief (2017), Skocaj, Hurney and Schroeder (2012), Schroeder, Hurney, Wood, Moody and Allsopp (2010) and Schroeder, Moody and Wood (2010) used this method to compare the profitability of different nutrient practices.

3.8 Statistical analysis for yield, NUE and economic data

Given the considerable variation in yields and CCS between different trial sites and regions, the statistical analysis was completed by analysing data for each treatment relative to urea applied at 6ES in each rep, to help isolate the treatment effect. This was achieved by setting the urea applied at 6ES outcome as the benchmark and dividing the outcome of each treatment by the outcome of the 6ES treatment (e.g. 95 tch (Urea -20%)/ 100 tch (Urea 6ES) = Relative yield of 0.95). Following analysis, the relative data was transformed back to its original format (TCH, CCS, TSH, $/ha) and included in figures with the relative data for easy interpretation.

Statistical analyses were conducted on how the treatments affect each of the following traits of interest - TCH, TSH, CCS, Net Revenue, Relative TCH, Crop N content (kg/ha), tc/kg of applied N, NUptEfert, and post-harvest soil N (kg/ha at 0-20 cm)

The nitrogen treatments examined were Urea 6ES, Urea -20%, DMPP/CRF -20% andthe Wildcard nitrogen treatment. Treatments in the wildcard mostly consisted of DMPP -20% or 20% CRF -20%. The remaining wildcard types were a mix of other nitrification inhibitors and straight CRFs.

Data were pooled across regions and sites and analysed based on the two forms of data (Relative or Actual).

Trial data were analysed by the common wildcard groupings:

1. All trial sites with wildcard treatments applied at 20% less N;
2. All sites with the DMPP wildcard treatment applied at 20% less N;
3. All sites with the 20% CRF wildcard treatment applied at 20% less N;
4. All sites with the EEF blend applied at 6ES N.

Linear mixed models were fitted to the data using ASReml-R statistical package. The model fitted to the data included the main effects of Product type, Soil type at 0-20 cm, Fertiliser rate, Cumulative rainfall 3 months post application, Harvest (Year) and Region and their 4-way interactions. Plots were nested within replicates and replicates nested within sites with each being fitted as random components of the model.

The traits analysed were TCH, TSH, CCS, Net Revenue, Crop N content (kg N/ha), Partial Factor N Productivity (tc/kg of applied N), NUptEfert, and post-harvest soil N (kg mineral N/ha at 0-20 cm) The significance of the fixed terms was tested using asymptotic Wald statistics. A least significant difference (LSD) multiple comparison test was used to determine which means among a set of treatment means differed from the rest at a significance level of 5%.

The treatment means with confidence interval bars for each analysis were graphed to visually display treatment variability. Letters (a, b, c, etc.) positioned above each bar indicate if means were statistically different from the other bars ($P<0.05$).

3.9 Statistical analysis for leaching data

The leaching data collected from the EEF60 sites were statistically analysed for the effect of the nitrogen treatments on NH_4-N (mg/L), NO_x-N (mg/L) and DIN (mg/L). The nitrogen treatments examined were Urea 6ES, Urea -20%, DMPP/CRF -20% and the Wildcard - 20% nitrogen treatment.

The treatment combinations (DMPP/CRF -20%, Urea -20%, Urea 6ES and Urea 6ES -Surface applied) investigated at the Babinda site were different from other sites in the Wet tropics, consequently the site was analysed separately. At this site the grower chose to surface apply urea at the 6ES recommended rate as his Wildcard treatment.

Analyses were for both individual region (Wet tropics, Babinda site in Wet tropics and Burdekin) and combined regional data. A linear mixed model was fitted to the data using ASReml-R statistical package. The model fitted to the combined regional data included the main effects of Greater Region, Treatment, Year and their 3-way interactions. Replicates were nested within Grower ID and Sampling Dates nested within Grower ID were fitted as the random components of the model.

The significance of the fixed terms was tested using asymptotic Wald statistics. A least significant difference (LSD) multiple comparison test was used to determine which means among a set of treatment means differ from the rest at a significance level of 5%. The treatment means with confidence interval bars for each analysis have been graphed to visually display treatment variability. Letters (a, b, c, etc.) positioned above each bar indicates means are statistically different from the other bars ($P<0.05$).

3.10 Limitations

While every action was taken to ensure that the highest quality standards were maintained, some aspects of the trials do have limitations. A key limitation of carrying out strip trials on commercial sugarcane farms is the number of plots (or strips) available for the trial. For example, each plot has to be of sufficient size to ensure the mill is able to measure the CCS level of the harvested cane. Depending on the size of the paddock, this may limit the number of plots available across a cane paddock for the trial. Plot availability influences the design of the trial, particularly around the quantity of treatments and replicates available forinvestigation and subsequent statistical analysis. Given that the quantity of treatments and replicates influences degrees of freedom, care should be taken when interpreting the individual crop statistical results at some of the trial sites. Importantly, degrees of freedom tend to increase when analysing data across multiple harvests and trial sites.

4 TRIAL SITE INFORMATION

4.1 Climate

The Wet Tropics is a region of extremely high rainfall which occurs predominantly over the summer period and encompasses the Mossman, Mulgrave, Innisfail, Tully and Herbert regions. Annual rainfall over the three years of the project along with the long-term averages is shown in Table 1. Rainfall varies dramatically across the region which impacts sugarcane yields. In almost all cases the sugarcane in the Wet Tropics relies exclusively on rainfall for soil moisture.

In the Burdekin, with higher radiation and lower rainfall, growers irrigate their cane crops predominantly via furrow irrigation. The combination of higher radiation and irrigation in the Burdekin results in the highest average yielding crops in Queensland. In the Mackay-Whitsunday's and Bundaberg regions, crops are generally supplementary irrigated using furrow irrigation or cannons, pivots or lateral move irrigators.

In 2018 the Wet Tropics received above average rainfall, while below average rainfall was experienced in all areas of the Wet Tropics in 2020. In the Burdekin, Mackay-Whitsunday's and Bundaberg regions, below average rainfall was received throughout the life of the project. In 2019 the Bundaberg region experienced its lowest annual rainfall in recorded history.

Table 1: Actual rainfall and long-term averages

REGION	RAINFALL (MM)			
	2018	2019	2020	AVERAGE
Mossman	3547	2671	1616	*2422*
Mulgrave	3378	2230	1554	*1921*
Innisfail	3903	2963	3048	*3823*
Tully	4367	3278	3288	*4073*
Herbert	2784	2525	1943	*2117*
Burdekin	947	724	997	*1043*
Mackay	1005	1301	1451	*1580*
Bundaberg	743	320	655	*996*

Source: Bureau of Meteorology 2021

4.2 Soil types

A range of soil types exist across the catchments of the Great Barrier Reef. The project aimed to include as many major soil types as possible in each of the cane growing catchments. The soil types included and the Soil group / order for each region are listed in Tables 2, 3, 4 & 5.

Table 2: Soil types and number of trial sites in the Wet Tropics

DISTRICT	AUSTRALIAN SOILS CLASSIFICATION SOIL GROUP/ORDER	QDPI SOIL TYPE*	NUMBER OF TRIAL SITES
Herbert	Kandosol	Cudmore	1
	Vertosol	Hamleigh	4
	Dermosol	Herbert	1
	Sodosol	Ingham	1
	Chromosol / Sodosol / Vertosol	Palm / Toobanna / Hamleigh	1
	Sodosol	Toobanna	2
	Sodosol / Vertosol / Hydrosol	Toobanna / Hamleigh / Brae	1
Tully	Hyrdosol	Bulgun	1
	Hyrdosol	Hewitt	1
	Hyrdosol	Lugger / Banyan - Hewitt	1
	Kandosol	Spanos	1
	Kandosol	Thorpe	1
	Dermosol	Tully	1
Innisfail	Tenosol	Brosnan	2
	Hyrdosol	Coom-Tully	1
	Dermosol	Eubenangee	1
	Dermosol	Galmara / Pin Gin	1
	Tenosol	Liverpool	1
	Dermosol	Timara-Coom / Pin Gin	1
	Dermosol	Tully	1
Mulgrave/Babinda	Organosol	Babinda	1
	Hyrdosol	Bulgun	1
	Dermosol	Edmonton	1
	Dermosol	Innisfail	2
	Organosol	Jarra-Inlet	1
	Tenosol	Liverpool	1
	Dermosol	Pin Gin	2
Mossman	Tenosol	Daintree	2
	Dermosol	Mossman	1

*Soil type descriptions sourced from the Queensland Government Soils Globe

Table 3: Soil types and number of trial sites in the Burdekin

DISTRICT	AUSTRALIAN SOILS CLASSIFICATION SOIL GROUP/ORDER	QDPI SOIL TYPES*	NUMBER OF TRIAL SITES
Delta	Dermosol	BUmb	1
		BUfb	1
		BUfc	3
		BUfc/BUma	1
		CUfb	1
	Hydrosol	CUfc/1UgcS	1
	Vertosol	RUgb	4
		RUgc	1
BRIA	Sodic Duplex	2Dyb	1
		6Drc	1
	Vertosol	2Uge	2
		6Dyf	1
		RUgd	1
		2Ugd/6Dyf	1
	Sodosol	6Dyj	1

*Soil type descriptions sourced from the Queensland Government Soils Globe

Table 4: Soil types and number of trial sites in the Mackay Whitsunday region

DISTRICT	AUSTRALIAN SOILS CLASSIFICATION SOIL GROUP/ORDER	NUMBER OF TRIAL SITES
Mackay-Whitsunday	Chromosol	4
	Chromosol Grey	1
	Kurosol	3
	Sodosol Grey	1
	Sodosol (Karloo)	1
	Black Vertosol	1
	Vertosol	1

*Soil type descriptions sourced from the Queensland Government Soils Globe

Table 5: Soil types and number of trial sites in the Bundaberg region

DISTRICT	AUSTRALIAN SOILS CLASSIFICATION SOIL GROUP/ORDER	QDPI SOIL TYPES*	NUMBER OF TRIAL SITES
Bundaberg	Dermosol	Sugarmill	1
	Dermosol	Flagstone	1
	Red Dermosol	Gooburrum	1
	Redoxic Hydrosol	Mahogany	1
	Redoxic Hydrosol	Alloway	2

*Soil type descriptions sourced from the Queensland Government Soils Globe

4.3 Mill areas and average yields

The average yield (TCH) in each mill area over the three years of the project is shown in Table 6.

Table 6: Statistics from mill areas included in the EEF60 trials

MILL	AVERAGE YIELD (TCH)		
	2018	2019	2020
Mossman Mill	91	80	79
Mulgrave Mill	82	76	88
South Johnstone Mill	72	71	82
Tully Mill	87	75	87
Herbert River Mills	83	72	77
Burdekin Mills	116	117	119
Proserpine Mill	74	74	76
Mackay Mills	67	73	79
Plane Creek Mill	66	71	67
Bundaberg Sugar Mills	73	71	76
Isis Sugar Mill	82	74	80

Source: Sugar Research Australia, Mill Area Statistics, 2020 Season

5 FERTILISER COSTS

Five different types of CRFs were applied in the trials. The price paid for CRFs ranged between $1,292/t and $1,723/t excluding GST but varied depending on CRF type and date of purchase (particularly between years[7]). DMPP was the main NI applied in the trials with Nitrapyrin also being applied at a few sites. DMPP coated urea (marketed as Entec®) costed on average $136 more per tonne than urea (e.g. Urea $643/t + $136 = $779/t), while the inclusion of Nitrapyrin added an average $132 to the price of urea per tonne. Fertiliser costs for each product type were assumed constant across all regions.

The average N costs and cost ranges for each fertiliser treatment by region, based on the products and rates used in the EEF trials, are shown in Table 7. The cost ranges reflect different N rates applied for each site (as recommended by the 6ES guidelines) and different products (e.g. types of CRFs and NIs). Average N costs for the 2/3 CRF 1/3 NI (80% N) treatment were approximately 50-60% more than Urea applied at 6ES N rates. Average N

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[7] The economic results depend on historical average prices, and prices are likely to change in the future (particularly given fluctuations in prices were observed for some fertilisers).

costs for the main wildcard treatments (NI and 20% CRF applied at 20% less N than 6ES), were generally a similar cost or slightly lower than Urea at 6ES N rates.

Table 7: Average N costs and cost ranges (min-max) for each treatment by region ($/ha)

REGION	T1	T2	T3	WILDCARD	
	UREA 6ES	UREA -20%	DMPP/CRF -20%	DMPP -20%	20% CRF -20%
Wet Tropics	$184 ($140 - $210)	$145 ($112 - $168)	$291 ($231- $349)	$175 ($149 - $203)	$191 ($174 - $217)
Burdekin	$256 ($202 - $275)	$199 ($155 - $216)	$400 ($291 - $453)	$246 ($227 - $259)	$256 ($230 - $273)
Mackay-Whitsundays	$184 ($145 - $207)	$142 ($108 - $167)	$279 ($217 - $337)	$174 ($131 - $203)	$175 ($147 - $193)
Bundaberg/ Isis	$189 ($168 - $210)	$151 ($134 - $168)	$312 ($277 - $347)	-	-

6 RESULTS

A total of 54 trial sites had at least one wildcard treatment (applied at 20% less N) with 125 crops harvested during the 2018, 2019 and 2020 harvest seasons. One of these sites had an additional wildcard treatment harvested over three seasons to make a total of 128 wildcard crops harvested. Table 8 shows a breakdown of crops harvested by type of wildcard and region, which shows that 46% of the crops were DMPP, 42% were 20% CRF and 12% were other wildcards.

Table 8: Summary of crops harvested by type of wildcard and region

REGION	DMPP	20% CRF	OTHER	TOTAL
Wet Tropics	35	17	5*	57
Burdekin	12	21	8	41
Mackay-Whitsundays	12	16	2	30
Total	59 (46%)	54 (42%)	15 (12%)	128

*Includes the 3 additional wildcard crops harvested at one site.

6.1 All Trial Sites with Wildcards

6.1.1 *Yield and profitability*

This analysis aims to provide an understanding of how the EEF treatments (DMPP/CRF -20% and Wildcard -20%) applied at N rates 20% lower than 6ES performed relative to the two urea treatments (applied at 6ES and 20% below).

Figure 10 displays the results for the overarching treatment effect across 54 trial sites in three regions (Wet Tropics, Burdekin and Mackay-Whitsundays). Of these sites 46% used DMPP as the Wildcard, 42% chose 20% CRF and 12% chose Wildcards which contained othernitrification inhibitor products or straight CRFs (not blended with urea).

Mean cane yield for Urea -20% was significantly lower than Urea 6ES and the DMPP/CRF - 20% (2.2 & 1.3 TCH respectively). Mean CCS was significantly lower for the 6ES urea treatment and the DMPP/CRF -20% treatment in comparison to the Urea -20% (0.14 and 0.7 CCS lower), while CCS for 6ES urea was significantly lower than the wildcard treatment (0.13 CCS). Mean sugar yield was significantly lower for the Urea -20% in comparison to the 6ES Urea treatment (0.21 tsh), while the DMPP/CRF - 20% and Wildcard -20% treatments were not significantly different to 6ES Urea.

For net revenue, the mean differences between the treatments were found to be statistically significant (p-value = 0.000). The Wildcard-20% maintained similar profitability to both urea treatments, while the DMPP/CRF -20% treatment was significantly less profitable than the other three treatments by $141/ha (Urea 6ES), $174/ha (Urea -20%) and $142/ha (Wildcard -20%). While the Urea -20% treatment had slightly higher average net revenue than

6ES urea (although not statistically significant), the significantly lower cane yield would decrease mill revenue by around $46/ha[8].

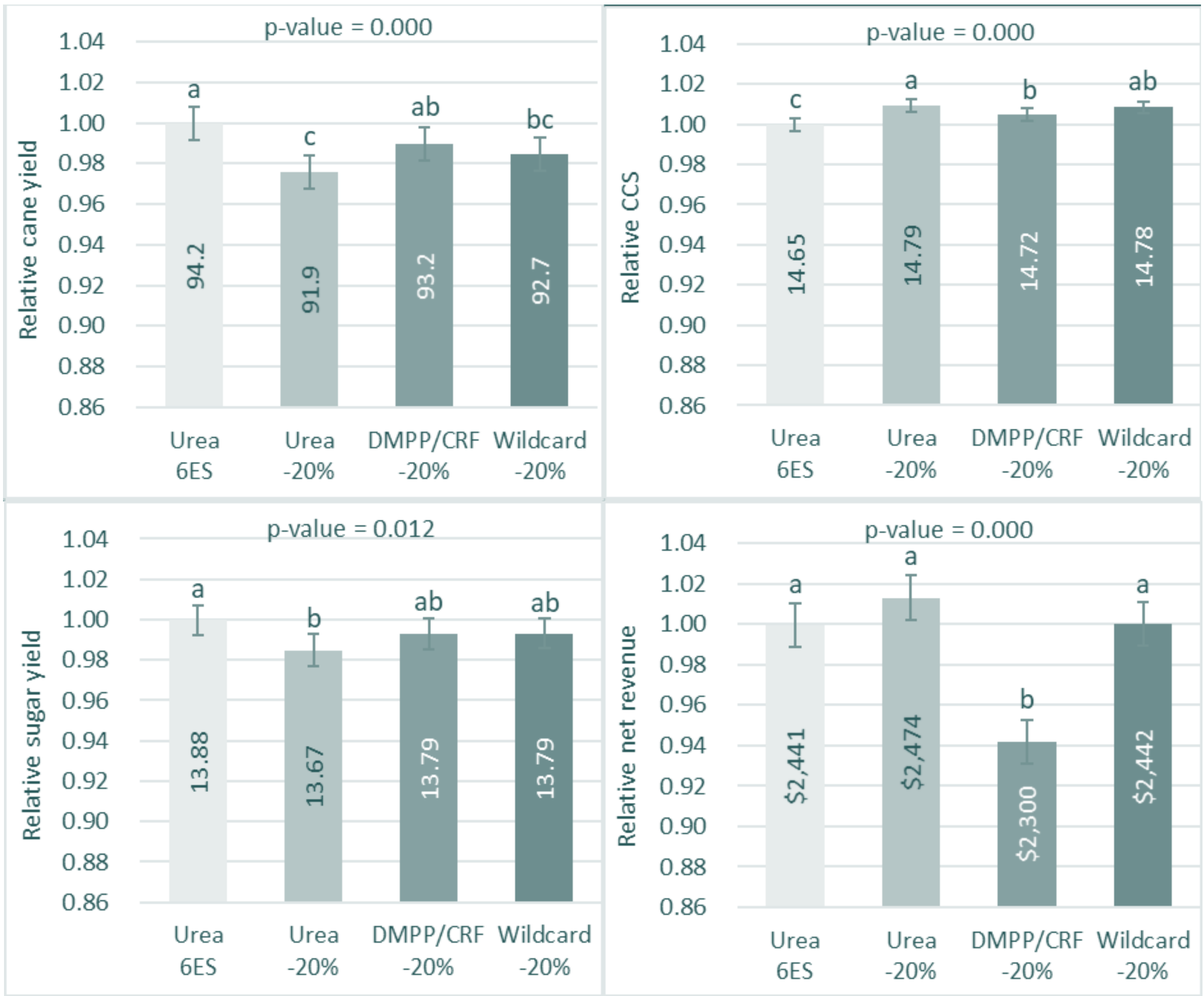

Figure 8: Mean cane yield (tch), CCS, sugar yield (tsh) and net revenue ($/ha) for Wildcard sites. Statistical comparisons have been made on a relative basis (y axis), while actual values are shown in text on each column. Error bars indicate the average 95% confidence interval.

Treatment x seasonal rainfall interaction

Rainfall data was collected from local Bureau of Meteorology sites over the course of the project and utilised in the analysis across all sites to determine if it influenced the performance of the EEFs. Cumulative rainfall was calculated over the three months following the application of fertiliser at each trial site. Rainfall was then categorised by being either low, medium or high according to regional averages, as shown in Table 9. A total of 47% of the site-year observations were classified as low rainfall years across all regions, while 37% were classified as medium rainfall and only 16% high rainfall.

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[8] Revenue received by the mill was calculated assuming: sugar price = $421/t, mill constant = $0.60, CoW = 1.00 and CCS = 13.79 (2012-19 average across Australia, https://asmc.com.au/policy-advocacy/sugar-industry-overview/statistics/)

Table 9: Rainfall categories by region

REGION	RAINFALL CATEGORY		
	LOW	MEDIUM	HIGH
Wet Tropics	<500 (15)	500-1000 (25)	>1000 (17)
Burdekin	<100 (26)	100-300 (12)	>300 (3)
Mackay-Whitsundays	<300 (19)	300-500 (10)	>500 (1)
Total	60 (47%)	47 (37%)	21 (16%)

Results from the statistical analysis indicate that rainfall influenced the performance of each treatment with significant interactions (treatment x rainfall) identified for CCS (p= 0.076[9] , Fig 11) and net revenue (p= 0.009, Fig. 12). Significant letters are only comparable between treatments for eachrainfall combination (not between rainfall conditions).

Under high rainfall conditions there were no significant differences in CCS amongst the treatments, but under medium and low rainfall conditions there is an increasingly significant trend for lower CCS to be recorded in the Urea 6ES and the DMPP/CRF -20% treatments.

For net revenue, DMPP/CRF -20% delivered significantly lower net revenue than both urea treatments in all rainfall conditions (between $110/ha and $171/ha lower than Urea 6ES). In contrast, the Wildcard -20% treatment obtained similar net revenue to 6ES urea in all rainfall conditions but appeared to perform particularly well in high rainfall (although not significantly different to the two urea treatments). The Urea -20% treatment obtained significantly higher net revenue than all treatments in low rainfall conditions ($64/ha higher than Urea 6ES). While Urea -20% achieved similar net revenue to Urea 6ES in medium and high rainfall, factoring in lower mill revenue of $46/ha due to lower cane yield (as previously mentioned) could make the overall net industry impact negative if marginal milling costs are low.

