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Boosting NUE in sugarcane through temporal and spatial management options

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ABSTRACT

This collaborative project involved the University of Southern Queensland (USQ) and the Sugar Research Australia (SRA) Technology Unit. It aimed to evaluate methods of matching nitrogen (N) supply (from soils and fertilisers) with crop N uptake and crop needs. It was conducted with cognizance of the industry's production goal of 36 million tonnes of sugar per annum, and water quality targets for the Great Barrier Reef lagoon set by government and environmental groups.

The project methodology comprised several discrete yet linked activities. The basic tenets of various N management strategies were reviewed. Several long-term N management trials that had previously been established in various districts were continued to provide essential background information. Additional field trials and pot experiments were established to assess N fertiliser formulations, uptake of N fertiliser and/or temporal aspects of N management. Adjustments to the N guidelines were considered in terms of existing evidence. A mechanism for incorporating future research outcomes and outputs into the SIX EASY STEPS nutrient management program was developed. An overarching objective was to subject trial and experimental results to multi-facetted evaluations by means of agronomic, economic and/or environmental assessments.

The SIX EASY STEPS program continues to be recognised as the basis for best practice nutrient management in the Australian sugar industry. Trial results have indicated that the SIX EASY SYEPS guidelines are generally appropriate. However, scope exists for fine-tuning of N application rates for specific circumstances. This will be best achieved via STEPS 5 and 6 of the SIX EASY STEPS program. Nitrogen use efficiency (NUE) indicators are useful for alerting growers and/or advisors to inefficiencies or circumstance where alternative on-farm management are worth considering, but that are not appropriate for determining N application rates *per se*. Enhanced efficiency fertilisers, such as DMPP-coated urea and poly-coated urea, offer promise to improve NUE. However, their use will probably be limited to situations where N losses (by leaching and/or denitrification) are more likely.

The flexibility of the SIX EASY STEPS program allows the component N guidelines to be amended and/or revised as new information becomes available. This also relates to the delivery channels, especially via the SIX EASY STEPS short course program and decision support tools such as NutriCalc™. In particular, the formation of the SIX EASY STEPS Advisory Committee will provide a mechanism for additional nutrient management strategies to be incorporated in the program in future.

EXECUTIVE SUMMARY

Much of the Australian sugar industry (Bundaberg northwards) is located adjacent to the World Heritage listed Great Barrier Reef (GBR). This proximity suggests that land-based farming activities have the potential to affect the quality of water in the GBR Lagoon. As a result, the industry has signalled its commitment to minimising such impacts via the development and adoption of farming best management practices (BMPs), particularly through the industry endorsed SmartCane BMP initiative. This has occurred in parallel to various agencies setting quality targets for water in the GBR Lagoon.

Given the pressures and expectations highlighted above, the project sought to develop innovative temporal and spatial methods within the SIX EASY STEPS nutrient management program to improve sugarcane N-use efficiency (NUE) and effectiveness. It was envisage that this could be done by investigating methods of matching N supply (from soils and fertiliser) with N uptake (by cane and within a crop cycle). Better and more targeted use of N (increased uptake and improved yields) was proposed as a distinct and viable alternative to simply reducing the amount of N fertiliser applied to sugarcane to meet environmental targets. This should be seen in relation to the intended continuous improvement and cyclical learning within the SIX EASY STEPS program system.

The project encompassed five interlinked activities:

- Re-evaluation of the basic tenets of various N management strategies
- Field investigations:
  - Continuing previously established long-term N rate trials (Tully, Herbert, Mackay and Bundaberg) to determine N uptake (N-use efficiency and effectiveness) in the field in order to set a base-line for the assessment of controlled-release formulations.
  - Assessing the most promising N fertiliser formulations to match N supply and N uptake in specifically established temporal N trials in the Herbert and Bundaberg regions.
  - Assessing in-field variation and the most appropriate means of managing N inputs at with-in block scales.
- Pot experiments conducted in semi-controlled environments to assess:
  - N-uptake of sugarcane varieties grown under ideal conditions.
  - Various EEF formulations to best match the N-uptake characteristics of sugarcane.
- Adjustments to the N guidelines (if appropriate) within the SIX EASY STEPS program based on the results of the field trials, pot experiments and any other information from previous or associated investigations.
- Development of a mechanism to provide information to growers, industry advisors and agri-business staff on a) the need for matching N supply with crop's N need b) how the SIX EASY STEPS can be updated to include future developments, and c) the use of N fertiliser formulations that increase N-use efficiency.