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[9] Statistical analyses were also completed excluding wildcard treatment data. For this interaction, a p-value of 0.044 was measured.

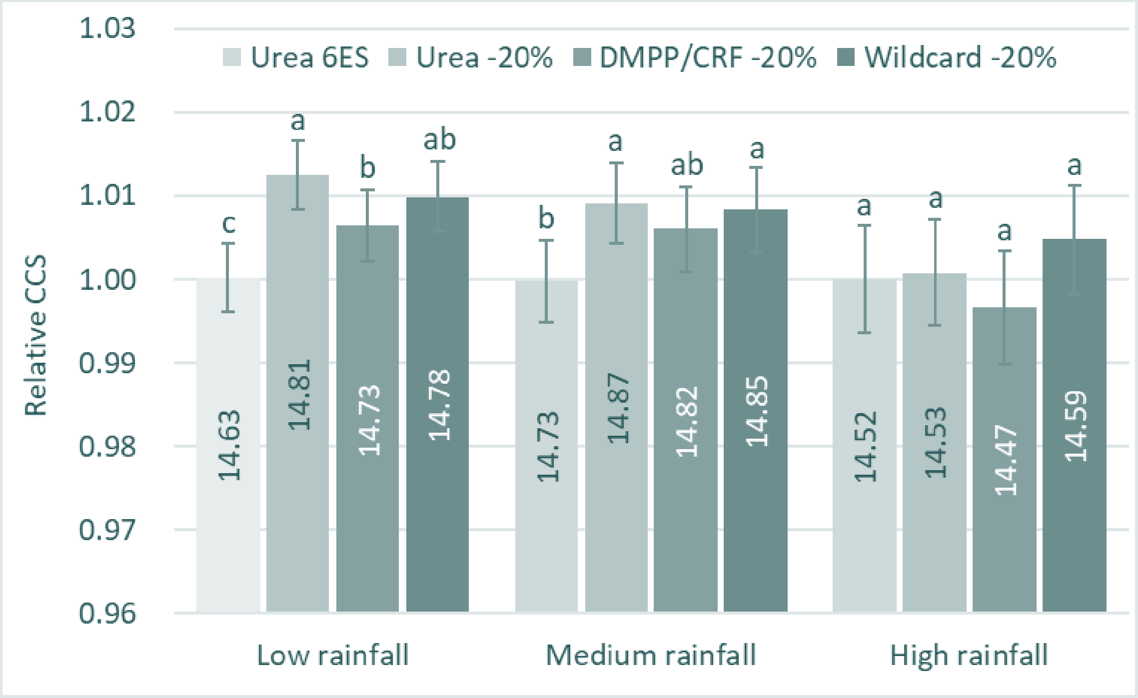

Figure 9: Mean CCS for Wildcard sites in each rainfall category. Statistical comparisons have been made on a relative basis (y axis), while actual values are shown in text on each column. Error bars indicate the average 95% confidence interval.

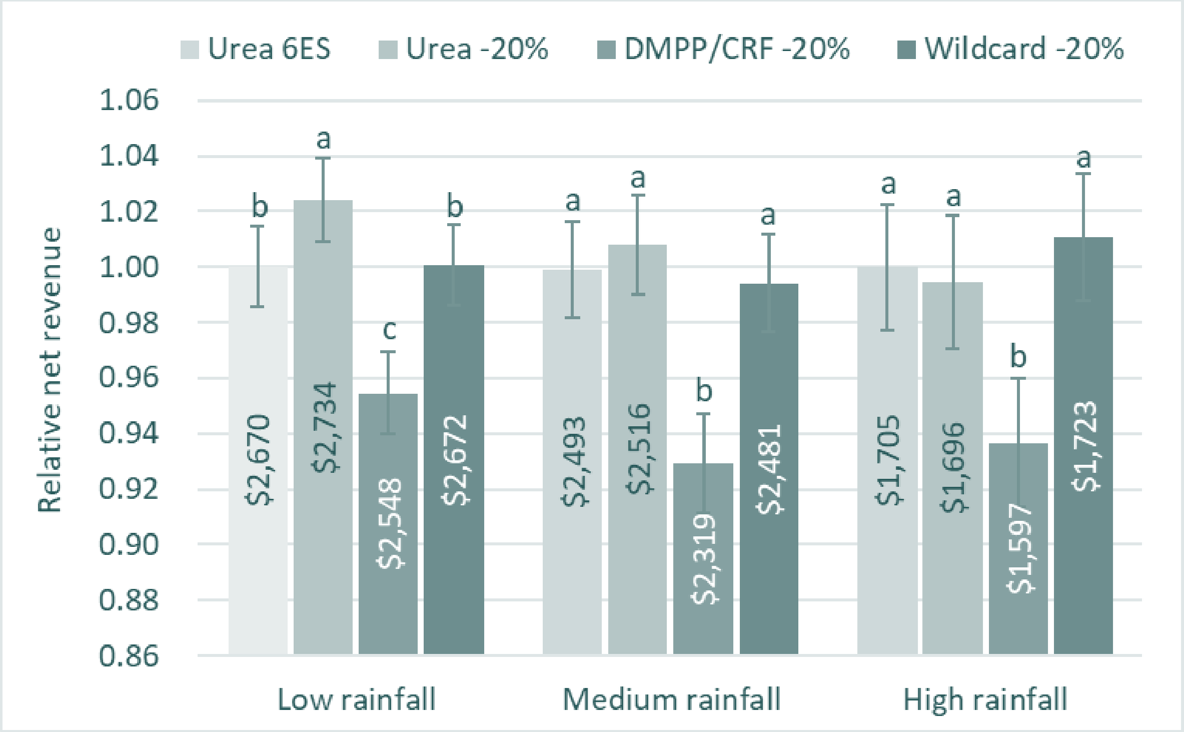

Figure 10: Mean net revenue ($/ha) for Wildcard sites in each rainfall category. Statistical comparisons have been made on a relative basis (y axis), while actual values ae shown in text on each column. Error bars indicate the average 95% confidence interval.

Treatment x Time of Fertiliser Application x Rainfall x Soil Type

A number of other interactions were also examined in the statistical analysis to help determine what environments the EEFs perform better or worse in (e.g. sandy soils versus clay or loam) and what application times are most and least suitable (e.g. applied late versusearly in the season). The most common soil texture found at trial sites was loamy soils which made up 62% of observations followed by clay soils and then sandy soils (28% and 10% respectively).

Timing of fertiliser application varied between regions with categories shown in Table 10. Most sites were fertilised mid-season (54% of observations) followed by late seasonapplications and a small number of early season applications (43% and 3% respectively).

Table 10: Timing of fertiliser application in each region

TIME OF APPLICATION	WET TROPICS	BURDEKIN	CENTRAL
Early		July	
Mid	August to October	August & September	August & September
Late	November & December	October & November	October & November

Results from the statistical analysis indicate that the time of fertiliser application, rainfall in the first three months following fertiliser application and soil type all interact to influence the performance of each treatment, with significant interactions identified for cane yield (p= 0.031, Fig 13) and net revenue (p= 0.034, Fig 14), no other significant interactions were found. Importantly, significant interactions identified that multiple variables interact to influence outcomes, indicating that these results are more explanatory than those from analyses with less (of the same) or no interactions (e.g. results in figures 13 and 14 are more explanatory that those in figures 10, 11 and 12).

Urea -20% produced significantly lower yields than Urea 6ES in both clay and loam soils (by 2.8 tch and 3.4 tch, respectively) when applied late season and subjected to high rainfall conditions. Similar yield decreases were found in some medium rainfall combinations (in loam applied mid-season by 3.5 tch and in clay applied late season by 4.5 tch) but no significant differences were identified in low rainfall years, indicating the lower N rate maintained yield in low rainfall (and presumably low loss) conditions. In contrast, the EEF treatments (DMPP/CRF -20% and Wildcard -20%) consistently maintained yields comparable to Urea 6ES in all soil type, fertiliser time and rainfall combinations except one (applied late in clay with medium rainfall). The EEF treatments appeared to outperform both urea treatments in sandy soils when applied late in high rainfall conditions, although this difference was not statistically significant (possibly due to a smaller data set for sandy soils). The EEF treatments also performed well in loam soil when applied late in high rainfall conditions, with DMPP/CRF -20% producing significantly higher yield than the lower N urea (by 3.2 tch) treatment.

Interestingly in loamy soils in all regions, sites fertilised mid-season under medium rainfall conditions showed a significant loss of yield in the Urea -20% treatment in comparison to the Urea 6ES treatment (by 4.5 tch) and the Wildcard treatment (by 4.7 tch). In similar soil types under high rainfall conditions no significant differences in yield between any treatments were found.

Additional analyses were undertaken to look for interactions using the same rainfall categories across all regions and excluding Burdekin data. Results for cane yield showed very similar interactions to those presented in Figure 13. However, no interactions were found for CCS, sugar yield, or net revenue possibly due to the larger number of missing combinations of rainfall categories, regions and other interactions (e.g. categories do not fit well with interactions in the dataset) and less statistical power.

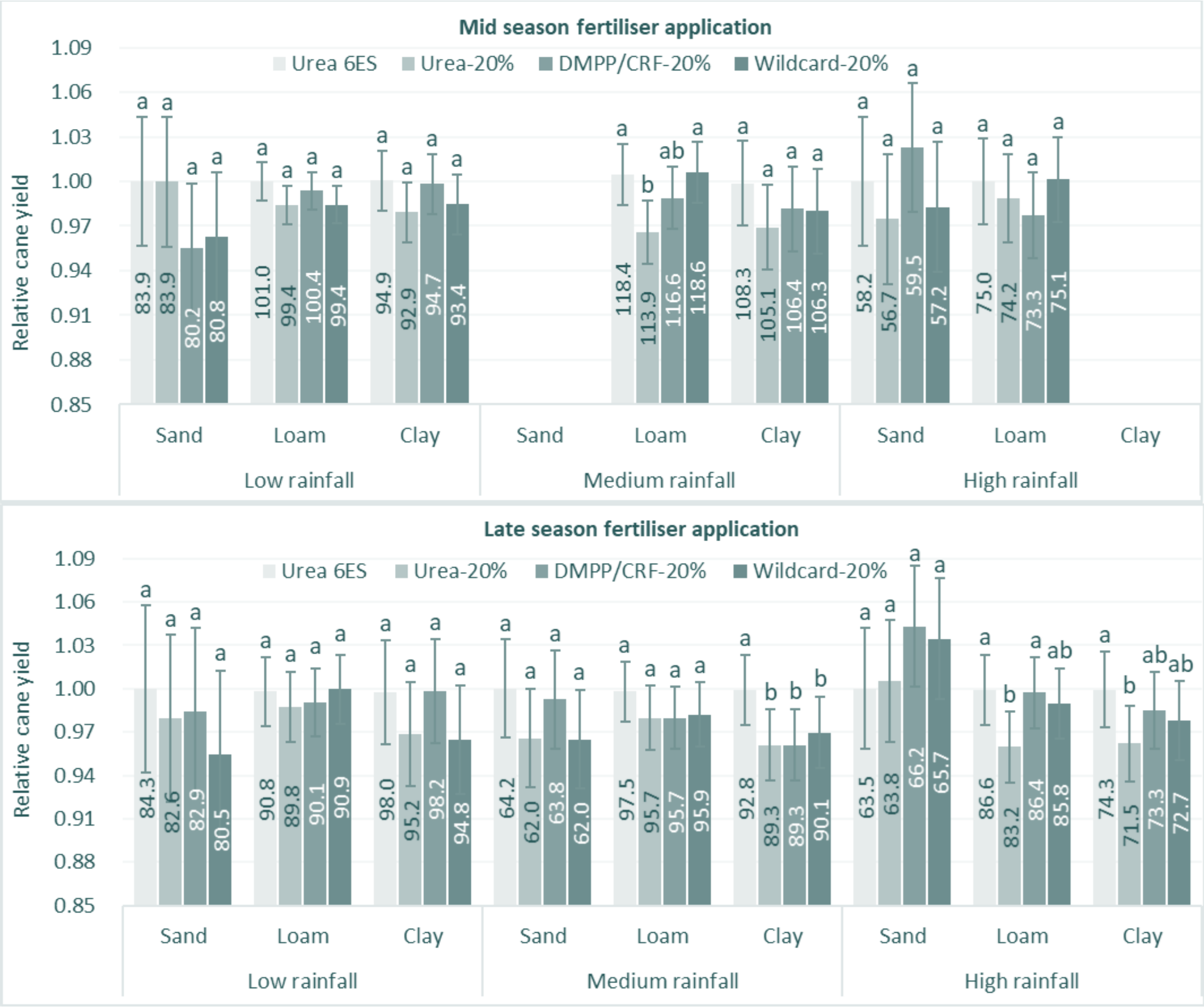

Figure 11: Mean cane yield (tch) for Wildcard sites for each time of fertiliser application, rainfall category and soil type. Statistical comparisons have been made on a relative basis (y axis), while actual values are shown in text on each column. Error bars indicate the average 95% confidence interval. Significance letters are only comparable between treatments for each soil type and rainfall combination (not between soil types or rainfall conditions).

In terms of net revenue (Fig 14), the Wildcard -20% treatment obtained similar net revenue to Urea 6ES treatment in every combination of rainfall, soil type and fertiliser application time. The Wildcard -20% performed well in a sand/high rainfall/late season combination although was not significantly different to the two urea treatments. DMPP/CRF -20% had significantly lower net revenue than at least one of the urea treatments in nearly all mid-season fertiliser application combinations (varying between $127/ha and $198/ha lower than 6ES urea) except sandy soils in high rainfall and most late season combinations except sand and loam soils in high rainfall and sand and clay soils in low rainfall. The Urea -20% treatment obtained significantly higher net revenue than the Wildcard -20% treatment in low rainfall on sandy soil when fertiliser was applied mid-season ($190/ha).

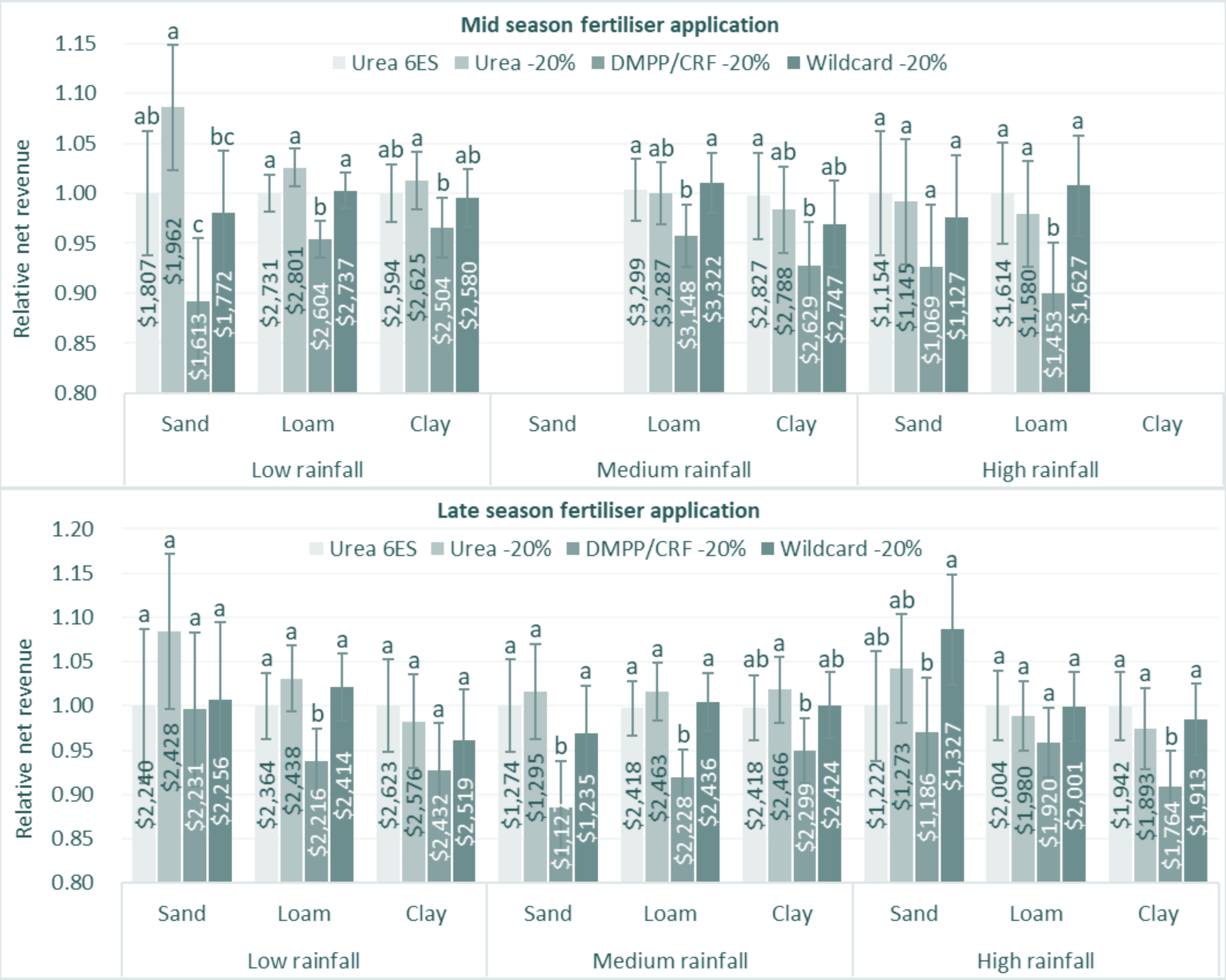

Figure 12: Mean net revenue ($/ha) for Wildcard sites for each time of fertiliser application, rainfall category and soil type. Missing columns indicate no trials were available that met this set of criteria. Statistical comparisons have been made on a relative basis (y axis), while actual values are shown in text on each column. Error bars indicate the average 95% confidence interval.

The results for the Wildcard -20% treatment identify the potential for broader application of EEFs in ratoon cane at N rates 20% below 6ES. Consequently, sections 6.2 and 6.3 investigate the most common types of EEF included in the wildcard treatment – DMPP and 20% CRF (a blend of 20% CRF and 80% urea).

6.1.2 *NUE indicators and post-harvest soil N - Wildcard*

The various analyses undertaken to investigate NUE and post-harvest soil N aim to provide an understanding of how the EEF treatments (DMPP/CRF -20% and Wildcard -20%) performed relative to the two urea treatments (applied at 6ES and 20% below). Data has been captured from 54 sites with between 1 to 3 years of data from each site included in this analysis. The Wildcard treatment includes either a DMPP urea or a CRF blended with urea (20% CRF).

A variety of NUE parameters (t cane/kg applied N and NUptEfert), crop N content and post-harvest soil mineral N in the fertilised soil layer (0-20cm) are presented as averages across each of the three trial regions (WetTropics, Burdekin and Mackay-Whitsundays) in Figure 15.

The industry Partial Factor Productivity metric (t cane/kg applied N) was significantly lower in the Urea 6ES treatment in comparison to all other treatments (0.13, 0.14 & 0.14 t/kg applied N lower than the Urea -20%, DMPP/CRF -20% and Wildcard -20%, respectively). This is solely due to the higher rate of N applied in this treatment, as there was very limited evidence of any yield increase in response to the higher N rate. The Urea -20% treatment was significantly less productive per kg of N applied than the EEF treatments (0.01 tch/kg N applied lower) although this difference was small.

The NUptEfert metric reflects the efficiency of crop recovery of applied fertiliser N in each treatment and shows that the proportion of fertiliser taken up in the Urea 6ES treatment was significantly less than all other treatments - again due primarily to the higher N rate applied. The Urea -20% and the EEF -20% treatments were not significantly different to each other. The DMPP/CRF -20% treatment had thehighest mean NUptEfert (0.31kg N uptake/kg fertiliser N applied) but was not significantly higher than the other treatments with fertiliser applied at the same rate.

Crop N content varied significantly with treatment. The DMPP/CRF -20% treatment resulted in significantly more crop N than the Urea 6ES treatment, the Wildcard -20% treatment, and the Zero N areas (4.1 kg N/ha, 4.6 kg N/ha and 46.9 kg N/ha, respectively). There was no difference in crop N content between the Urea 6ES treatment and the Wildcard -20% treatment.

Post-harvest soil N in the top 20cm of the soil profile was lowest in Urea 6ES relative to all other treatments, although differences were not large. The greatest difference was only 1.8 kg N/ha between Urea 6ES and DMPP/CRF -20% treatment, and residual mineral N in all fertilised treatments was effectively the same as the unfertilised Control, suggesting the residual fertiliser N in the topsoil was negligible.

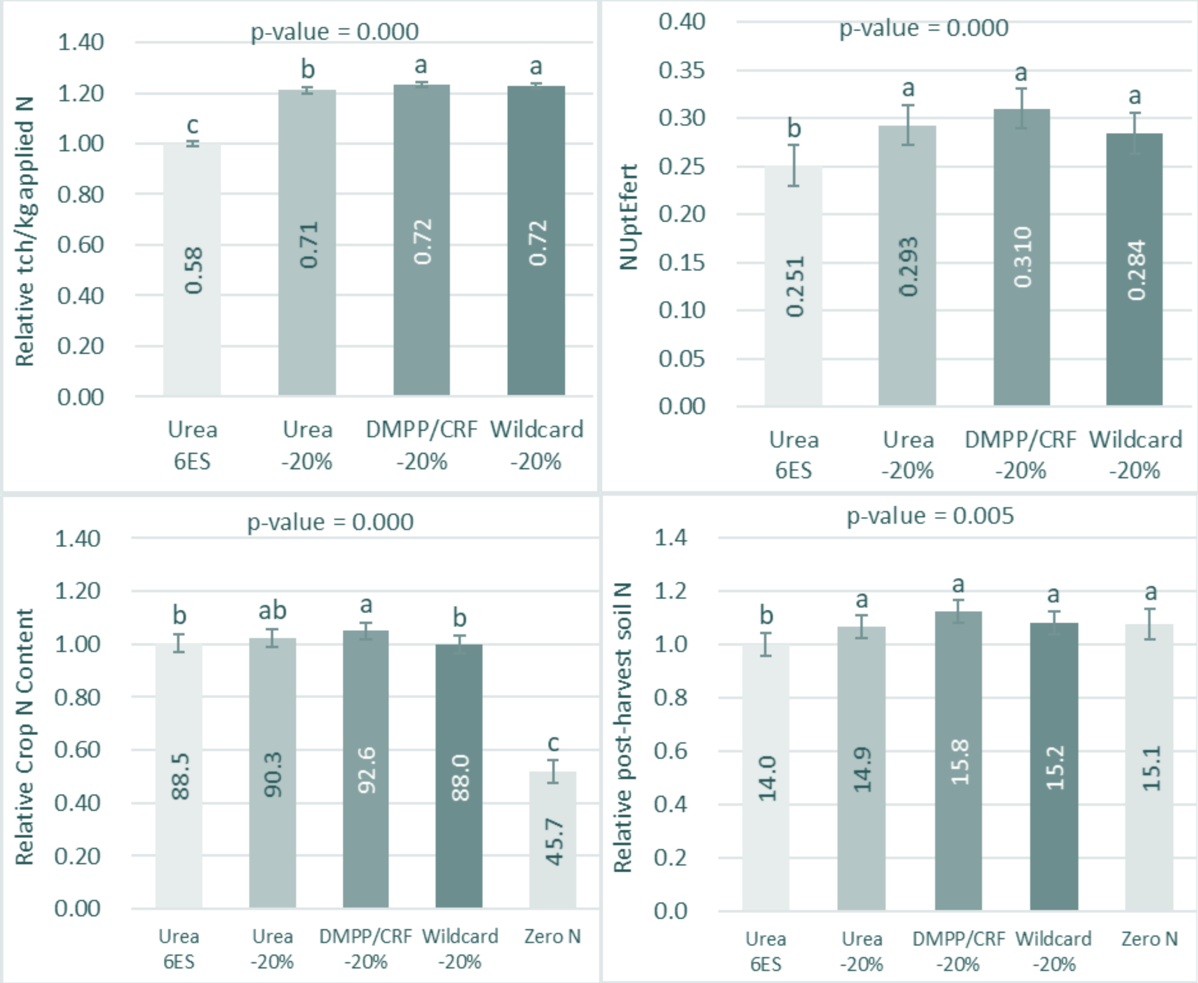

Figure 13: Indices of crop NUE (tc/kg applied N and NUptEfert), Crop N content (kg N/ha) and Post-harvest Soil N (kg N/ha in the top 20cm of the soil profile). Statistical comparisons have been made on a relative basis (y axis), while actual values are shown in ***text on each column.*** *Error bars indicate the average 95% confidence interval.*

Treatment effects within production regions

Crop N data from trial sites in each region was obtained on an annual basis, with data from 24 sites in the Wet Tropics, 18 sites in the Burdekin and 12 sites in the Mackay-Whitsundays regions available from 1 to 3 seasons for this analysis. Data presented in Figure 16 indicates that significant interactions between treatments were obtained (p-value = 0.007) within each region. In the Burdekin and Mackay-Whitsundays regions there were no significant differences in crop N content amongst the fertilised treatments, with all being different to the Zero N treatment. However, in the Wet Tropics, crop N content was significantly lower in the Urea -20% treatment in comparison to the DMPP/CRF -20% treatment (5.3 kg N/ha less), but the lower rate of urea was not significantly different to the Urea 6ES treatment or the Wildcard -20% treatment.

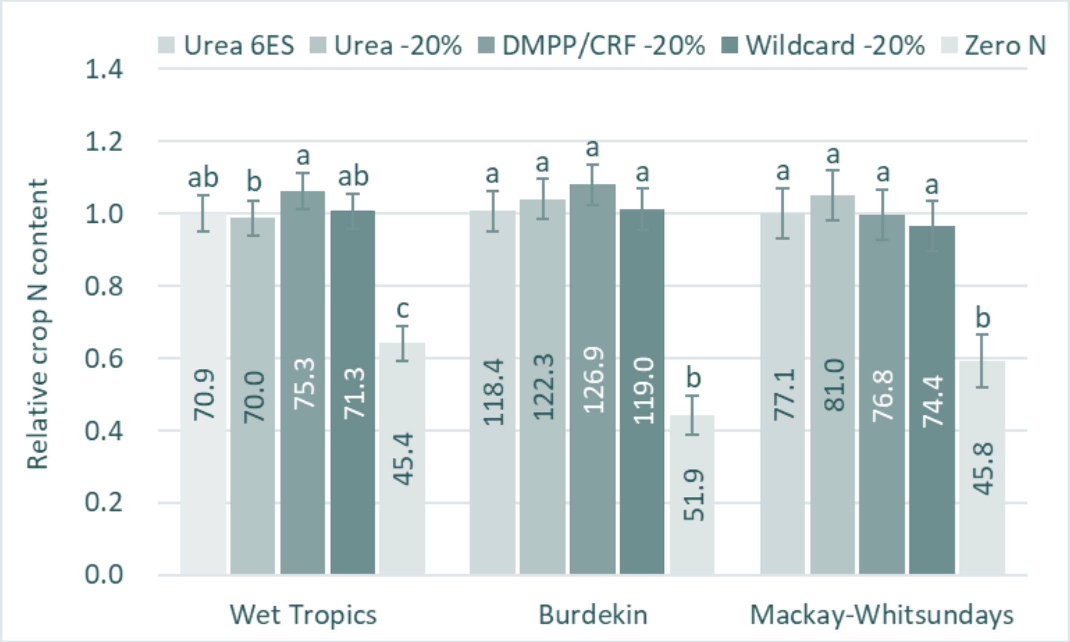

Figure 14: Mean Crop N (kg/ha) content for sites that included Wildcard treatments in each region. Significant letters are only comparable between treatments within each region (not between regions). Statistical comparisons have been made on a relative basis (y axis), while actual values are shown in text on each column. Error bars indicate the average 95% confidence interval.

The consistency of performance of the Wildcard -20% treatments (Figures 10, 13 and 14) supports the potential for broader application of nitrification inhibitors (such as DMPP) and CRF blends (e.g. 20% CRF) to maintain crop N access in ratoons at N rates 20% below 6ES. The next section investigates results of trials where the different EEF products were used in the Wildcard treatments at different sites.

6.2 All sites with a DMPP treatment as Wildcard

6.2.1 *Yield and net return*

This analysis compares how the DMPP and CRF/DMPP treatments (applied at N rates 20% lower than 6ES) performed relative to the two urea treatments (applied at 6ES and 20% below). The number of sites in each region with DMPP as the Wildcard varied, with 15 in theWet Tropics, 6 in the Burdekin and 4 in the Mackay-Whitsundays region. From these sites,35 crops were harvested in the Wet Tropics and 12 crops in each of the Burdekin and Mackay- Whitsundays.

The overarching treatment effect across the 59 harvested crops is shown in Figure 17. Although results show similar trends to the preceding aggregated analysis that included all the Wildcard -20% treatment (Fig. 10), no significant differences were identified between treatments for cane yield and sugar yield in this smaller subset of the trial sites. Differences in CCS were still significant (p= 0.002), with 6ES Urea producing significantly lower CCS than all the other treatments (0.17, 0.11 and 0.14 units lower than recorded in the Urea -20%, DMPP/CRF -20% and DMPP -20% treatments, respectively). Net revenue was also significantly different between the treatments (p= 0.000), with DMPP/CRF -20% delivering significantly lower net revenue than all the other treatments and Urea -20% returning significantly higher net revenue than Urea 6ES. The DMPP -20% treatment produced similar net revenue to both urea treatments.

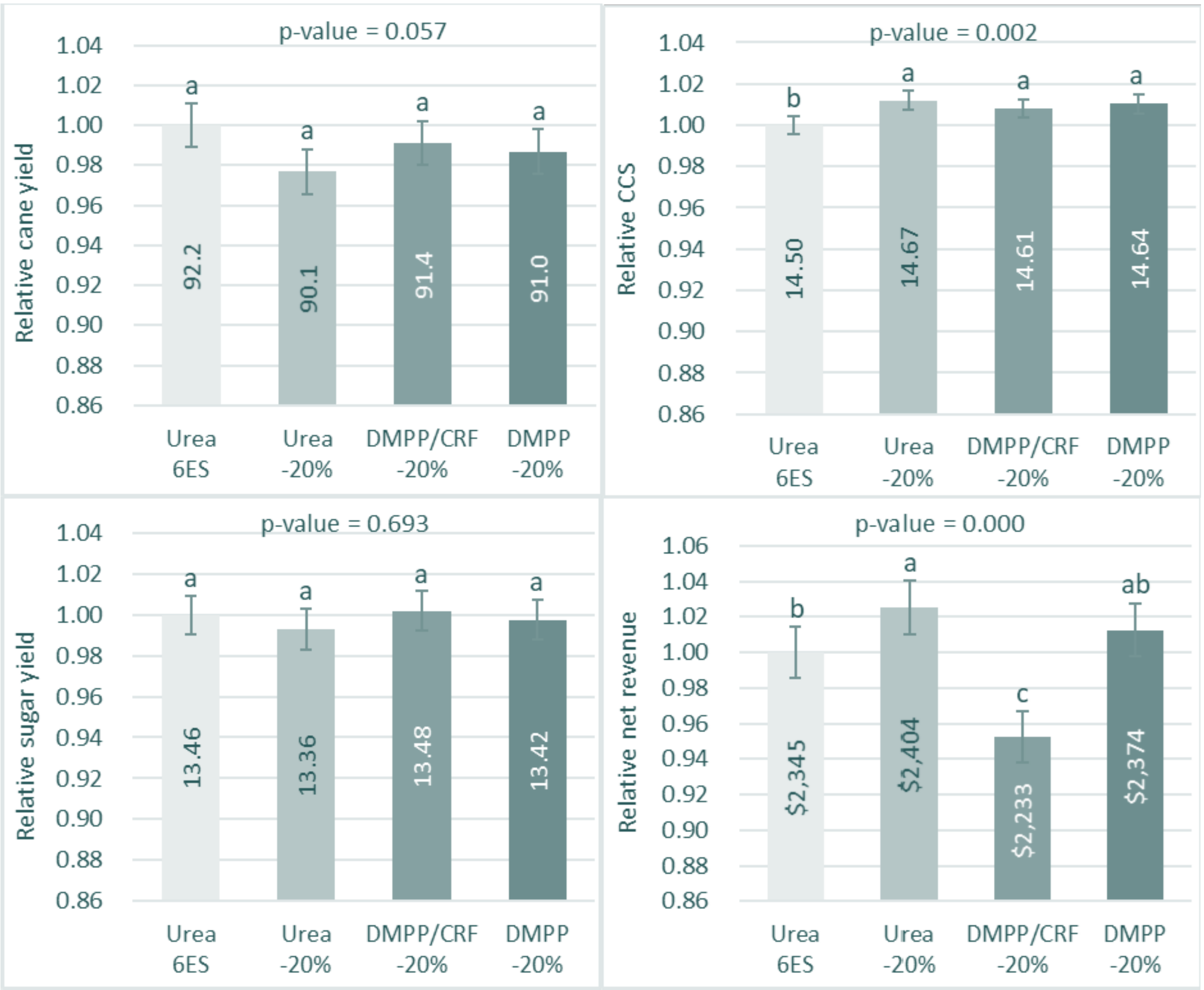

Figure 15: Mean cane yield (tch), CCS, sugar yield (tsh) and net revenue ($/ha) for DMPP sites. Statistical comparisons have been made on a relative basis (y axis), while actual values are shown in text on each column. Error bars indicate the average 95% confidence interval.

Treatment x Rainfall

Rainfall at trial sites in the 3 months following fertiliser application was categorised according to Table 9. Low rainfall was most frequently observed in sites with DMPP -20% as the Wildcard and accounted for 44% of observations, followed by medium (32%) and high rainfall (24%). Results from the statistical analysis indicate that rainfall influenced the performance of each treatment with significant interactions (treatment x rainfall) identified for sugar yield (p= 0.059) and net revenue (p= 0.003). Significance letters are only comparable between treatments for each rainfall combination (not between rainfall conditions).

The Urea -20% treatment (Figure 18) produced significantly lower sugar yield (tsh) than all other treatments under high rainfall conditions but attained similar sugar yield in low rainfall conditions. For net revenue (Figure 19), DMPP/CRF -20% generated significantly lower net revenue than all the other treatments in all rainfall conditions except Urea 6ES in low rainfall ($165/ha and $95/ha lower than Urea 6ES in medium and high rainfall respectively). The DMPP -20% treatment obtained similar net revenue to 6ES urea in all rainfall conditions but performed particularly well in high and low rainfall (not significantly different to the two urea treatments). The lower N urea treatment obtained significantly higher net revenue than Urea 6ES in low rainfall conditions ($122/ha).

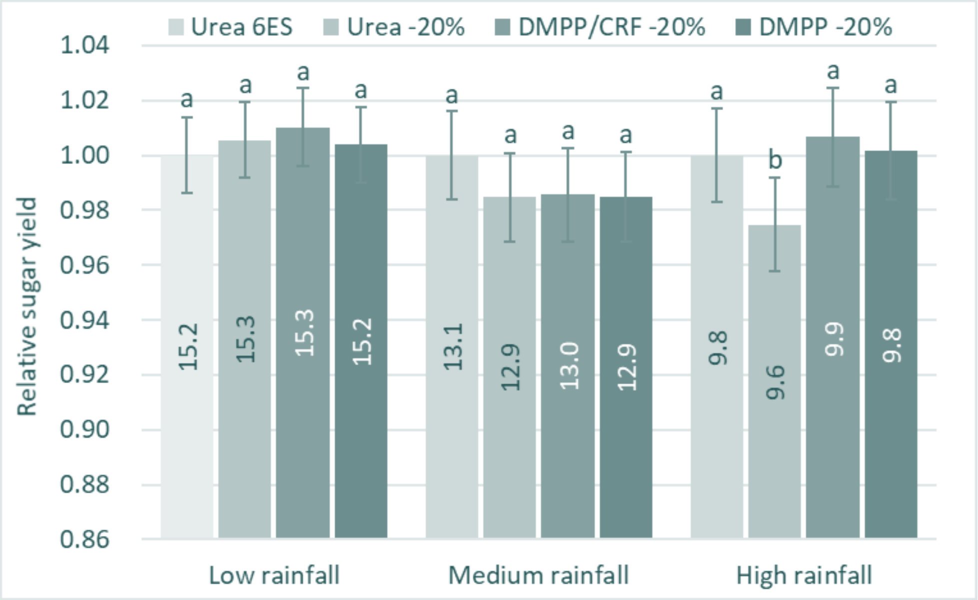

Figure 16: Mean sugar yield (tsh) for DMPP sites in each rainfall category. Statistical comparisons have been made on a relative basis (y axis), while actual values are shown in text on each column. Error bars indicate the average 95% confidence interval.

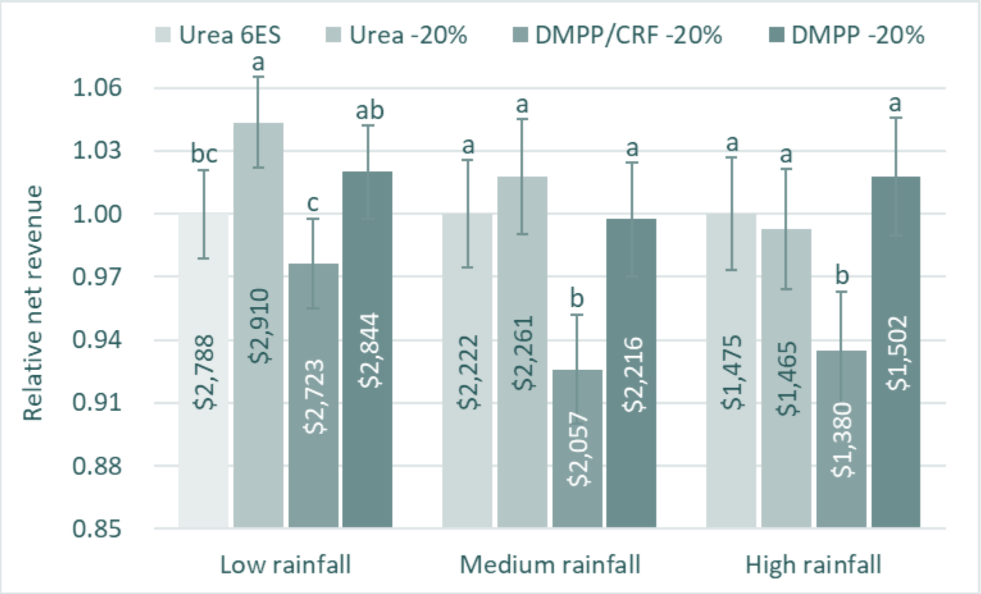

Figure 17: Mean net revenue ($/ha) for DMPP sites in each rainfall category. Statistical comparisons have been made on a relative basis (y axis), while actual values are shown in text on each column. Error bars indicate the average 95% confidence interval.

6.2.2 *NUE indicators and post-harvest soil N -DMPP*

The various analyses undertaken to quantify NUE indicators and post-harvest soil N were available for 25 sites (15 in the Wet Tropics, six in the Burdekin and four in the Mackay-Whitsunday regions) with between 1 to 3 years of data from each site included in this analysis. The results of treatment effects across all trial sites in three regions (Wet Tropics, Burdekin and Mackay-Whitsundays) where DMPP -20% was the chosen Wildcard are presented in Figure 20.

The partial factor productivity of applied N (t cane/kg applied N) was significantly lower in the Urea 6ES treatment in comparison to all other treatments (by 0.129, 0.142 and 0.139 t/kg N applied for the Urea -20%, DMPP/CRF – 20% and DMPP – 20% treatments, respectively). Once again, this was due to the higher rate of N applied without any corresponding productivity increase. The Urea -20% treatment was significantly less productive per kg of applied N than the DMPP/CRF -20% treatment (0.013 t/kg applied N lower) although this difference was small. The Urea -20% treatment was not significantly different to the DMPP -20% treatment.

The index for efficiency of fertiliser N recovery (NUptEfert) showed no significant treatment effects, although similar to the combined product analysis in Fig. 15, the highest mean valuewas found in the DMPP/CRF -20% treatment. Crop N content was also not significantly different between any of the treatments where N was applied, with all fertilised treatments containing more N than the unfertilised (0N) treatment.

Post-harvest soil N (kg/ha) calculated for the top 20cm of the soil profile also showed no significant differences between any of the treatments, with no evidence of additional residual mineral N in any of the fertilised treatments compared to the 0N reference.

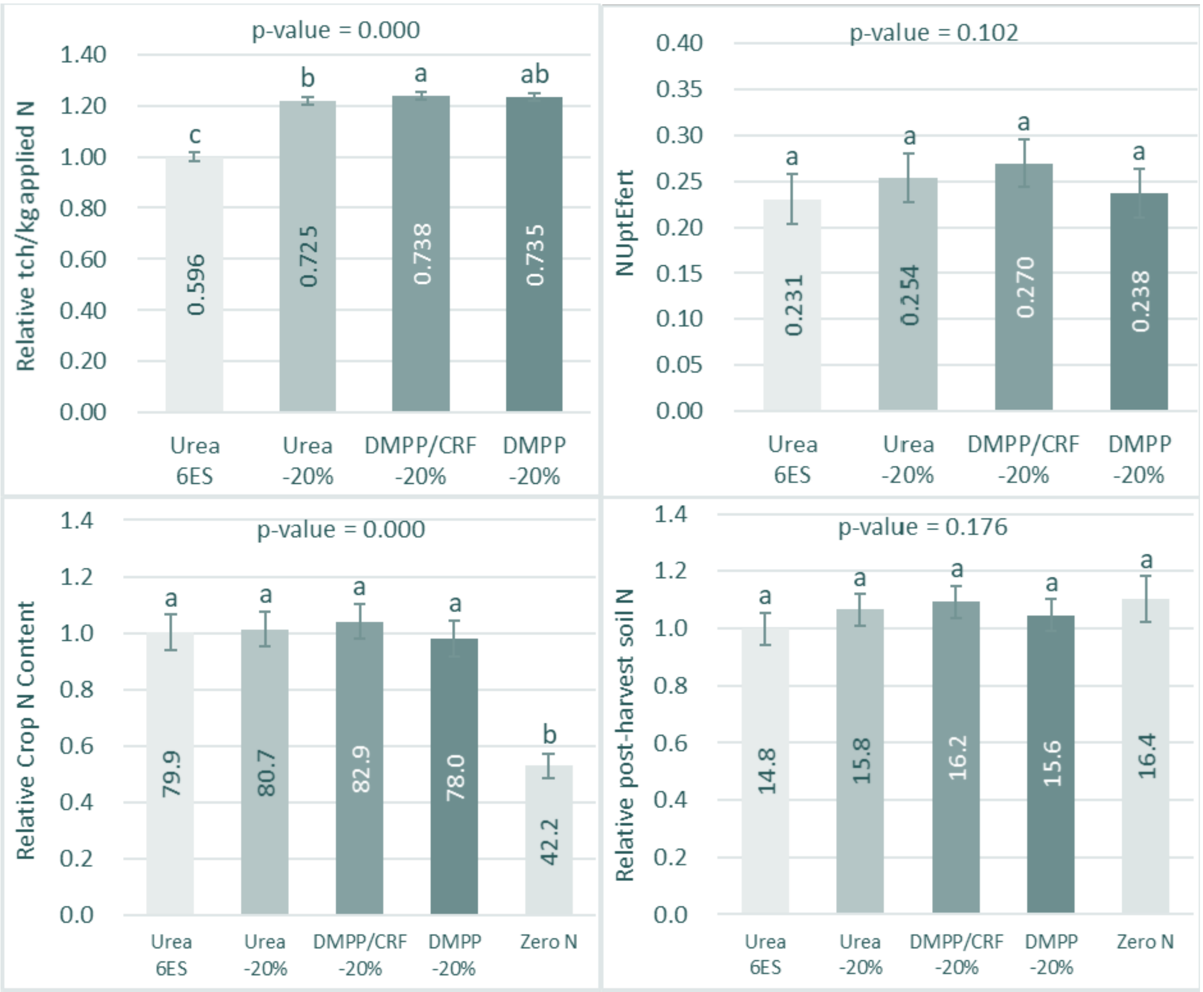

Figure 18: Indices of crop NUE (tc/kg applied N and NUptEfert), Crop N content (kg/ha) and Post-harvest Soil N (kg N/ha in the top 20cm of the soil profile). Statistical comparisons have been made on a relative basis (y axis), while actual values are shown in text on each column. Error bars indicate the average 95% confidence interval.