Outputs from this project focused on several key deliverables and included:

- **Information on how to match N supply with N demand to improve N use-efficiency and effectiveness**. This covered the concept of 'balanced nutrition', influence of farming systems on N fertiliser requirements, impacts of ratoon age on N fertiliser requirements, information about N uptake, and strategies that could help solve the conundrum of balancing sustainable sugarcane production and water quality N targets in the GBR lagoon.
- **Patterns of release of various N formulations in different climatic environments**. Such information included the availability and uptake of N from various sources including

mineralisation of N during fallows, release of N from green cane trash blankets, and EEFs compared to single applications of standard urea and split applications of urea.

- **Nitrogen management guidelines that target in-field variability**. Such strategies are best achieved via the cyclical learning and continuous improvement processes within STEPS 5 and 6 of the SIX EASY STEPS program. The use of on-farm nutrient management plans and the tools within the SIX EASY STEPS TOOLBOX will enable nutrient inputs that are appropriate for specific on-farm and in-field circumstances within particular sugarcane farming enterprises. Identification of management strategies to alleviate constrained yields in particular blocks or parts of blocks will contribute to effective use of the N rates within the established SIX EASY STEPS guidelines. Harvester-derived yield data in combination with recorded N application rates (conventional or variable) may be used to develop maps showing areas of different NUE within and across blocks of cane. This provides a further tool for growers to identify areas within block that need specific management to improve yields, and efficient and effective use of N fertiliser.
- **Information to update the existing SIX EASY STEPS tools**. The SIX EASY STEPS program is evolving with time, adapting to stakeholder (industry, government, community and environmental) needs, and remaining at the forefront of advances in research and development (R&D) and extension and adoption (E&A). The project team proposed the establishment of the SIX EASY STEPS Advisory Committee (SESAC) to enable current and future R&D outputs to be assessed for compatibility with the intent of the SIX EASY STEPS program. The SESAC will also ensure that growers, extension providers and advisors have confidence in the SIX EASY STEPS 'tools' they choose, use and/or promote for specific on-farm circumstances. It is important that the sugar industry continues to commit to widespread adoption of BMPs. This dual awareness of economic and environmental sustainability will ensure that any water quality impacts on the sugar industry and the GBR are considered in a mutually beneficial way.

Outcomes resulting from the project have shown that nutrient management within sustainable sugarcane production systems needs to be underpinned by optimised productivity, maintenance or improved profitability, environmental responsibility and social awareness. Multi-factored assessments of new and/or amended nutrient management strategies will prevent, or at least minimise bias or over-emphasis of one objective over others (Poggio et al. 2016). The standard SIX EASY STEPS N guidelines (within STEP 4), in combination with the continuous improvement and cyclical learning in STEPS 5 and 6, enable this approach to be achieved at the enterprise, farm or in-field scales.

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1.1. Australian sugar industry

The Australian sugar industry spreads across a distance of about 2000 km from Mossman in far north Queensland to Grafton in coastal northern New South Wales. The industry comprises about 4400 cane-growing businesses, 24 sugar mills owned by eight companies, six bulk storage ports, several refineries and two distilleries (Figure 1-1). It provides livelihoods to several thousand people/families and supports many businesses and communities on the eastern seaboard of the continent. The annual average sugarcane and sugar production (30 – 36 Mt and 4 – 4.5 Mt, respectively) from 400 000 ha of land contributes about AU$2 billion annually to the Australian economy (Anon., 2016a). Maintaining productivity and profitability is dependent on appropriate use of agricultural inputs and practices to supplement/bolster on-farm natural resources within the various climatic regions across the industry.

1.2. Great Barrier Reef

The Great Barrier Reef (GBR) is located adjacent to much of the Australian sugar industry from Bundaberg northward (Figure 1-2). The GBR is the world's largest coral reef ecosystem that contains about 3,000 coral reefs, 600 continental islands, 300 coral cays and about 150 inshore mangrove islands, within an area covering about 350,000 km2 (Anon. 2017a). It is considered the largest living entity on Earth and was declared a World Heritage Site in 1981. This national icon is contained in a body of water (with an average depth of 35m) that is referred to as the GBR Lagoon and has a volume of 1.225 x 1013 m^3 of water. In the past decade its environmental significance has increased markedly.

Figure 1-1 Australian sugar industry – Mossman in far north Queensland to Grafton in northern New South Wales (Anon., 2016a).