6.3 All sites with 20% CRF treatment as Wildcard

6.3.1 *Yield and net return*

This analysis compared the performance of the blend of 20% CRF and 80% urea applied at N rates 20% lower than 6ES to that from urea or the CRF/DMPP blend applied at the same rate, or to the Urea 6ES reference. Similar to the analysis for the DMPP wildcard, this analysis was restricted to the subset of sites at which this version of the Wildcard -20% treatment was used, with only eight sites in the Wet Tropics, 10 in the Burdekin and 7 in the Mackay-Whitsundays region. A total of 17 crops were harvested in the Wet Tropics, 21 in the Burdekin and 16 in the Mackay-Whitsundays.

Crop productivity data are presented for the overarching treatment effect across the 54 harvested crops in Figure 21. The urea treatment at the 6ES N rate produced significantly more cane (2.6 tch) than the Urea -20% treatment, while both the DMPP/CRF -20% treatment and the 20% CRF -20% treatment were not significantly different to the

Urea 6ES treatment. Treatment effects on CCS showed similar trends to the combined Wildcard and DMPP analyses (higher CCS in the Urea -20% versus lower CCS in the Urea 6ES and DMPP/CRF -20% treatments), but the smaller number of site-years resulted in no statistically significant differences being identified. Both the Urea -20% and the DMPP/CRF -20% treatments produced significantly less sugar than the Urea 6ES treatment (0.19 tsh and 0.24 tsh, respectively), while sugar yield was not significantly different between the 20% CRF -20% and Urea 6ES treatments. Net revenue was similar between the 20% CRF wildcard and two urea treatments, while DMPP/CRF -20% had significantly lower net revenue (between $156/ha and $180/ha lower).

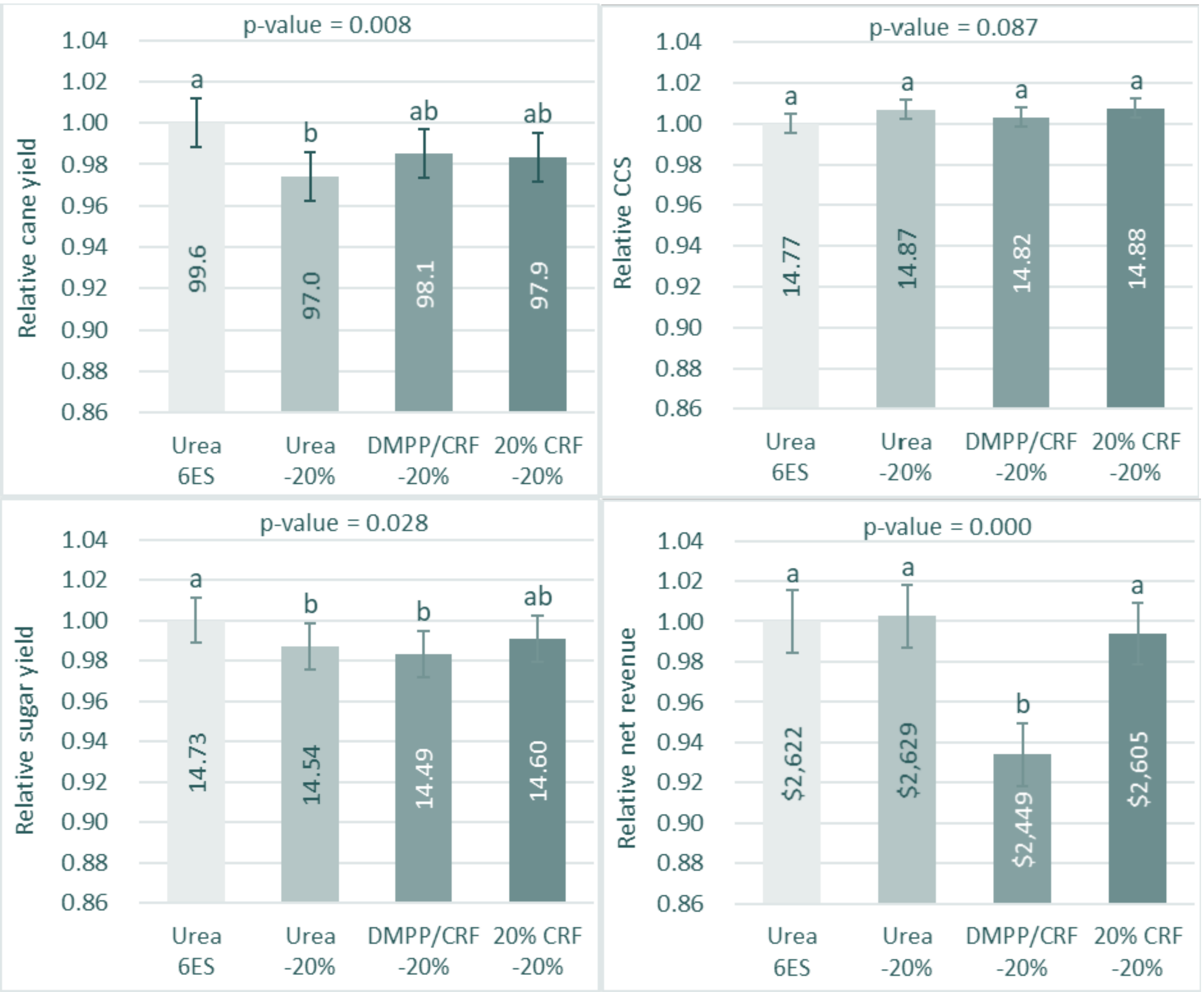

Figure 19:Mean cane yield (tch), CCS, sugar yield (tsh) and net revenue($/ha) for 20% CRF sites. Statistical comparisons have been made on a relative basis (y axis), while actual values are shown in text on each column. Error bars indicate the average 95% confidence interval.

6.3.2 *NUE indicators and post-harvest soil N – 20% CRF*

The various analyses undertaken to quantify NUE indicators and post-harvest soil N were available for 25 sites (eight Wet Tropics, 10 Burdekin and seven Mackay-Whitsunday) with between one and three years of data from each site included in this analysis. The relative treatment effects across all trial sites in the three regions are presented in Fig. 22 for the metrics of partial factor productivity of N (t cane/kg applied N), NUptEfert (kg fertiliser N uptake/kg applied N), crop N content and post-harvest soilN for each treatment.

The amount of cane produced/kg of applied N was significantly lower in the Urea 6EStreatment in comparison to all other treatments (0.13, 0.14 & 0.14 t/kg N applied for the Urea -20%, DMPP/CRF -20% and the 20% CRF -20% treatments, respectively). There was no significant difference between the Urea -20% treatment and either of the EEF treatments.

The NUptEfert for the Urea 6ES treatment was significantly less than all other treatments, again due to the higher rate of N applied in this treatment for no additional crop N uptake. The Urea -20% and both EEF -20% treatments were not significantly different to each other, although the DMPP/CRF -20% treatment had the highest mean of 0.35, meaning that 35% of the applied N in this treatment was captured by the crop.

Crop N content data showed the DMPP/CRF -20% treatment captured significantly more N than the Urea -20% treatment, the 20% CRF -20% treatment and the Zero N treatment (4.7 kg/ha, 4.8 kg/ha and 53.3kg/ha higher, respectively). There was no significant difference in crop N content between the 20% CRF -20%, the Urea -20% and the Urea 6ES treatments.

Post-harvest soil N (kg/ha) calculated for the top 20cm of the soil profile also showed no significant differences between any of the treatments, with no evidence of additional residual mineral N in any of the fertilised treatments compared to the 0N reference.

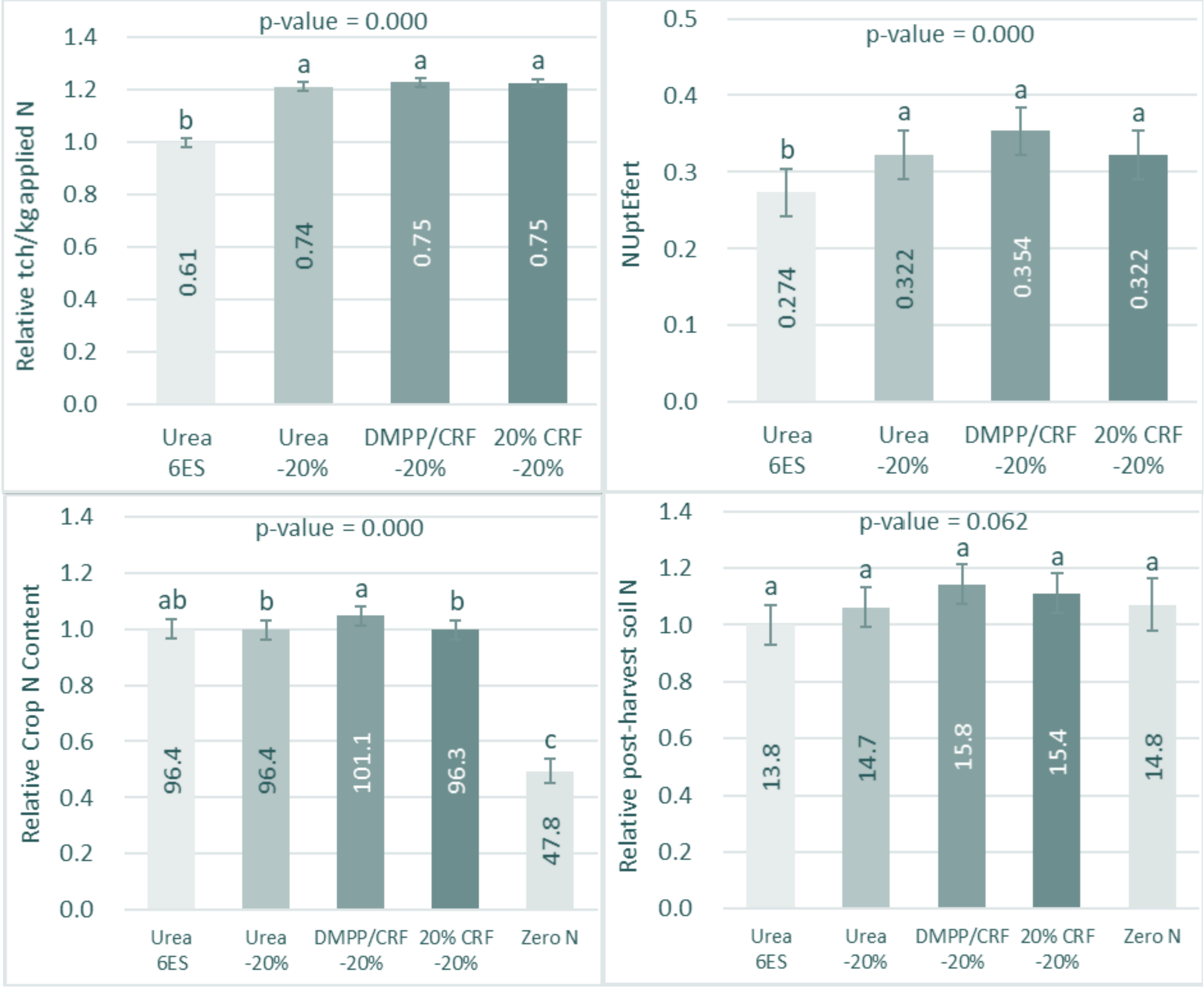

Figure 20: Mean NUE (tc/kg applied N), NUptEfert, Crop N content (kg/ha) and Post-harvest Soil N (kg/ha) for 20% CRF sites. Statistical comparisons have been made on a relative basis (y axis), while actual values are shown in text on each column. Error bars indicate the average 95% confidence interval.

Treatment x Region – Crop N content

Trial sites in each region were sampled on an annual basis to calculate crop N content, with data presented for each region in Figure 23. There was a significant treatment x region interaction (p = 0.011), with no significant differences in crop N content amongst fertilised treatments in the Burdekin and Mackay-Whitsunday regions but a significantly higher crop N content in the DMPP/CRF -20% treatment in the Wet Tropics. There was no significant difference in crop N content between the two urea treatments and the 20% CRF -20% treatment in any region.

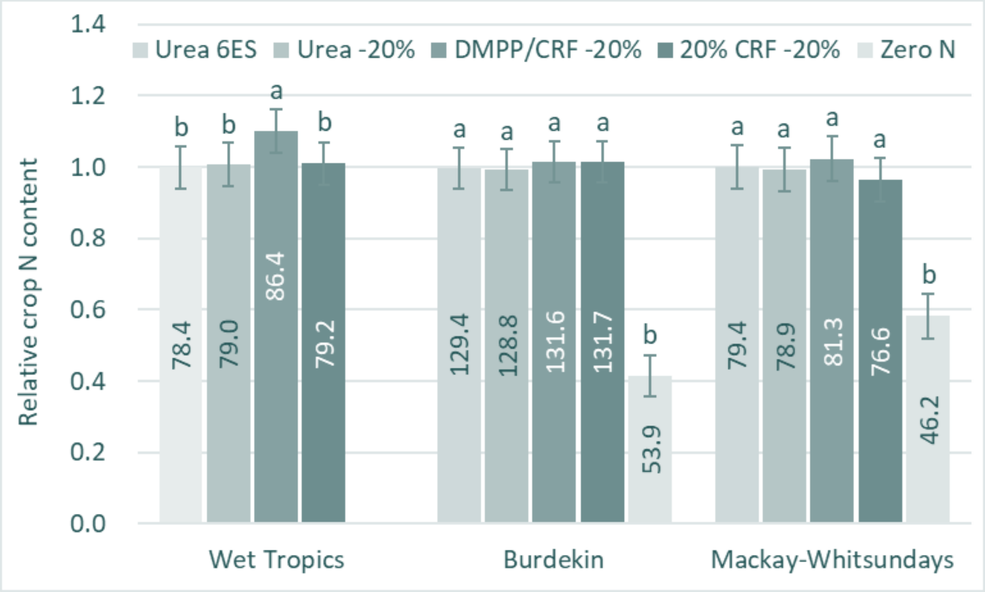

Figure 21: Mean crop N content (kg/ha) for 20% CRF sites in each region. Significant letters are only comparable between treatments within each region (not between regions). Statistical comparisons have been made on a relative basis (y axis), while actual values are shown in text on each column. Error bars indicate the average 95% confidence interval.

6.4 EEFs applied at the 6ES recommended N application rate

6.4.1 *Yield and net return*

This analysis was based on a small subset of sites (two sites in the Wet Tropics each with 1st, 2nd and 3rd ratoon harvests) in which the Wildcard treatment compared the 6ES N rate applied as the DMPP/CRF blend to urea at the same rate (Urea 6ES) and to the two products also applied at the 20% lower rate (i.e. Urea -20% and DMPP/CRF -20%). Due to the low number of trials with this treatment, this analysis can only provide limited insights.

The cane yield, CCS, sugar yield and net revenue averaged across the two sites are shown in Figure 24. No significant differences between treatments were identified in cane yield, CCS, sugar yield or net revenue, with the very limited dataset a key factor in the inability to detect treatment differences. There was no indication that increasing the rate of application of the DMPP/CRF blend to the full 6ES rate provided any trend for higher cane or sugar yields. Given the added cost from applying a higher rate of DMPP/CRF fertiliser and the lack of yield response, the DMPP/CRF blend applied at the full 6ES N attained the lowest mean net revenue.

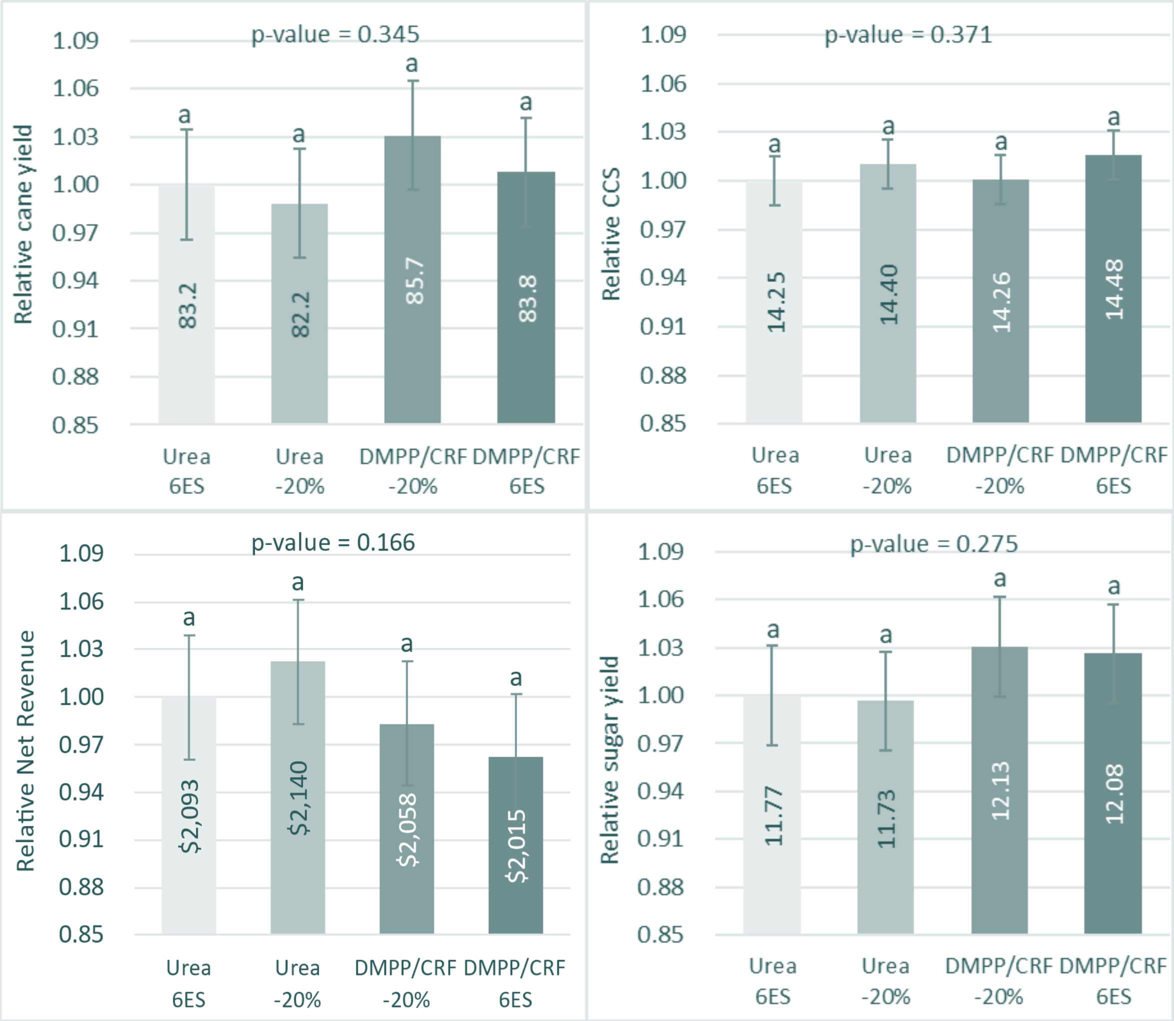

Figure 22: Mean cane yield (tch), CCS, sugar yield (tsh) and net revenue ($/ha) for sites with EEFs applied at 6ES. Statistical comparisons have been made on a relative basis (y axis), while actual values are shown in text on each column. Error bars indicate the average 95% confidence interval.

6.4.2 *NUE indicators and post-harvest soil N – Wildcard at 6ES rate*

A comparison of the various NUE metrics, crop N content and residual mineral N averaged across the two sites in which the Wildcard treatment was DMPP/CRF 6ES are shown in Fig 25. The Partial Factor Productivity of applied N (t cane/kg applied N) was significantly lower in treatments that received the full 6ES N rate, regardless of whether applied as urea or the EEF blend, due to the higher rates and lack of any productivity response. Similarly, there was no difference between the urea and DMPP/CRF blend at the 6ES -20% rate.

Crop N content showed no significant difference between any of the treatments and in this case demonstrates that when applying an EEF at the 6ES recommend rate there was no additional crop N accumulation. However, in this situation there was a significant difference between treatments in the post-harvest soil N in the top 20 cm of the soil profile. Soil N was significantly higher in the DMPP/CRF 6ES treatment in comparison to the two urea treatments (both 10 kg N/ha lower), with the DMPP/CRF -20% intermediate between these extremes. In contrast to analyses on the larger data sets in Figs 20 and 22, however, there was much higher average residual soil N after harvest in these two sites where the Wildcard EEF treatment was applied at the full 6ES rate. Average residual N of 36-46 kg N/ha was recorded at these sites, compared to 13-16 kg N/ha in the rest of the sites where Wildcard treatments were deployed.

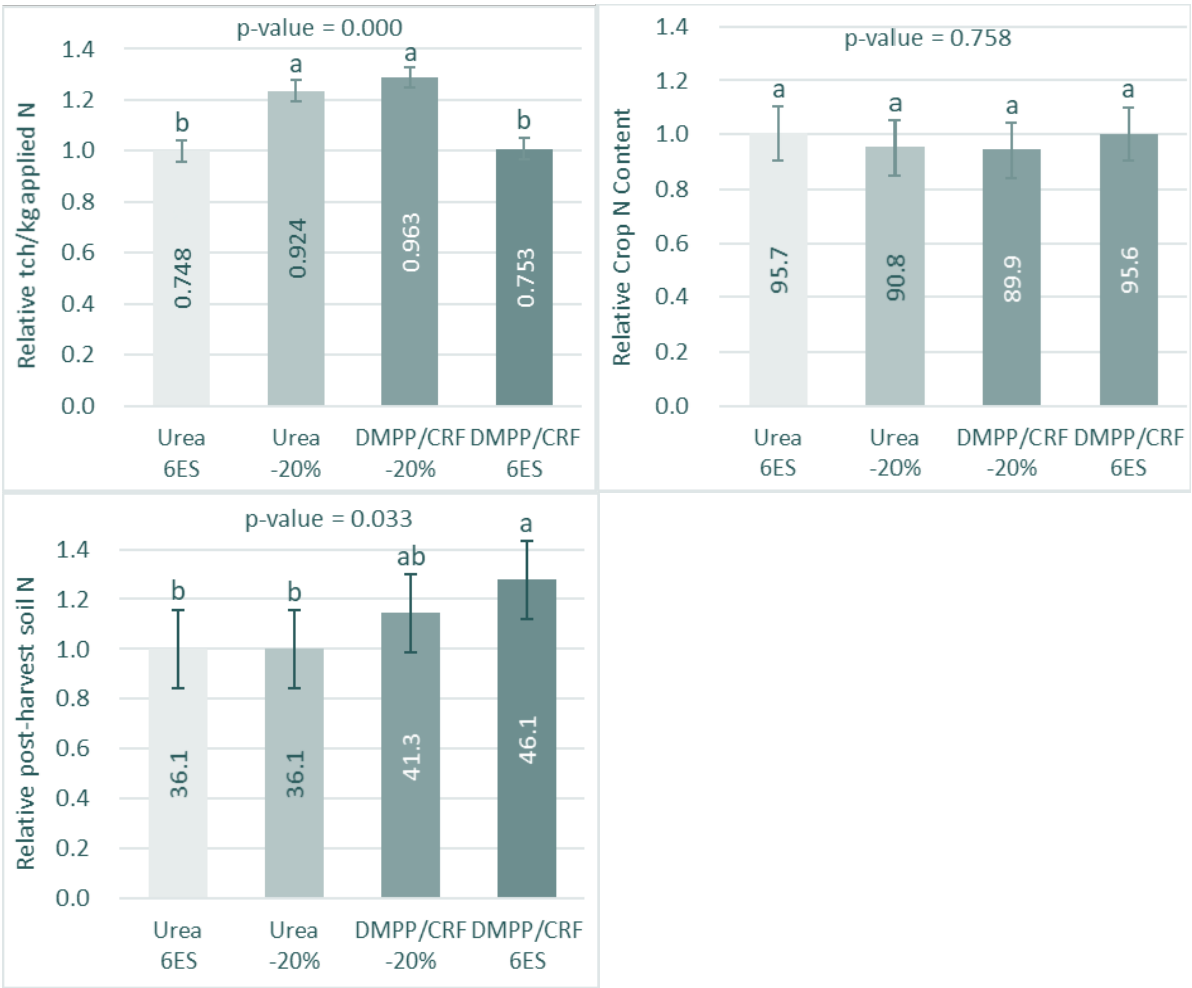

Figure 23: Mean NUE (tc/kg applied N), NUptEfert, Crop N (kg/ha) content and Post-harvest soil N (kg/ha) for sites with EEFs applied at 6ES. Statistical comparisons have been made on a relative basis (y axis), while actual values are shown in text on each column. Error bars indicate the average 95% confidence interval.

Treatment x soil type

The effects of site/soil type on the residual soil N at these two sites are shown in Figure 26, with a significant interaction between soil type and N treatment (p-value = 0.013). The clay loam site was classified as a Pin Gin (Organic carbon 1.6%) and located in the Mulgrave region, whilst the silty clay loam site was classified as a Hewitt (Organic carbon 5.5%) and located in the Tully region. The clay loam site showed significant differences in post-harvest soil N, with the DMPP/CRF 6ES treatment retaining significantly more N in the top 20cm of the soil profile in comparison to Urea 6ES (15.9 kg N/ha less) and the Urea -20% treatments (20.9 kg N/ha less). There were no significant differences in residual soil N between the Urea 6ES and Urea -20% treatments or between the DMPP/CRF blended treatments. In contrast, there were no significant differences between any of the treatments at the silty clay loam site.

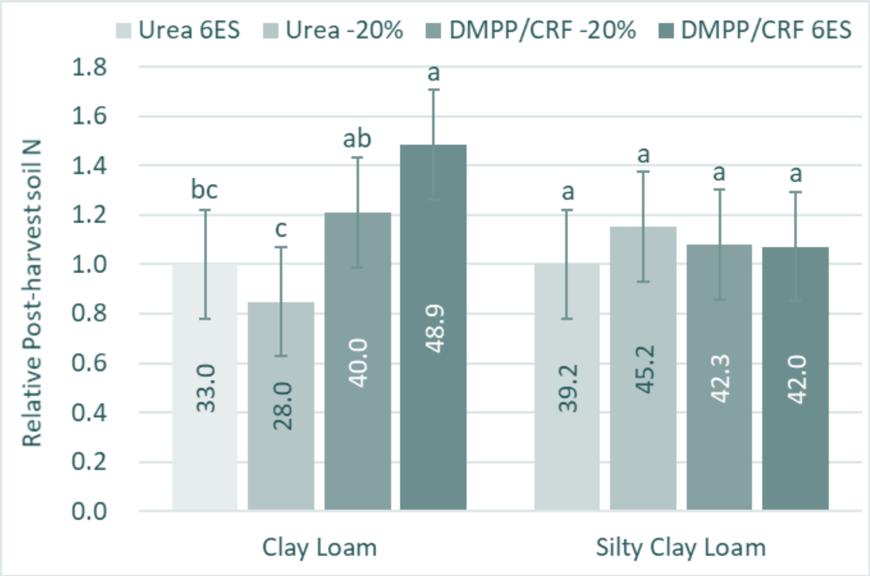

Figure 24: Mean post-harvest soil N (kg/ha) for a site in clay soil and a site in loam soil. Statistical comparisons have been made on a relative basis (y axis), while actual values ae shown in text on each column. Error bars indicate the average 95% confidence interval.

6.5 Water quality

6.5.1 *Leaching – Burdekin and Wet Tropics*

At four sites in the Wet Tropics and two in the Burdekin the movement of dissolved inorganic N (DIN) through the soil profile was monitored by ceramic pore water samplers positioned directly below the crop row at a depth of 1 meter. Soil water samples were extracted under vacuum and were collected on a weekly basis. Twenty-four samplers were positioned across each trial site (2 in each replicate of each treatment), allowing for statistical analysis of data captured. The chosen Wildcard treatment for three of the four Wet Tropics sites was DMPP -20%, whilst 20% CRF -20% was chosen to be the wildcard treatment in the Burdekin. A total of 3960 water samples from both regions were analysed.

Leaching data for the Babinda water quality monitoring site was not included in this analysis due to the chosen Wildcard being surface applied urea at the 6ES recommended rate. This data is presented in Appendix 1 for completeness.

The average DIN concentrations over the three ratoon crops across the monitoring sites are presented in Figure 27. Mean DIN concentrations (mg DIN/L) in leachate extracted below the Urea 6ES treatment were significantly (p-value = 0.000) higher than in the EEF treatments, and more than twice the concentration of the Urea -20% treatment. The concentration of DIN in leachate from the Urea -20% treatment was significantly lower again than that found in the EEF treatments.

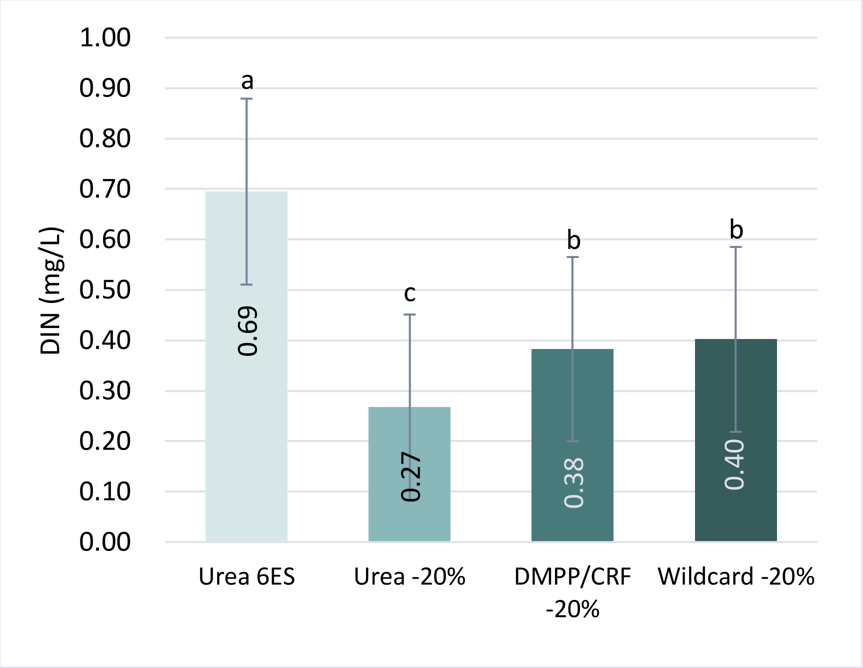

Figure 25: Mean DIN (mg/L) in soil water at 1m below the crop row across all regions and over three ratoons.

6.5.2 *Leaching - Regional data*

There was a significant interaction between the fertiliser N treatments and the seasonal average DIN concentrations in leachate recorded in the Burdekin and Wet Tropics regions (p-value = 0.012, Figure 28).

In the Burdekin, DIN concentrations in soil water from the Urea 6ES treatment were significantly higher than all other treatments, with no differences between the other treatments at 20% lower application rates (i.e. Urea -20%, DMPP/CRF -20% and the Wildcard -20%, which in the Burdekin was the 20% CRF blend). The results from the Wet Tropics sites were consistent with those from the Burdekin in that DIN concentrations in soil water were significantly higher in the Urea 6ES treatment in comparison to all other treatments. However, in these sites DIN concentrations from the Urea -20% treatment were significantly less than that recorded for the two EEF treatments applied at the same rate.

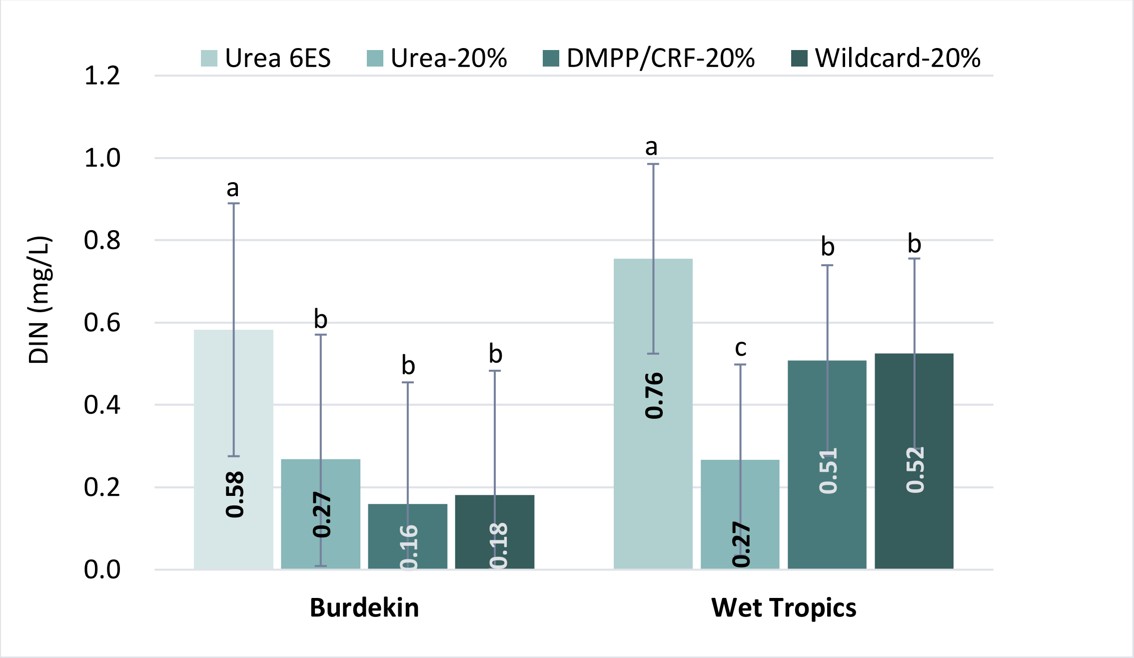

Figure 26: Mean DIN (mg/L) in soil water measured 1m below the crop row in each region over three ratoons.

6.6 Run-off data

At four sites in the Wet Tropics and two sites in the Burdekin the flow of water and the export of DIN (mg/L) from each treatment was monitored over a period of four months (November to March) for three ratoons. The aim of this work was to gain an understanding of the potential run-off losses from the EEF treatments in comparison to the two urea treatments. Data in Figures 29, 30 & 31 show the volume of rainfall and run-off (mm) and the concentration of DIN for the Innisfail water quality monitoring site, with data for all other water monitoring sites presented in Appendix 2. Water samples from run-off events were captured by KP samplers and delivered to storage bottles. Samples were collected from sites as soon as possible, however due to limited access in wet conditions and the remote locations of sites, some samples remained at sites for up to four days following run-off events.

6.6.1 *Innisfail site*

Variety:	Q208	Water source:	Rainfall

Soil Characteristics (0-20cm)

The Innisfail water quality data indicates that there was an initial flush of DIN from the field with run-off events soon after fertiliser application, after which concentrations declined rapidly in subsequent events and in almost all cases remaining below 1 mg/L for the rest of the monitoring period. In each ratoon the highest concentrations of DIN were from the Urea 6ES treatment.

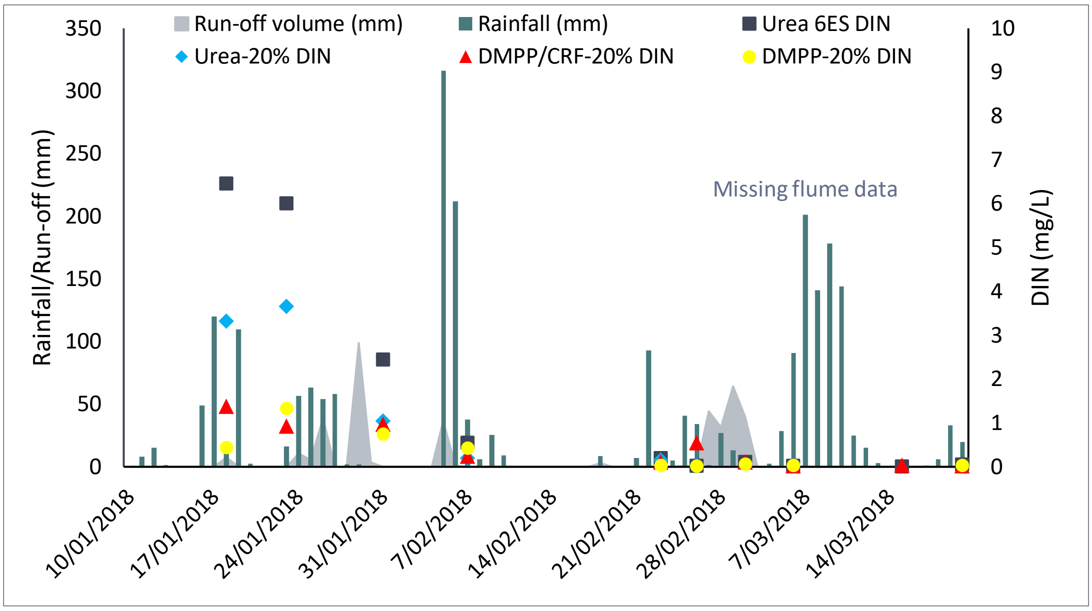

Figure 27: Rainfall (mm) and run-off volumes (mm) with the concentration of DIN (mg/L) for the Innisfail site 2017/18.

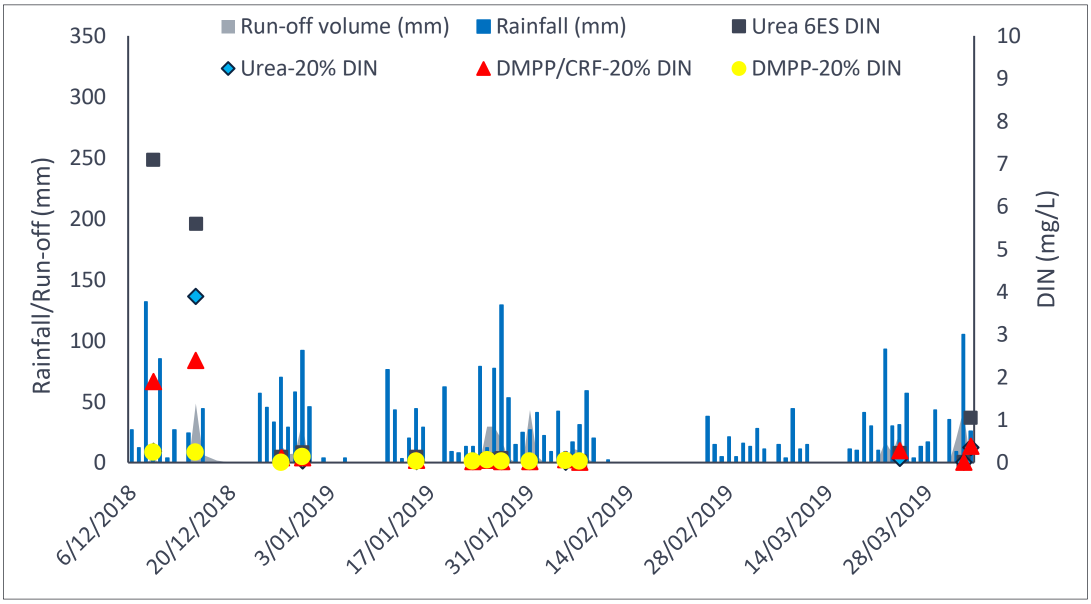

Figure 28: Rainfall (mm) and run-off volumes (mm) with the concentration of DIN (mg/L) for the Innisfail site 2018/19.

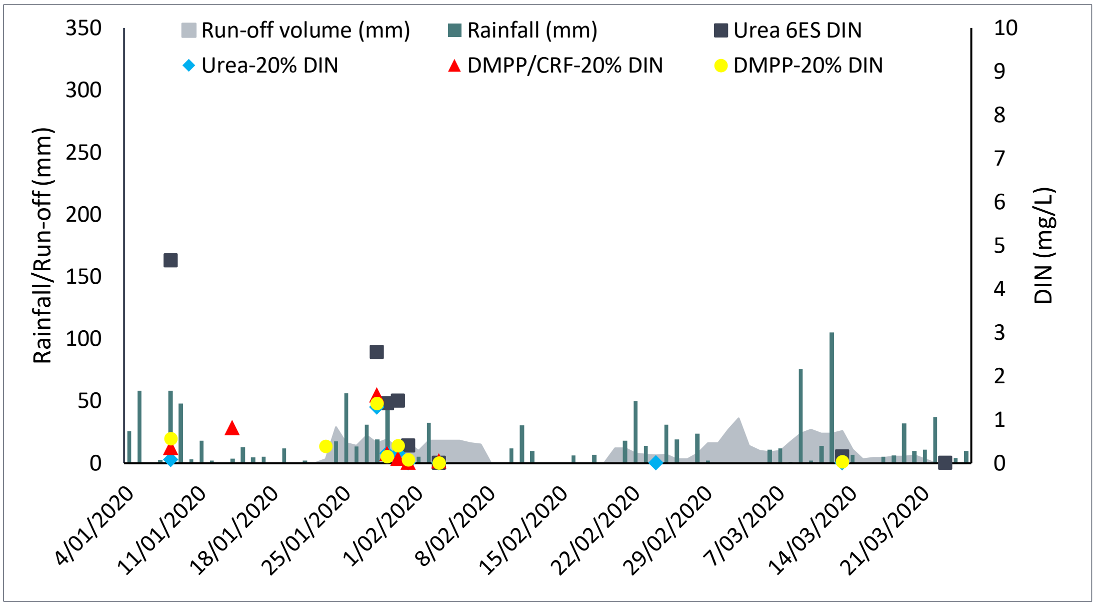

Figure 29:. Rainfall (mm) and run-off volumes (mm) with the concentration of DIN (mg/L) for the Innisfail site 2019/20.

Limitations of run-off data

Water sampling equipment (KP samplers) employed at all water quality monitoring sites were found to be inadequate for collecting representative water samples across the duration of extended flow events, even though runoff volumes were recorded. This means that total DIN loads could not be calculated, so only DIN concentrations and total runoff volumes have been presented in this report. Visual comparison of figures can be made across sites and over time, but no meaningful statistical comparisons could be made using this data.