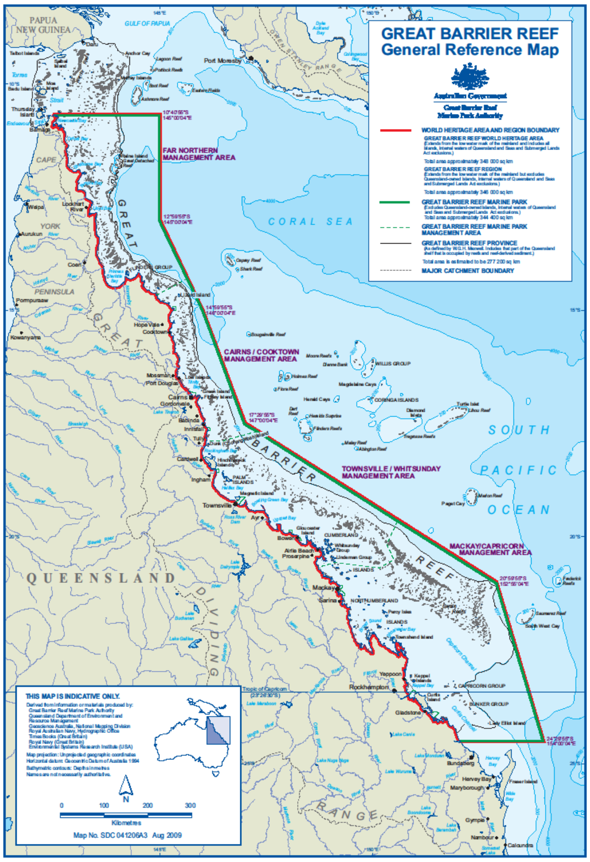


Figure 1-2 Great Barrier Reef, north of Bundaberg to the northern tip of Cape York in northern Queensland (Anon., 2016d).

1.3. Balancing profitable sugarcane production with water quality requirement

The proximity of the sugar industry to the GBR suggests that land-based farming activities have the potential to affect the quality of water in the GBR Lagoon (Thorburn *et al*., 2013). The sugar industry has signalled its commitment to minimising such impacts via the development and adoption of farming best management practices (BMPs), particularly through the industry endorsed SmartCane BMP initiative (Anon., 2016b; Kealley and Quirk, 2016). This has occurred in parallel with various agencies setting quality targets for water in the GBR Lagoon with the aim of preserving/improving the living environment within the boundaries of the GBR and minimising influx of nitrogen (N) and phosphorus (P) to the lagoon (Anon., 2017b). As of late 2016, the SmartCane BMP program was reported to be fully aligned with Bonsucro's global standard for sustainable sugar production (Anon., 2016c). However, Kroon *et al*. (2016) predicted that adoption of current BMPs (as contained in the SmartCane BMP program) was unlikely to meet these targets. They suggested that more directed strategies, such as further reduction in the amount of N applied and withdrawing land from sugarcane production and/or planting alternative low-input annual/tree crops, would be necessary to attain the desired water quality

1.4. Nitrogen – a critical issue

Nitrogen (N) is one of 16 essential plant nutrients required for crop production. Sugarcane biomass requires substantial quantities of N (60 to 200 kg/ha) to be applied annually for sustainable production (Calcino, 1994). These rates reflect the amounts of N needed by the crop in excess of that supplied by the soil primarily due to the mineralisation of N from soil organic carbon (Org C).

1.4.1. SIX EASY STEPS N guidelines

Appropriate N application rates for Australian conditions have been determined through R&D projects over many decades (Schroeder *et al*., 1998). Since the mid-2000s, 'optimum N rates' were established for key soil types based on 95% of the maximum attainable yield determined from response curves associated with several long-term replicated small-plot experiments (Schroeder *et al*., 2005, 2009a). These N rates were then linked to a suite of parameters that enabled extrapolation to various districts/regions. This involved using the concept of District Yield Potential (DYP)], an N-utilisation index (1.4 kg N/t cane up to a cane yield of 100 t/ha and 1.0 kg N/t cane thereafter), and soil type using a soil mineralisation index based on Org C (Schroeder *et al*., 2010a). This system provides the framework for the N management guidelines within the SIX EASY STEPS program and the subsequent BMP standards in the Australian sugar industry (Schroeder *et al*., 2006). It also enables a hierarchy of scales (region, district, soil, block and crop) for decision-making. Importantly, the SIX EASY STEPS program allows for the N guidelines to be further adapted for specific circumstances using the cyclical learning and continuous improvement process provided by steps 5 and 6 within the constituent 'six steps' (Calcino *et al*., 2010):

1) Knowing and understanding our soils.
2) Understanding and managing nutrient processes and losses.
3) Soil testing regularly.
4) Adopting soil-specific nutrient management guidelines.
5) Checking on the adequacy of nutrient inputs (leaf analysis, on-farm strip trials, etc.).
6) Keeping good records to identify trends and modify nutrient inputs when/where necessary.