7 DISCUSSION

The EEFs were tested at N rates below 6ES due to their promoted ability to better match crop N uptake over the growing season, and to minimise the impact of the higher cost of these fertilisers relative to urea. A complementary benefit from improving fertiliser NUE such that reduced fertiliser N application rates are possible without productivity losses will be a reduction in the risk of offsite N losses, particularly as DIN. This will have significant benefits for water quality outcomes. Given the tight margins experienced by sugarcane growers and millers, together with heightened risks experienced by farming businesses (climate, price volatility, disease, etc.), it is vital that improvements in NUE are not perceived to come at the cost of industry profitability. Likewise, management practices are less likely to be widely adopted where there are perceived risks to the longer-term sustainability and resilience of businesses. Consequently, a key emphasis of the project was placed on interpreting results in terms of their collective impact on production, profitability and NUE, rather than individual aspects in isolation. Crop N content (at 9-months), fertiliser uptake efficiency and residual mineral N in the soil post-harvest (soil samples analysed for nitrate and ammonium N and reported as kg N/ha) were also measured at all sites to compare the impact of the different fertiliser treatments.

The combined analysis of data across all 54 trial sites that included a Wildcard -20% treatment indicated that applying urea at N rates 20% below 6ES would result in lower cane yields than with urea at 6ES rates on clay and loamy soils when high cumulative rainfall during the 3-months post fertiliser application was experienced and when fertiliser was applied late in the season. Yield losses of 2.8 and 3.4 t/ha were recorded for clay and loamy soils, respectively. Similar cane yield losses were also recorded in some medium rainfall situations. In contrast, urea with 20% less N delivered higher CCS than urea 6ES in low and medium rainfall conditions (0.18 and 0.14 CCS units higher for low and medium rainfall regions, respectively) but not under high rainfall conditions. Given yield was maintained and CCS was improved in low rainfall conditions, combined with lower fertiliser costs, the urea with 20% less N delivered higher grower profitability (net revenue was $64/ha higher) than 6ES Urea in low rainfall conditions. Compared to Urea 6ES, urea applied at rates 20% lower resulted in 21% greater NUE and 17% higher fertiliser uptake efficiency, while crop N content and post-harvest soil N were maintained.

While grower profitability was similar between the two urea options in medium and high rainfall conditions, widespread adoption of urea with 20% less N would reduce mill revenue given the structure of the cane payment formula (e.g. less tonnes of cane reduces mill revenue while higher CCS adds relatively little revenue). For example, if 20 per cent of the Australian sugarcane harvested area (74,639 ha) had reduced yield of 2.8 to 3.4 t/ha, mill revenue could potentially decrease by $4.3 to $5.2 million per year. While targeting low rainfall conditions to apply urea with 20% less N could be effective at maintaining yield and increasing profitability, the current accuracy of seasonal climate forecasts make this strategy risky for growers.

The DMPP/CRF -20% treatment was chosen to maximise the possible NUE benefits across different soil types and seasonal conditions. The resulting N fertiliser costs were quite expensive, primarily due to the high cost of the CRF component and averaged 50-60% more than Urea 6ES even though 20% less N was applied. Across all 54 trial sites, DMPP/CRF -20% treatment produced similar cane yield to Urea 6ES in most situations (except clay soil with medium rainfall applied late in the season) and higher CCS in low rainfall conditions (0.1 CCS). While not significantly different, DMPP/CRF -20% appeared to yield best in sandy soils that experienced high rainfall conditions after fertiliser application, particularly when fertiliser was applied closer to the onset of the wet season. This finding is consistent with reports from past EEF trials conducted in the Burdekin (Dowie, Thompson and Anderson, 2019). The higher N fertiliser costs therefore ensured that the DMPP/CRF -20% treatment mostly resulted in significantly lower net revenue than Urea 6ES, except for a few situations such as in sand and loamy soils that experienced high rainfall conditions after late season fertiliser application. This also was consistent with previous research (Dowie, Thompson and Anderson, 2019). Compared to Urea 6ES, DMPP/CRF with 20% less N improved NUE by 23% (2% higher than Urea -20%), fertiliser uptake efficiency by 24% and post-harvest soil N by 12%, while crop N content was similar to that from the Urea 6ES treatment in all regions and was 8% higher than the equivalent rate of Urea in the Wet Tropics. The improvements in NUE with the DMPP/CRF blends at 20% lower application rates highlights some potential for innovative products like this to be developed.

The Wildcard treatments employed across the trial network represented existing commercial products or blends that were already available in the marketplace. Growers in the project were given a choice of EEFs to trial for the wildcard treatment, with many deciding to test either urea with DMPP or low proportion blends of CRF (20%) with urea (80%) at N rates 20% below 6ES. Both choices applied at rates supplying 20% less N than Urea 6ES generally had similar N fertiliser costs or were slightly less expensive than Urea 6ES. These Wildcard treatments performed well across all 54 trial sites, producing similar cane yield to Urea 6ES in all soil type, rainfall and fertiliser application time combinations except one (a clay soil with medium rainfall applied late in the season) and higher CCS in low and medium rainfall conditions (0.15 and 0.12 CCS higher, respectively). The Wildcards had similar profitability to Urea 6ES across all soil, rainfall and application time combinations, and like the DMPP/CRF -20% treatment, the Wildcards appeared more profitable in sandy soils with high rainfall after late fertiliser application.

Compared to Urea 6ES, the Wildcards with 20% less N improved NUE by 23% (1% higher than Urea -20%) and fertiliser uptake efficiency by 13%, while they maintained crop N content (in all regions) and improved post-harvest soil N by 8% despite the lower N application rate. Collectively, these results highlight the potential for broader use of EEFs in ratoon cane at N rates that are 20% less than the 6ES standards.

Comparisons between wildcard options were to some extent constrained by the lower numbers of site-years available to each option, and the fact that each option was tested in a different subset of the experimental locations. At sites where DMPP -20% was the chosen Wildcard treatment, crops achieved higher CCS (0.14 units) than Urea 6ES and produced similar cane yields and profitability. Also, DMPP -20% improved NUE by 23% and maintained fertiliser uptake efficiency, crop N content and post-harvest soil N. Similar analyses for sites where the chosen Wildcard was the 20% CRF -20% showed that cane yield, CCS and profitability were similar for Urea 6ES and 20% CRF -20%. Also, 20% CRF -20% improved NUE by 23% and fertiliser uptake efficiency by 18%, while maintaining crop N content and post-harvest soil N.

At two sites in the Wet Tropics, growers chose the DMPP/CRF treatment applied at the 6ES recommended N rate as their Wildcard treatment (although not included in the combined Wildcard -20% analysis). Comparing both N rates for DMPP/CRF (6ES and 6ES-20%) indicated that the additional N applied as EEF did not increase cane or sugar yield. Given no additional revenue and higher fertiliser costs, the DMPP/CRF applied at 6ES N had lower profitability. Compared to Urea 6ES, the DMPP/CRF applied at 6ES N did not improve NUE (28% less efficient than DMPP/CRF -20%) and maintained crop N content indicating that no additional N was captured by the crop (the lower N rate treatments had similar crop N content). Post-harvest soil N was maintained at the silty clay loam site and increased at the clay loam site by 16 kg/ha (48%), highlighting that more N was retained in the top 20cm of the soil profile. The lower rate of DMPP/CRF was not significantly different to the DMPP/CRF 6ES treatment. Data potentially indicates that N from high rates of EEFs may persist longer in the soil profile than the indicative product release rate (3 months).

Water quality monitoring sites were established in the Wet Tropics (4 sites) and in the Burdekin (2 sites) to monitor DIN loss from leaching and run-off events. Analysis of data suggest DIN concentrations in soil water in the Urea 6ES treatment were significantly greater than the two EEF treatments and the lower rate of urea. On a regional basis the findings were similar to this overall outcome, indicating that by utilising an EEF the potential for N loss via leaching can be reduced significantly.

Run-off data was also collected from each of the six water quality monitoring sites over the duration of the project. Data from the Innisfail site was presented in the main body of the report whilst data from all other sites have been presented in Appendix 2. Information from this dataset is limited to comparison of DIN concentrations in specific runoff events, due to an inability to collect weighted runoff samples across the hydrograph, and so calculate realistic DIN loads in runoff. Results from the Innisfail site indicate that peak DIN concentrations in run-off were highest in the Urea 6ES treatment. This was consistent over the 3 years of monitoring at this site. At most sites it was found that DIN concentrations in run-off appeared to peak soon after the first run-off event and quickly (within 4-6 weeks) decline to very low or non-detectable levels.

Workshops are planned to be held in each region to extend results and help growers identify in what situations they have the option of applying EEFs profitably. Recently, there has also been interest in incorporating the EEF recommendations arising from this work into the SIX EASY STEPS toolbox.

8 RECOMMENDATIONS FOR EXTENSION ACTIVITIES AND AREAS OF INVESTIGATION

8.1 Adoption of EEFs

The findings of this report support the adoption of EEFs at N rates 20% less than those recommended by the 6ES method. These products are likely to be particularly beneficial when high rainfall is expected, suggesting that the EEF option could be endorsed as the recommended nutrient management strategy when high rainfall is likely (e.g. in situations where fertiliser is applied closer to the onset of the wet season). Uptake of knowledge generated by this project has the potential to improve sugarcane NUE in all catchments of the Great Barrier Reef. Efficient and effective transfer of information will be crucial for gaining widespread adoption. To achieve this, the development of effective longer term extension strategies will be required, and most importantly on-ground support needs to be provided to growers to implement changes to practices. Providing additional grower incentives (e.g. utilising existing funded programs) to adopt EEFs would also help accelerate uptake.

8.2 Review of current EEF research

To date several organisations working with the sugarcane industry have undertaken research to test EEFs for their agronomic, economic, and environmental benefits. Ideally bringing key information from this work together in one document through a review would provide industry with a valuable resource which could be utilised by growers, industry service providers and government organisations.

During field activities, polymer coatings devoid of any urea were observed on the soil surface approximately 12 months after application. This was also noted by several farmers who were part of the project and had expressed concern that these polymers would eventually make their way to the Reef. The identification and testing of suitable biodegradable coatings which could replace polymer coated urea would provide industry with additional options in the marketplace. Preliminary testing of these products has been undertaken through a partnership between Haifa and CSIRO, and is also underway at the University of Queensland, with promising results. An evaluation of these products across a broad range of production environments across the catchments of the Great Barrier Reef, using testing methodology similar to that employed in this project but at smaller scale, would be ideal to determine their effectiveness.

8.3 Biodegradable EEFs

During field activities, polymer coatings devoid of any urea were observed on the soil surfaceapproximately 12 months after application. This was also noted by several farmers who were part of the project and had expressed concern that these polymers would eventually make their way to the Reef. The identification and testing of suitable biodegradable coatings which could replace polymer coated urea would provide industry with additional options in the marketplace. Preliminary testing of these products has been undertaken through a partnership between Haifa and CSIRO, and is also underway at the University of Queensland, with promising results. An evaluation of these products across a broad range of production environments across the catchments of the Great Barrier Reef, using testing methodology similar to that employed in this project but at smaller scale, would be ideal to determine their effectiveness.

8.4 Improved placement of EEFs

Most sites in this project were fertilised using the stool splitting method to deliver fertiliser in a single subsurface band in the centre of the plant rows. This method concentrates products in a band at a depth of approximately 10 cm below the soil surface. Observations from this work suggest that it may be worth testing other methods of delivery such as side dressing and other approaches designed to distribute EEFs more evenly across the plant bed at the desired depth with adequate slot closure. The objective would be to maximise the effectiveness of EEFs at lower N rates, possibly achieving even greater efficiency gains. It should be noted that most growers who took part in this project did not have press wheels, StoolZippa or chains etc. to cover slots created by fertiliser boxes when applying fertiliser, so productivity responses reported in this project may be conservative.

8.5 Broader assessment of N losses through leaching, run-off and denitrification

Only six sites (four in the Wet Tropics and two in the Burdekin) were established with water quality monitoring equipment to track the movement of N in surface water and its movement through the soil profile as leachate. Unfortunately, the equipment used for capturing water samples from run-off events was not robust enough to provide flow-weighted samples across the hydrograph, and so the quantities of N (kg N/ha) moving off the field could not be determined. Similarly, while the equipment used to monitor leachate moving deeper in the soil profile was robust and reliable, the lack of lysimeters at each site meant that leaching losses could also not be quantified, and treatments were only able to be compared on the basis of differences in concentrations. Finally, fertiliser N losses due to gaseous emissions (volatilisation and/or denitrification) were also not able to be determined in these studies. Given the low crop uptake of fertiliser N observed in all sites, particularly with urea, there may be opportunities to further reduce other N loss pathways.

To better understand N loss benefits from using EEFs, and therefore their potential benefits for the Great Barrier Reef, it is recommended that detailed studies comparing all losses of N from EEFs versus urea should be conducted at selected sites in production areas from Mackay north. These sites should be equipped to quantify N loss as leachate using ceramic pore water samplers in combination with lysimeters, combined with runoff losses (flumes with more effective water quality sampling) and monitoring of total loss using isotopic methods. Differences between measured runoff and leaching losses and total N loss from isotope studies would allow gaseous N losses to be estimated and therefore prioritised for the industry.

8.6 Optimisation of ratoon fertiliser application timing with EEFs

EEF60 trials have demonstrated that there may be additional N in the soil profile following harvest, although the amount of N is not currently known due to testing being limited to the top 20cm of the soil profile. Understanding how much N is available has implications for the timing and rate of fertiliser for the following ratoon crop. Currently there is a limited amount of knowledge regarding the ideal timing of fertiliser application for a ratoon. Establishing EEF trials to better understand post-harvest soil N availability and ideal timing of fertiliser applications for ratoons would provide additional information to further improve NUE when utilising EEFs.

9 Conclusion

There is growing pressure from the community and government for farmers located within the Great Barrier Reef catchments to reduce nutrient losses. EEFs provide an opportunity to improve N fertiliser uptake by sugarcane crops and reduce N losses by better matching N supply with crop demand. Complementary benefits from improving fertiliser uptake efficiency are the resultant improvements in NUE and reduced risk of DIN losses, thus improving water quality outcomes.

The objective of the EEF60 project was to compare the production, profitability and water quality from applying urea at rates defined by the 6ES guidelines with urea and EEFs tested at lower application rates. To test the efficacy of EEFs, 60 replicated strip trials were established in a range of climates and soil types to examine the potential of EEFs to improve the NUE of sugarcane crops. For each trial, an unfertilised Control treatment was generally compared to two urea and two EEF treatments to measure their relative performance. The large number of trials and consistent trial design enabled the identification of what products and N rates work well and the factors that influence their performance (soil, rainfall, time of application, etc.).

The EEF60 project identified that DMPP and low proportion blends of CRF (20%) with urea (80%) applied at N rates 20% below 6ES were successful at maintaining production and profitability compared to Urea 6ES, while increasing NUE by 23%, maintaining crop N content and maintaining or improving fertiliser uptake efficiency and post-harvest soil N. Maintaining production and profit will be crucial to achieving broader uptake of EEFs (applied at lower N rates) by industry and substantial increases in NUE (and improvements in fertiliser uptake efficiency) are likely to reduce the risk of DIN losses and improve water quality outcomes.

Another EEF treatment trialled was a proportional blend of DMPP (1/3) with CRF (2/3) applied at N rates 20% below 6ES. While it produced similar cane yield to Urea 6ES in most situations, and higher CCS in low rainfall conditions, higher fertiliser costs generally made this blend less profitable to apply except for a few situations such as in sand and loamy soils that experience high rainfall conditions after late season fertiliser application. Compared to Urea 6ES, this EEF blend improved NUE by 23%, fertiliser uptake efficiency by 24% and post-harvest soil N by 12% and maintained crop N content.

Two sites also trialled the same 1/3 DMPP 2/3 CRF blend at the higher 6ES recommended N rate. However, it was not found to increase yield relative to the same EEF blend at the 20% lower N rate, which made it less profitable due to the higher fertiliser costs. Also, it did not improve NUE relative to Urea 6ES nor capture any additional N in the crop. In contrast to this, there was significantly more N in the top 20cm of the soil profile post-harvest where EEFs (DMPP/CRF) were applied at the 6ES recommend N application rate.

Urea applied at N rates 20% below 6ES was also trialled. Overall, it was found to maintain similar cane yield to urea 6ES in low rainfall conditions, while improving CCS and delivering higher grower profitability. However, it produced lower cane yields in medium and high rainfall and didn’t obtain higher CCS in high rainfall environments. While it still maintained grower profitability, substantial adoption of urea with 20% less N would reduce mill revenue, making the net impact to industry negative.

Leaching data from three sites in the Wet Tropics (DMPP -20% was the chosen Wildcard) and two sites in the Burdekin (20% CRF -20% was the chosen Wildcard) collected over three seasons showed that DIN concentrations from the Urea 6ES treatment were significantly higher than those recorded in the Wildcard and the Urea -20% treatments. These data indicate that by utilising EEFs at 20% lower application rates, leaching losses could be substantially reduced in comparison to urea applied at the 6ES recommended application rate.

Data presented in this report demonstrates that by utilising EEFs at an N application rate 20% less than recommended by the 6ES method, growers can maintain similar levels of productivity and profitability as applying urea at the 6ES recommended rate. By using this strategy they can improve farm NUE and reduce N losses from leaching events. This project has not identified any impediment to the adoption of 20% lower rates of N applied as EEFs as a standard fertiliser practice in place of urea applied at the 6ES recommended N application rate. Rather, data has suggested that such an approach could be a very effective strategy when high rainfall conditions are expected.

10 Industry deliverables

Following completion of the analysis of the EEF60 dataset an information booklet will developed and delivered to industry.

Regional workshops will also be undertaken to extend the findings of this work. Proposed locations of workshops include:

- Gordonvale
- Innisfail
- Tully
- Ingham
- Burdekin
- Mackay
- Bundaberg

An ASSCT paper titled ‘An evaluation of enhanced efficiency fertilisers in Queensland sugarcane’, summarising findings of this work will be available for download from the ASSCT website in 2022.

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APPENDIX 1

Leaching

Data Location: Babinda

The Babinda water quality site was established on a peat soil with an organic carbon level of 11.1%. Data collected from this site over the 3 years was combined and analysed separately to the other three Wet Tropics sites due to the following reasons:

1. the grower wildcard treatment was surface applied urea at the 6ES recommend rate.
2. Extremely low levels of DIN found in soil water from all treatments, over all years of monitoring.

This analysis aims to provide an understanding of how the EEF (DMPP/CRF) treatmentapplied at N rates 20% less performed in comparison to the three urea treatments (applied at 6ES and 20% less). Figure 33 shows the treatment effects over three years of monitoring at this site.

Figure 32 shows mean DIN levels in the DMPP/CRF -20% treatment were significantly lower than Urea -20% treatment, however not significantly less than the Urea 6ES treatment and the Urea 6ES-surface applied treatment. In general DIN levels are very low in comparison to all other sites monitored as part of this project and may be related to the high organic carbon levels in the soil profile.

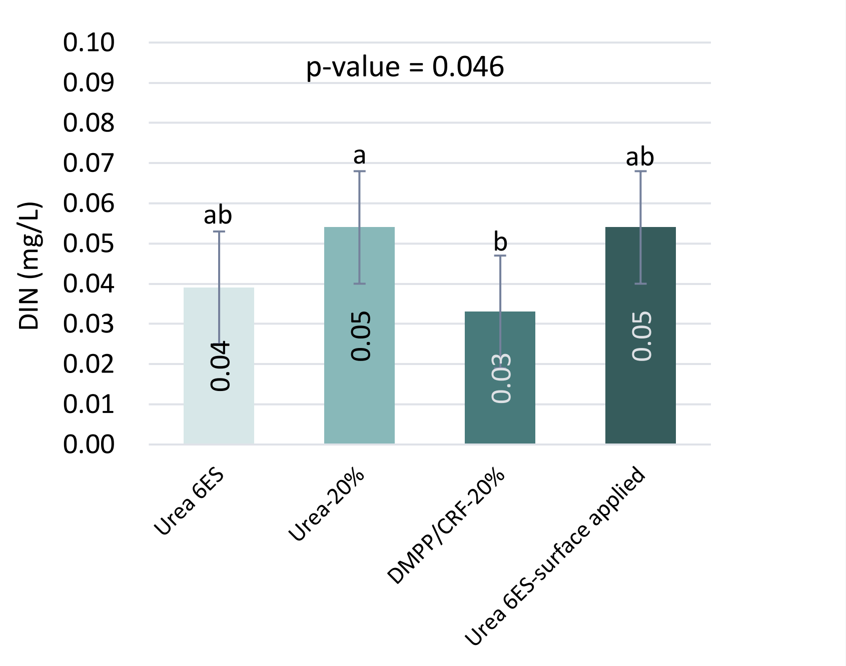

Figure 30: Mean DIN concentrations for soil water over three ratoons.

APPENDIX 2

Wet Tropics run-off data

Location: Mulgrave Site

Site characteristics

Variety:	Q231

Water source:	Rainfall

Soil characteristics (0-20cm)

Soil classification:	Jarra-Inlet
Texture:	Loam
% Organic carbon:	0.8

Ratoon No.	Fertiliser date
1st	16/09/2017
2nd	30/10/2018
3rd	19/11/2019

In October 2017 approximately 1 month following the application of fertiliser a total of 268 mm of rain fell at this site over an 8-day period with a single day maximum of 178mm on 19 October. At this time there was no monitoring equipment in the field to collect water samples. It is likely that a significant run-off event occurred and may explain why DIN levels were low over the duration of the monitoring period (Figure 33).

In October 2017 approximately 1 month following the application of fertiliser a total of 268 mm of rain fell at this site over an 8-day period with a single day maximum of 178mm on the 19 October. At this time there was no monitoring equipment in the field to collect water samples. It is likely that a significant run-off event occurred and may explain why DIN levels were low over the duration of the monitoring period (Figure 33).

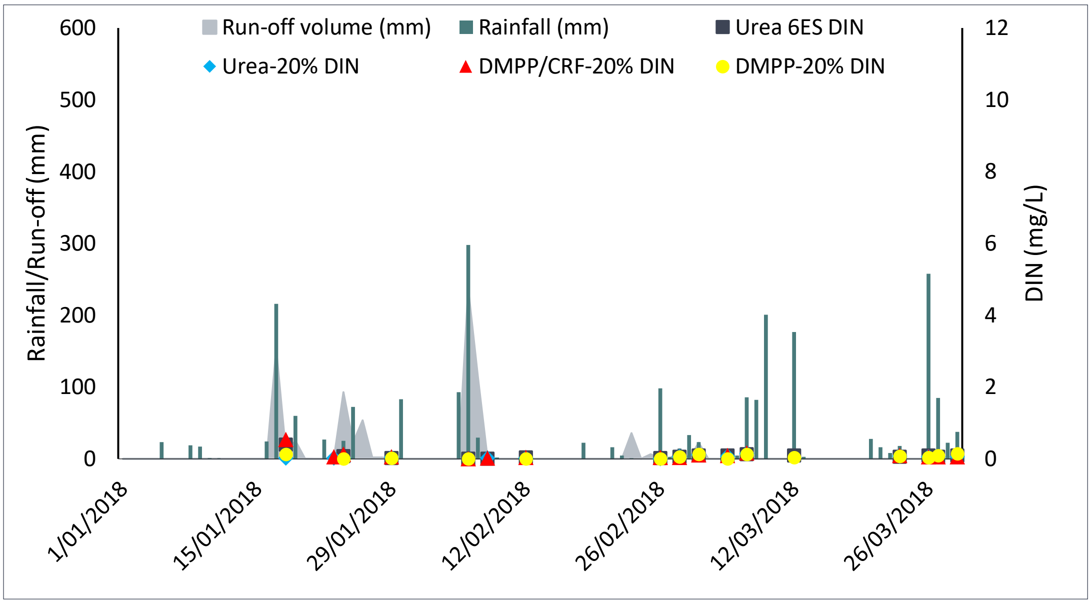

Figure 31: Rainfall (mm) and run-off volumes (mm) with the concentration of DIN (mg/L) for the Mulgrave site 2017/18.

Over the 2018/19 monitoring period (Figure 34), DIN concentration in run-off water appeared to peak in December with the highest concentration from the Urea 6ES treatment followed by Urea -20%. Following the initial peak DIN levels quickly declined to less than 1 mg/L for the remainder of the monitoring period.

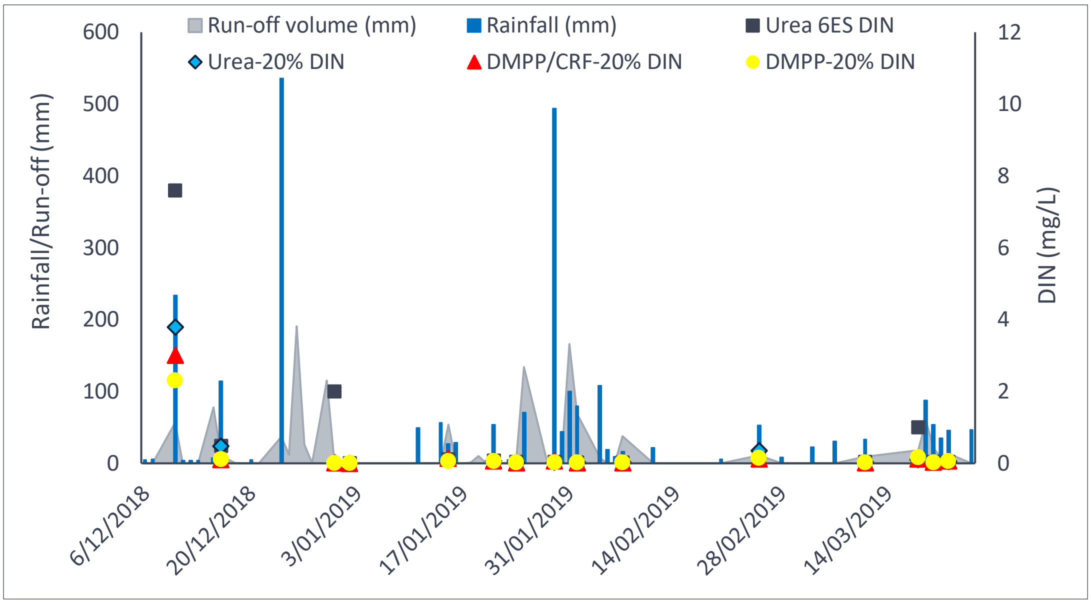

Figure 32: Rainfall (mm) and run-off volumes (mm) with the concentration of DIN (mg/L) for the Mulgrave site 2018/19.

Fertiliser application took place in November 2019 with the first significant rainfall event taking place in late January 2020 as shown in Figure 35. At this time the highest concentration of DIN was from the DMPP/CRF treatment, followed by the Urea 6ES treatment. DIN levels declined rapidly following this event.

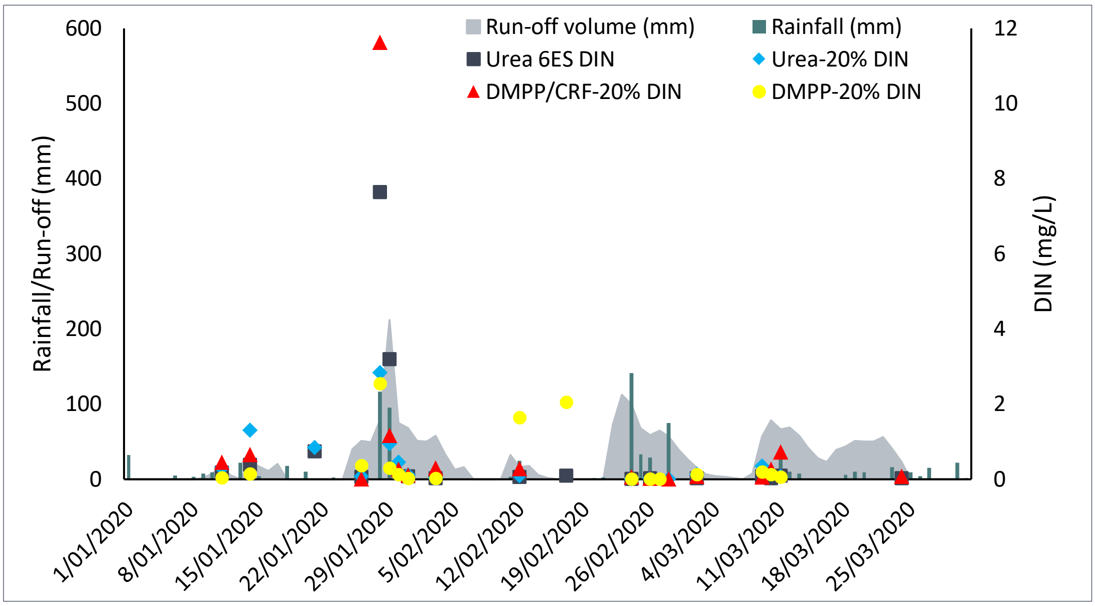

Figure 33: Rainfall (mm) and run-off volumes (mm) with the concentration of DIN (mg/L) for the Mulgrave site 2019/20.

Location: Babinda site

Site characteristics

Variety:	Q200

Water source:	Rainfall

Soil characteristics (0-20cm)

Soil classification:	Babinda
Texture:	Loam (Peat)
% Organic carbon:	11.1

Ratoon No.	Fertiliser date
1	11/10/2017
2	26/09/2018
3	9/10/2019

The Babinda site is unique among the water quality monitoring sites due to its extremely high Organic Carbon content of 11.1% and can be described as a peat soil. At this site the grower's preferred practice is to surface apply fertiliser to the plant bed. The grower's choice for the Wildcard treatment was to surface apply urea at the 6ES recommended N rate.

In the first year of monitoring at this site (Figure 36) a significant rain event (269mm) occurred on 19 October which occurred before any monitoring equipment could be installed. Concentration of DIN were low during the remaining monitoring period. Three run-off events shown in the Figure were not captured due to equipment failure.

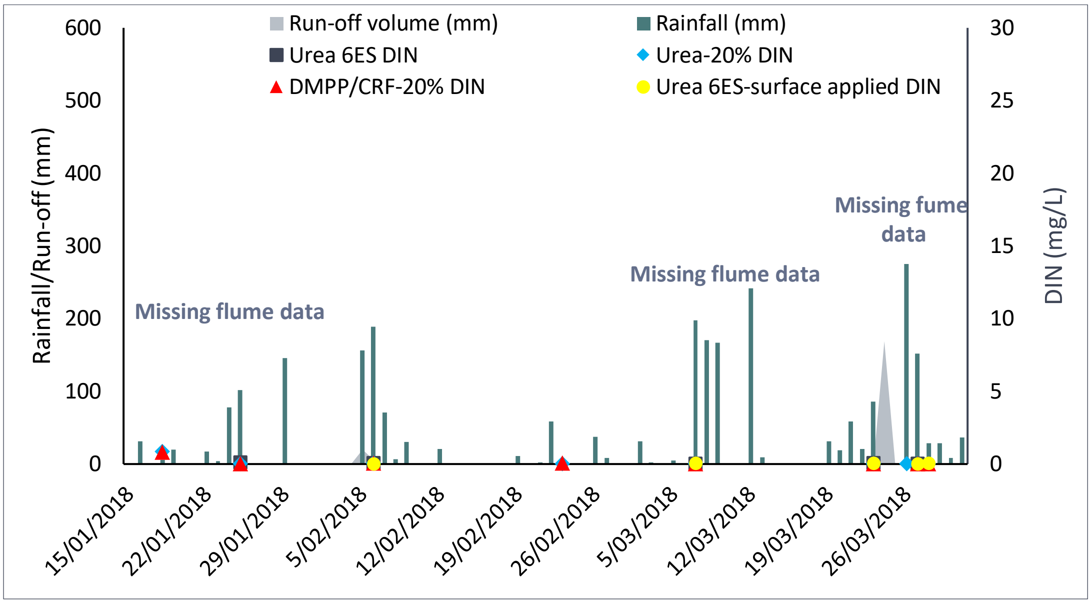

Figure 34: Rainfall (mm) and run-off volumes (mm) with the concentration of DIN (mg/L) for the Babinda site 2017/18.

Figure 37 shows significant rainfall (>100mm) occurring on 11 December 2018 which resulted in a significant run-off event. DIN concentrations during this event were highest from the Urea 6ES-surface applied urea treatment (25 mg/L) followed by the DMPP/CRF - 20% treatment (15.4 mg/L). Following the run-off events in December DIN level declined to below 1 mg/L for the remainder of the monitoring period.

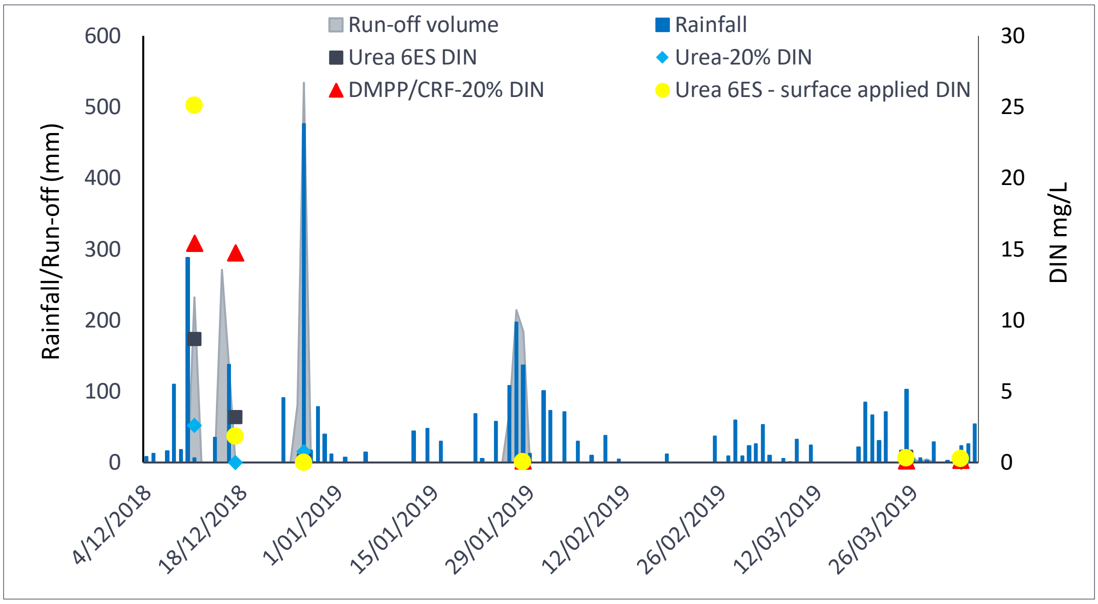

Figure 35: Rainfall (mm) and run-off volumes (mm) with the concentration of DIN (mg/L) for the Babinda site 2018/19.

Over the 2019/20 monitoring period (Figure 38) rainfall was well below average at this site, with few run-off events and in general low levels of DIN detected expect for a single event on 1 March 2020 with 3.7 mg/L of DIN in run-off from the Urea 6ES – surface applied treatment.

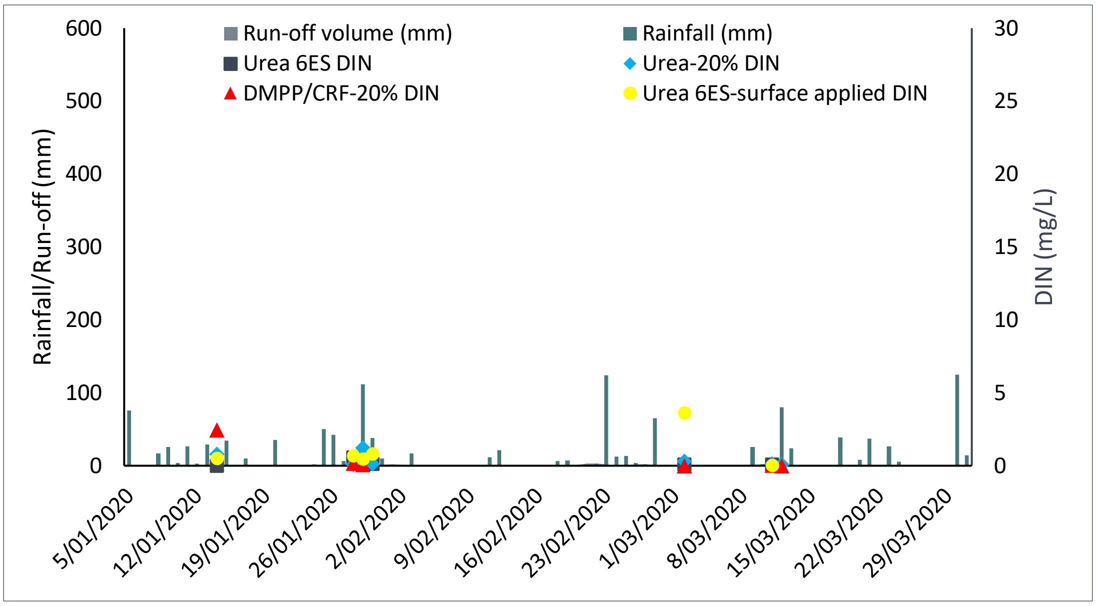

Figure 36: Rainfall (mm) and run-off volumes (mm) with the concentration of DIN (mg/L) for the Babinda site 2019/20.

Location: Tully site

Site characteristics

Variety:	Q250

Water source:	Rainfall

Soil Characteristics (0-20cm)

Soil classification:	Spanos
Texture:	Clay Loam
% Organic carbon:	1.9

Ratoon No.	Fertiliser date
1	25/08/2017
2	11/09/2018
3	12/09/2019

In the first year of monitoring at this site (Figure 39) a significant rainfall (>300mm) occurredbetween 15 and 22 October 2017, approximately two months following the application of fertiliser to this site. This event occurred before any monitoring equipment could be installed at the site and may explain why DIN levels were low during the monitoring period.

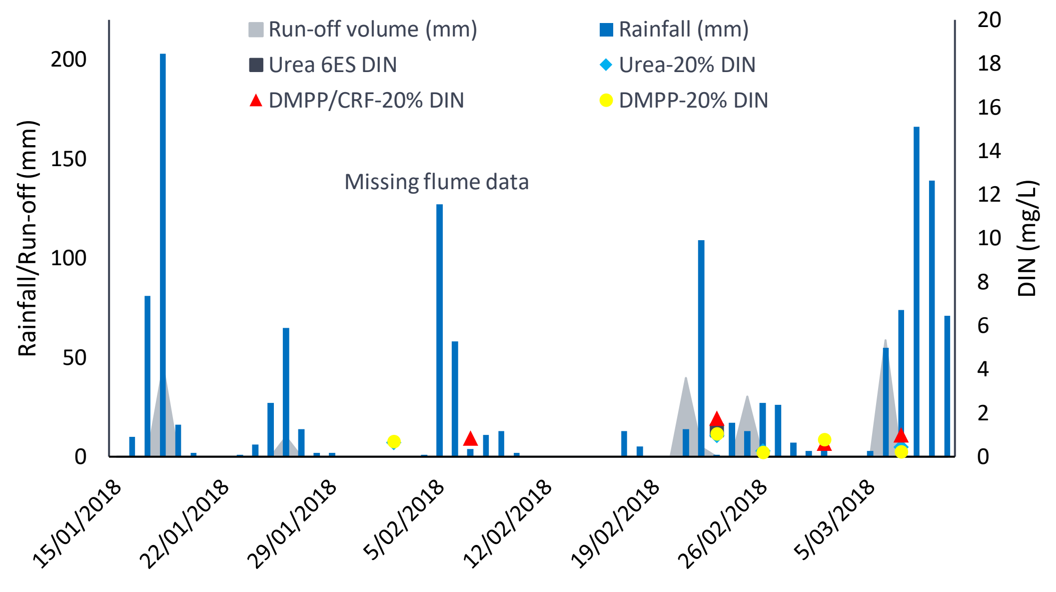

Figure 37: Rainfall (mm) and run-off volumes (mm) with the concentration of DIN (mg/L) for the Tully site 2017/18.

Figure 40 shows significant rainfall (>150mm) occurring in mid-December 2018 along with a run-off event. DIN concentrations from this event were highest in the Urea 6ES treatment (15.8 mg/L) followed by the Urea -20% treatment (6.3 mg/L). Following this run-off event DIN levels declined rapidly to below 1 mg/L by late January and remained low for the remainder of the monitoring period.

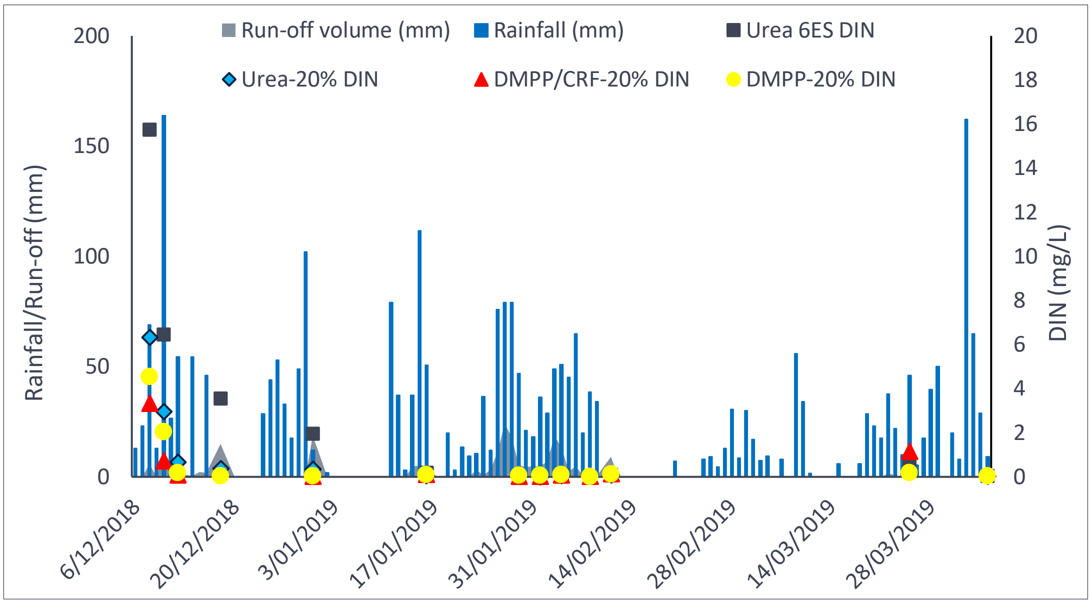

Figure 38: Rainfall (mm) and run-off volumes (mm) with the concentration of DIN (mg/L) for the Tully site 2018/19.

From September 2019 until the end of February 2020 rainfall was below long-term monthly averages for the Tully region. Run-off events began to occur in late January with a peak in DIN concentration in run-off soon after the first event (Figure 41). DIN levels were found to be highest from the DMPP -20% treatment (12.4 mg/L) followed by the DMPP/CRF -20% treatment (12.2 mg/L). Levels of DIN from all treatments steadily declined over the remaining two-month period of monitoring.