An example of a set of SIX EASY STEPS N management guidelines for specific districts is presented in Table 1-1. This example shows the baseline N application rates for plant cane after a grass or bare fallow and ratoon cane in the Wet Tropics, and Herbert and Bundaberg districts that have a DYP of 120 tc/ha.

The development of the SIX EASY STEPS program has contributed to a net decline in average N application rates across cane districts (Wood *et al*., 2008; Bell *et al*., 2015a) and helped to reduced off-site losses of N fertiliser.

Table 1-1 SIX EASY STEPS N guidelines for plant cane after a grass or bare fallow and ratoon cane grown in the Wet Tropics, and Herbert and Bundaberg districts.

Crop	N mineralisation index						
	VL	L	ML	M	MH	H	VH
	Application rate (kg N/ha)						
Plant cane after a grass/bare fallow	140	130	120	110	100	90	80
Ratoon crops	160	150	140	130	120	110	100

1.4.2. Environmental perspectives

Much activity and progress have occurred in pursuing water quality improvement in the GBR Lagoon following the 2008 Scientific Consensus Statement (Anon., 2008) that highlighted the link between agricultural activities in the Queensland coastal areas and GBR water quality. This included:

- Australian Government's Reef Rescue Plan that commenced in 2009 provided financial incentives for growers to improve crop/nutrient management practices (Anon., 2013).
- Queensland Government's Reef Regulations in 2010 that specifically targeted N and P inputs (Anon., 2016e).
- Queensland Government's Great Barrier Reef Water Science Taskforce in 2014 that provided advice/recommendations on the best approaches to meet the established water quality targets (Anon., 2016f)
- Australian Government's Reef Trust initiatives that are aimed at improving water quality by increasing N use efficiency (NUE), and funding growers to reduce N fertiliser inputs (Anon., 2017c). These are underpinned by the aforementioned water quality improvement targets, i.e. reducing dissolved inorganic N (DIN) in water reaching the Great Barrier Reef Lagoon by 50% by 2018 and 80% by 2025 (Anon., 2017b). These initiatives are informed and supported by the updated *Scientific Consensus Statement (2013) - Land use impacts on Great Barrier Reef water quality and ecosystem condition* (Anon., 2013).
- The Reef Water Protection Plan that aims to "*ensure that by 2020 the quality of water entering the reef from broad-scale land use has no detrimental impact on the health and resilience of the Great Barrier Reef*." This is driven by reports from the Institute of Marine Science (AIMS) of declining hard coral cover by 50% over the past 27 years (Anon., 2013). Forty two percent of this decline is attributed to accelerated outbreaks and increased populations of crown-of-thorns starfish (COTS) associated with increased concentration of dissolved inorganic N (DIN) originating predominantly from land-based agricultural activities (Brodie *et al*., 2005).
- Reef Integrated Monitoring and Reporting Program that aims to provide evidence of linkages between land-based activities, water quality and reef health (Carroll *et al*., 2012).

To help achieve the water quality targets, the Australian Department of the Environment commissioned a review of nitrogen-use efficiency (NUE) in sugarcane in Australia through Sugar Research Australia (SRA). Research and development needs and future opportunities for improving NUE were identified (Bell and Moody, 2015). These included reducing N inputs and/or using more modern N fertiliser formulations [e.g. enhanced efficiency fertilisers (EEFs)]. Although such options provided a means of meeting the Great Barrier Reef water quality targets (Anon., 2017b,c), their efficacy still needed validation.

1.4.3. Economics and social perspectives

Recent research on technology adoption has indicated that expectations are not easily met when the economic effectiveness, risk to farmers, industry productivity and profitability, and the social impacts are not assessed, nor taken into account (Llewellyn, 2011; Robertson *et al*., 2012).

Sugarcane is part of a tightly connected value chain, and mill viability is dependent on throughput. A disruption of the economic balance of production could have wide-ranging social impacts on regional economies inclusive of all stakeholders in the sugar industry, and especially growers, millers, local communities and regions. Comprehensive assessments are therefore required using multi-performance-based indicators such as the 'triple-bottom-line approach' that considers economic, social and ecological implications of practices (Vanclay, 2004; Mooney, 2004; Thompson, 2007).

This type of approach is supported by Poggio *et al*. (2016) who indicated that the evaluation of changed practices or strategies linked to industry or political issues is best undertaken when multiple objectives/consequences [agronomic, social, economic and environmental and social (ASEE)] are considered. Such multi-factored assessment may prevent, or at least minimise, bias or over-emphasis of one objective over others (Poggio *et al*., 2016).

1.5. Previous industry investment and developments

This project builds on a number or previous projects and initiatives. In particular, it adds value to the existing SIX EASY STEPS best practice nutrient management program. It will provide additional information and data to ensure that nutrient inputs are specific to particular situations and circumstances via the use of STEPS 5 and 6 (Checking on the adequacy of nutrient inputs and modifying such inputs when and where necessary). Specific past project included:

- Opportunities for better nutrient supply and usage in the Australian sugar industry (CRC Sugar 2.3.8/BSES: Schroeder *et al*.).
- Improved nutrient management and understanding of nutrient interactions, imbalances and limitations in the Australian sugar industry (CRC Sugar 2.3.10/BSES: Schroeder *et al*.).
- Improved nutrient management for the Australian sugar industry (SRDC/BSES BSS232: Schroeder *et al*.).
- Accelerated adoption of best practice nutrient management in the Australian sugar industry (SRDC/BSES BSS268: Schroeder *et al*.).

The above-mentioned projects were linked sequentially, and hence developed and delivered improvements to the SIX EASY STEPS program on an ongoing basis. In particular, they resulted in:

- The SIX EASY STEPS short course that has been delivered to the majority of cane growers and their advisors across the Australian sugar industry.
- SIX EASY STEPS workbooks that continue to be used during the short-courses and as subsequent reference to attendees.
- Soil reference booklets for a number of regions (Herbert, Proserpine, Johnstone, Bundaberg, Mackay, Plane Creek, Isis, NSW, all with additional funding from elsewhere).
- More than 15 scientific papers that were prepared and presented at conferences (ISSCT, ISSCT, etc)
- A series of 50 articles that were written for the Australian Canegrower magazine.
- Soil test interpretation guidelines.
- A web-based nutrient advisory and record-keeping system, badged at NutriCalc^{TM}.
- The framework used to develop the original SIX EASY STEPS concept, also serves as an appropriate means for further updates and refinements.
- A number of longer-term replicated small plot rates of N trials that provide a scientific basis for the SIX EASY STEPS N guidelines.
- Several series of demonstration strip-trials that have illustrated the advantage of using the SIX EASY STEPS for determining nutrient inputs to blocks of sugarcane.

The above-mentioned developments formed the platform for the work undertaken in this project.

1.6. Project rationale

Given the pressures and expectations highlighted above and, in particular, Reef Plan 2013 that set the priority target of reducing dissolved inorganic N (DIN) in water reaching the Great Barrier Reef Lagoon by at least 50%, the project sought to develop innovative temporal and spatial methods to improve sugarcane N-use efficiency (NUE) and effectiveness. It was postulated that this could be done by investigating methods of matching N supply (from soils and fertiliser) with N uptake (by cane within a crop and in the full crop cycle). Better and more targeted use of N (increased uptake and improved yields) was proposed as a distinct and viable alternative to simply reducing the amount of N fertiliser applied to sugarcane to meet environmental targets.

The SIX EASY STEPS program continues to be accepted as the basis for nutrient best management practice (BMP) within the Australian sugar industry. However, an essential aspect of the program that is often overlooked, is the intended continuous improvement and learning cycle within the system. As growers and/or their advisors become familiar with the SIX EASY STEPS principles, informed changes to nutrient inputs to particular blocks of cane on their farms become possible. It is generally accepted that about 35% of N fertiliser applied to sugarcane is taken up by the crop in the season in which it is applied. The remainder resides in different 'pools' consisting of soil organic N that is temporarily unavailable, and mineral N that is available in ionic form, but subject to possible loss (Wood *et al*., 2010). Improving NUE would be best achieved by matching N supply with crop N uptake as the sugarcane ages within a season and as the crop cycle progresses. This could be done by:

- Making use of fertiliser formulations or combinations of fertiliser formulations that release N into the sugarcane system over time so that the most effective use is made of the supplied N (temporal strategies). This will include better understanding of EEFs and associated N uptake by crops.
- Adapting the SIX EASY STEPS system to deliver appropriate N strategies and guidelines to take account of in-field soil and yield variability (spatial strategies).