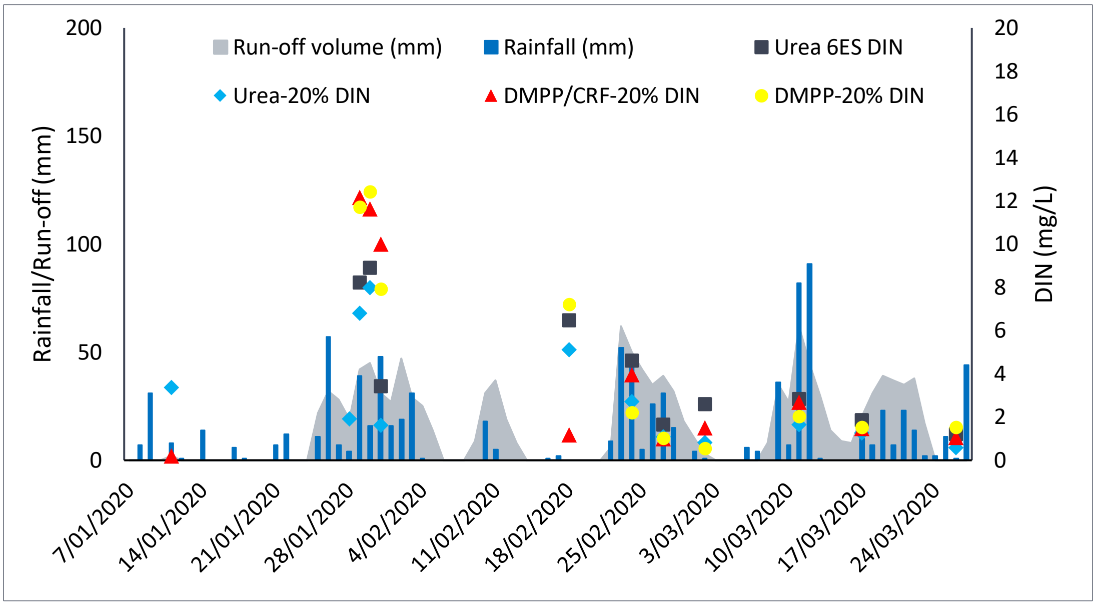

Figure 39: Rainfall (mm) and run-off volumes (mm) with the concentration of DIN (mg/L) for the Tully site 2019/20.

Burdekin run-off data

Location: Delta

Site characteristics

Variety:	KQ228

Water source:	Irrigation

Soil characteristics (0-20cm)

Soil classification:	Vertosol
Texture:	Silty Clay Loam
% Organic carbon:	1.1

Ratoon No.	Fertiliser date
1	13/9/2017
2	29/8/2018
3	2/10/2019

The Delta site in the Burdekin was fully irrigated. Irrigation volumes were not assessed over all seasons and have been assumed to supply 50mm of irrigation with each application. Irrigation water was sampled at the fluming on a random basis during the monitoringperiod. Mean levels of DIN for irrigation water for each crop stage are presented in Table 11.

Table 11: Mean and standard error of DIN in irrigation water

YEAR	CROP STAGE	DIN (MG/L)
2017/18	1st Ratoon	0.25 (±0.17)
2018/19	2nd Ratoon	0.03(±0.02)
2019/20	3rd Ratoon	0.26(±0.23)

Figure 42 shows DIN levels remained low throughout the season with the highest concentration found in the 20% CRF treatment at the beginning of the monitoring period at this site (1 mg/L), although levels were not high.

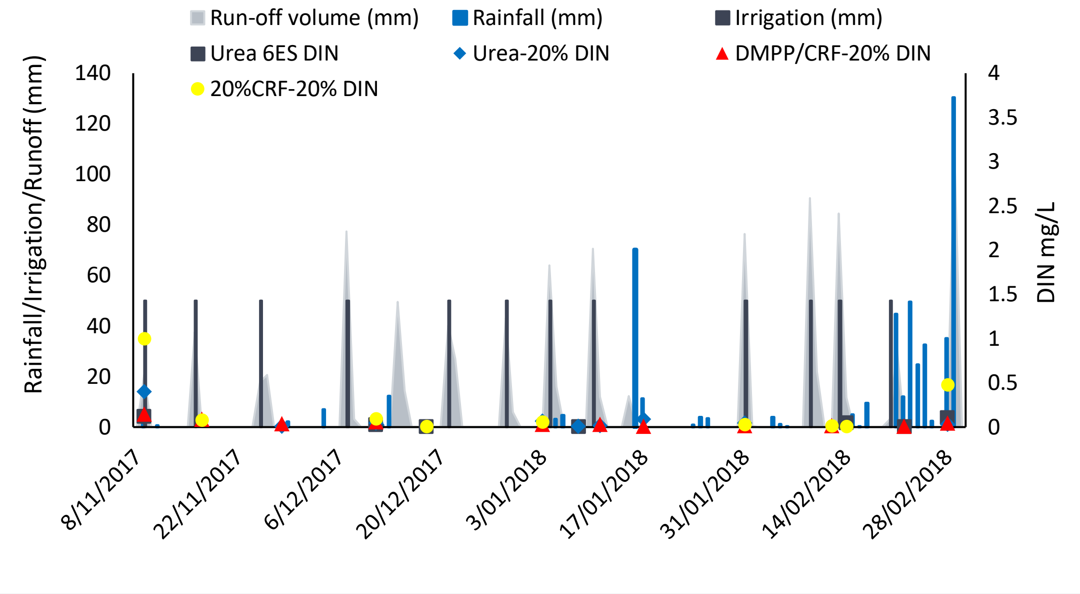

Figure 40: Rainfall (mm) and run-off volumes (mm) with the concentration of DIN (mg/L) for Burdekin Site No.1 2017/18.

During the second ratoon DIN levels remained low (Figure 43) for all treatments until a run- off event on 16 December 2018. The highest concentration of DIN was found in the Urea 6ES (3.15 mg/L) treatment followed by the 20% CRF -20% (3.1 mg/L) treatment.

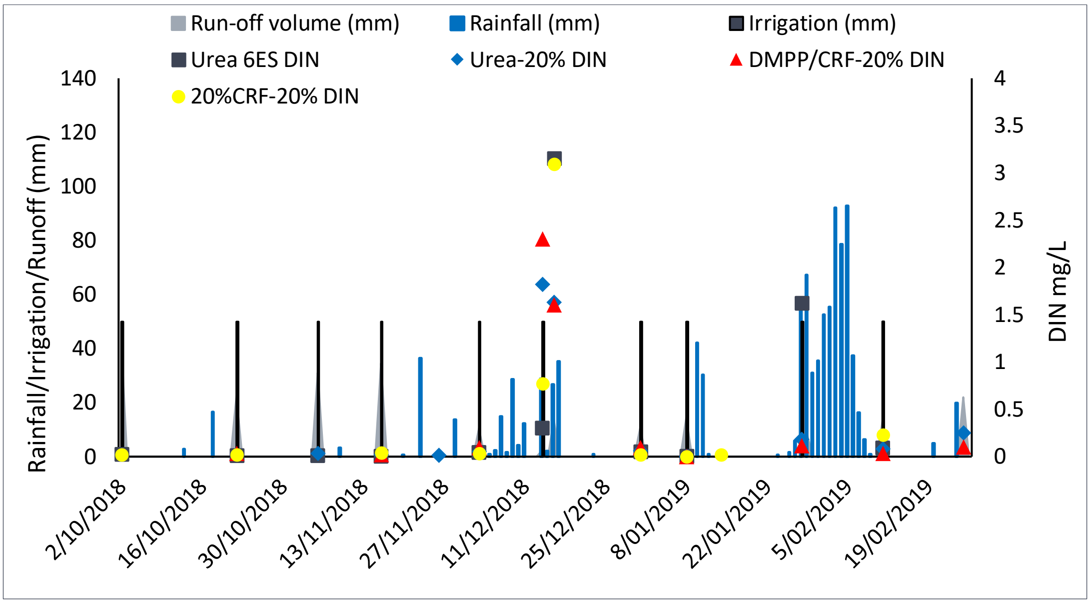

Figure 41: Rainfall (mm) and run-off volumes (mm) with the concentration of DIN (mg/L) for Burdekin Site No. 1 2018/19.

Over the 3rd ratoon DIN levels were low throughout the monitoring period (Figure 44).

On 28 January, 426mm of rain fell which resulted in flooding of the site and across the Burdekin region.

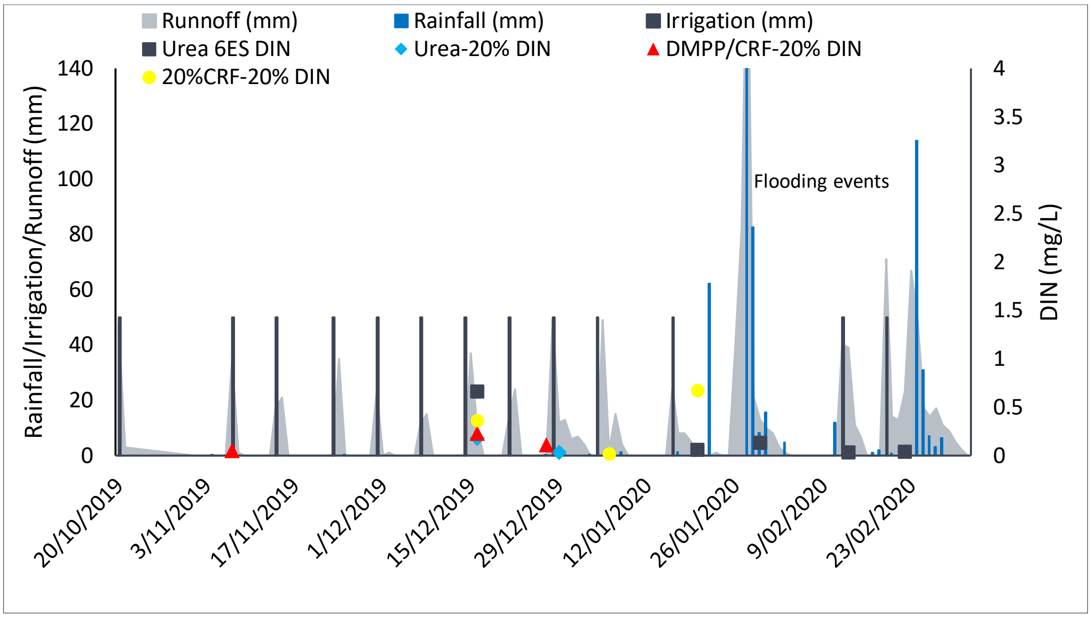

Figure 42: Rainfall (mm) and run-off volumes (mm) with the concentration of DIN (mg/L) for Burdekin Site No. 1 2019/20.

Location: BRIA

Site characteristics

Variety:	Q208

Water source:	Irrigation

Soil characteristics (0-20cm)

Soil classification:	Vertosol
Texture:	Clay Loam
% Organic carbon:	0.7

Ratoon No.	Fertiliser date
1	3/10/2017
2	14/8/2018
3	31/10/2019

The BRIA water quality monitoring site in the Burdekin was fully irrigated. Irrigation volumeswere not assessed over all seasons and have been assumed to apply 50mm of irrigation witheach application. Irrigation water was sampled at the fluming on a random basis during the monitoring period. Mean levels of DIN measured for each crop stage are presented in Table 12.

Table 12: Mean and standard error of DIN in irrigation water

YEAR	CROP STAGE	DIN (MG/L)
2017/18	1st Ratoon	0.21 (±0.16)
2018/19	2nd Ratoon	0.28(±0.15)
2019/20	3rd Ratoon	0.03(±0.01)

Figure 45 shows DIN levels peaked in the Urea 6ES treatment on 22 February 2018, with a concentration of 3.2 mg/L following a number of rainfall events. Missing data is also highlighted in the figure and was due to equipment malfunction.

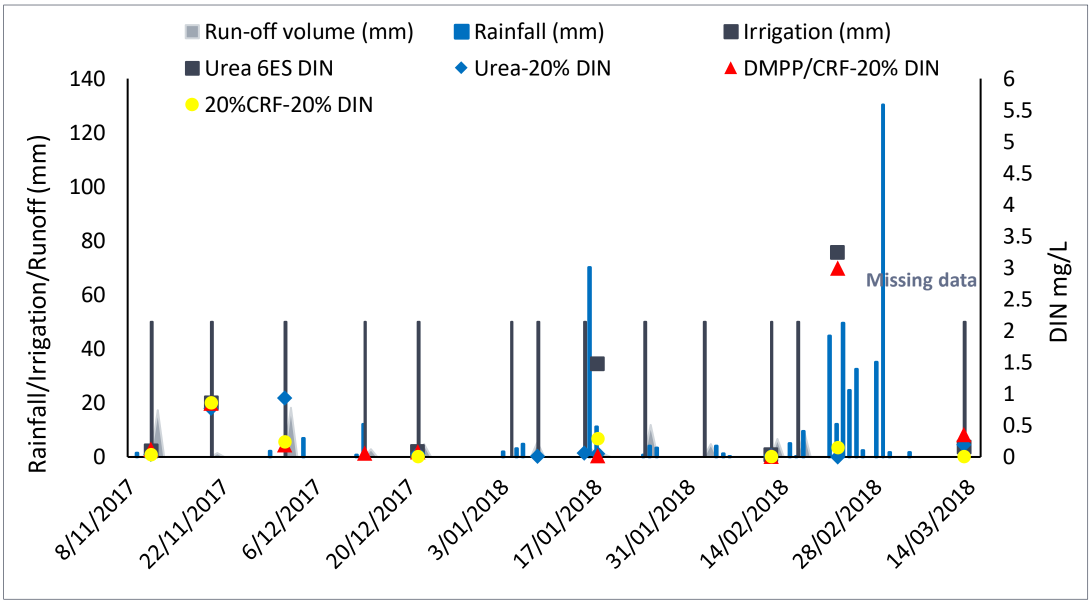

Figure 43: Rainfall (mm) and run-off volumes (mm) with the concentration of DIN (mg/L) for Burdekin Site No. 2 2017/18.

Over the second ratoon (Figure 46) DIN levels were highest from the Urea 6ES treatment(5.0 mg/L) followed by the 20% CRF -20% treatment (4.8 mg/L).

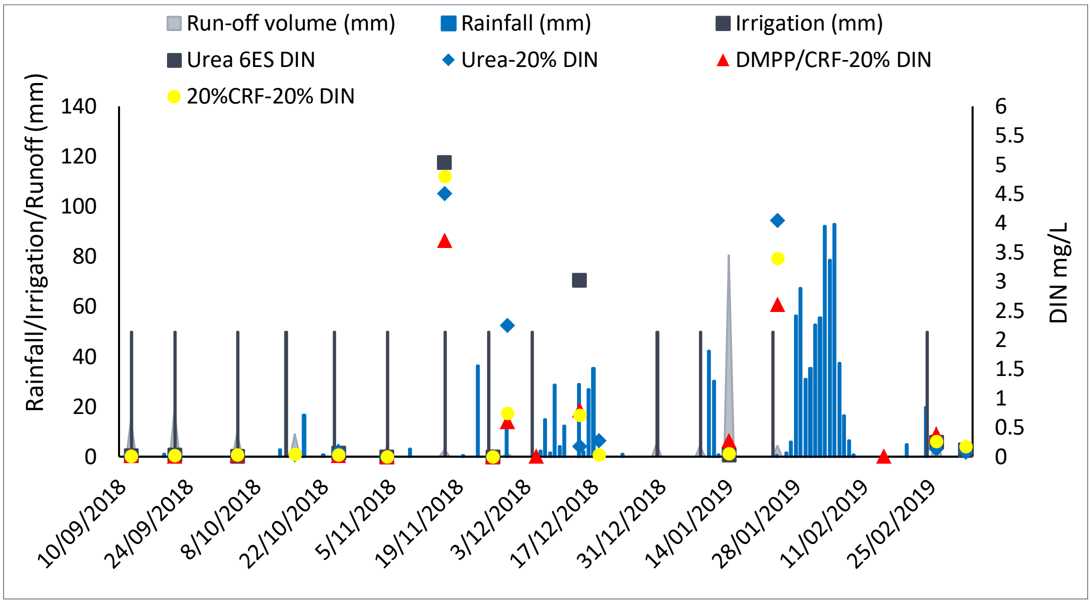

Figure 44: Rainfall (mm) and run-off volumes (mm) with the concentration of DIN (mg/L) for Burdekin Site No. 2 2018/19

Prior to the January 2020 flooding event at this site (Figure 47) the highest DIN levelsrecorded were from the DMPP/CRF -20% treatment (2.6 mg/L).

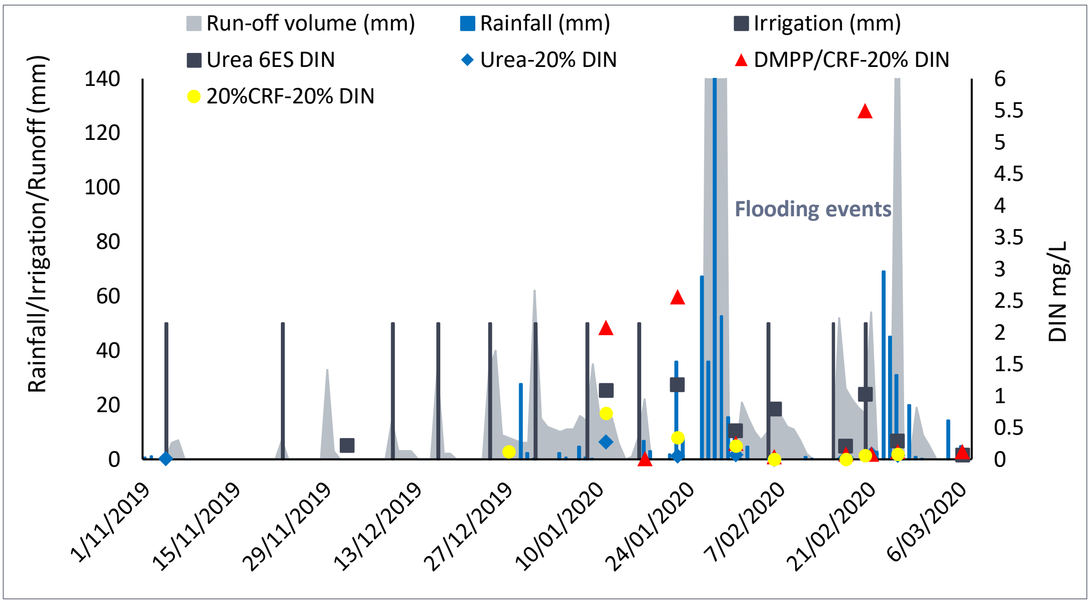

Figure 45: Rainfall (mm) and run-off volumes (mm) with the concentration of DIN (mg/L) for Burdekin Site No. 2 2019/20.

APPENDIX 3

EEF60 Biomass sampling protocol

Non-lodged sites:

All treatment strips and 0 N plots to be sampled (side of block that has the 0 N plots) For each plot:

- Select two 5 m sections of row (different rows and not adjacent to each other –
- approximately 50 m from headland or within the 0 N plot) generally row 2 and row 4. Count stalks in each 5 m section (use this data to determine stalks/m2)
- Select 12 stalks from each 5 m section – 4 stalks one pace from the front end, 4 stalks from the middle and 4 stalks one pace from the far end of each section
- Select stalks that are representative of the plot

Lodged sites:

For each plot:

- Enter in 10mtrs from the Flume / Trial site marker end of the trial site In a row central to the treatment (i.e. row 3 or 4)
- Measure out 5mtrs in length from the 10mtr mark.
- Cut and count each stalk over the 5mtr distance. Record the number of stalks. Record total weight for all stalks removed from the 2mtr distance
- For the Controls follow the same procedure; take samples from the 25 to 30mtr distance. Sub-sample 12 representative stalks from the total number of stalks removed.

Sample weighing and processing

- Weigh the 12 stalks that are collected (Total fresh wt) from each section Partition stalks into 1. Millable stalk (MS) 2. Green leaf and cabbage (LC) Cut top off between 5th and 6th dewlap
- Remove dead leaf and green leaf from millable stalk Discard dead leaf
- Include green leaf with cabbage (top) Weigh the 12 millable stalks (MS fresh wt)
- Weigh the green leaf and cabbage from the 12 stalks (LC fresh wt)
- Select 5 millable stalks and process with garden mulcher (reminder: ensure you are inducted on this equipment, turn-off and wait for blades to stop spinning before attempting to clean
- – refer to safe work procedure)
- Collect material in plastic tub or similar
- Mix material and collect 300-500 grams of mulched material in a paper bag
- Weigh paper bag in the field (MS subsample fresh wt) (make sure the balance is tared with an empty paper bag)
- Select LC from 5 stalks and process with garden mulcher (reminder: ensure you are inducted on this equipment, turn-off and wait for blades to stop spinning before attempting to clean
- – refer to safe work procedure)
- Collect material in plastic tub or similar
- Mix material and collect 300-500 grams of mulched material in a paper bag
- Weigh paper bag in the field (LC subsample fresh wt) (make sure the balance is tared with an empty paper bag)
- Transport paper bags back to station Place in oven set at 60 oC
- Dry until constant dry weight is achieved (1 week is usually sufficient)

- Re-weigh all bags (sub-sample dry wts) (make sure balance is tared with empty bag) Use to calculate MS and LC moisture content
- Process sample in plant grinder (2 mm sieve) (Ensure you have been inducted on this equipment and refer to safe work procedure)
- Collect ground material and send to Zofia for N analysis

Non-Lodged sites: In total there should be 30 MS and 30 LC samples per site (5 treatments x 3 reps x 2 sections of row)

Lodged sites: In total there should be 15 MS and 15 LC samples per site (5 treatments x 3 reps x 1 section of row)

EEF60 soil sampling post-harvest

All treatment strips and 0 N plots to be sampled (side of block that has the 0 N plots) Take samples from the vicinity of the biomass sampling

2 cores per plot (one from each side of a cane row), which are combined prior to drying 0-20 cm increment only

Take samples back to station and place in soil driers Wait until dry

Process with soil grinders (2 mm)

Send to Zofia for mineral N analysis (nitrate-N and ammonium-N)