2. PROJECT OBJECTIVES

The project aims to develop innovative temporal and spatial methods to improve sugarcane N-use efficiency and effectiveness by:

1. Determining the N-demand of a set of current sugarcane varieties.
2. Determining formulations or combinations of formulations of N fertilisers that have the ability to match N supply with the sugarcane crop’s N demand.
3. Determining how the current N guidelines (SIX EASY STEPS) can be adapted for targeting within-block soil and yield variation.

3. OUTPUTS, OUTCOMES AND IMPLICATIONS

3.1. Outputs

Outputs from this project focused on several key deliverables:

1. Information on how to match N supply with N demand to improve N use-efficiency and effectiveness

Continuation of the longer-term N trials within this project resulted in information pertaining to both nitrogen use efficiency and effectiveness. This related to the concept of ‘balanced nutrition’, influence of farming systems on N fertiliser requirements, and impacts of ratoon age on N fertiliser requirements. The pot experiments provided information on N uptake. The project team also identified some strategies that could help solve the conundrum of balancing sustainable sugarcane production and water quality N targets in the GBR lagoon (these are listed under "Overall Conclusions").

Balanced nutrition

- Applying N fertiliser to crop when other nutrients are not adequately supplied (as in the NxK trial in Bundaberg) will result in inefficient and ineffective use of N fertiliser. Productivity and profitability will be compromised. Nitrogen use efficiency will be lower under such circumstances (reduced yield per kg N applied).

Influence of farming systems on N fertiliser requirements

- The N x Farming Systems trial in Mackay showed that crop N uptake and biomass development were slow in the first 3 months after harvest, and there were few differences due to N rates at this time. This suggests that the crop had low N demand and that background N in the soil pool was mostly able to support growth during this period. This result is consistent with recommendations that suggest a delay to fertiliser application after harvest by up to 6 weeks is unlikely to have any impact on yield. It should, however, be noted that this is not a practical management practice for crops harvested late in the season.
- The Macknade trials also showed that conventional tillage and minimum/zero tillage treatments in permanent beds had no significant effect on N uptake by the crops in either trial (on different soil types) or in any of the seasons. Although similar yields were produced at these two sites where zero N was applied, the response to applied N was greater and larger crops were produced at the higher rates of N on the River Bank silty loam than on the Clay Loam (which is in a lower position in the landscape) in both seasons. The commonly used NUE expressed as tonnes cane/ha decreased as the N rates increased across the trials and seasons. Conversely, NUE expressed as kg N/t cane increased with the rate of N applied, as did the Agron Eff_{fert}. The various NUE indicators were not particularly well-aligned with optimum N rates (as determined from response curves). These results show that it would have been inappropriate to set NUE targets because of the range and variability in values, particularly due to seasonal climatic conditions.

Impact of ratoon age on N fertiliser requirements

- The rates of N trials in Tully that included 'older' ratoons (4R and 5R crops) showed that the amount of N applied had a statistically significant effect on dry biomass, crop N uptake and yields (cane and sugar yield) for most crops at both sites. However, there was no statistically significant effect of N rate measured for CCS in any crop.

Nitrogen uptake

The pot experiments supplied the following information:

- There was little difference between sugarcane cultivars in the N uptake dynamics within the first 16 weeks of growth.
- A decrease in N supply to the crop (due to a reduced rate) commensurately delayed the uptake of N and reduced cane biomass measured in the first 150 days after planting compared with higher and earlier N supply.
- Nitrogen uptake in a high N environment peaked by 100 days after planting whereas N uptake in a low N environment had not yet peaked 150 days after planting.

- Nitrogen uptake by sugarcane plants (cv. Q200), grown with an equivalent rate of 150 kg N/ha (but with discounts for the N uptake at zero N applied), was found to contain 18% of the applied N in the stalks, 34% of the applied N in the leaves and tops, and 20% of the applied N in the roots. In total, 28% of the 150 kg N/ha application (42 kg N/ha) could not be accounted for in the crop. This N was probably held within the soil reserves as denitrification losses were unlikely and leaching losses were minimised due to leachates being returned to the pots on a routine basis. A similar distribution pattern of N in the crop was obtained for cultivar Q208.

2. Patterns of release of various N formulations in different climatic environments

The various investigations within this project contributed information about the release, availability and uptake of N from various sources including mineralisation of N during fallows, release of N from green cane trash blankets, and EEFs versus standard urea and split applications of urea.

Release of N from fallows

- Long (12 month) uncropped fallows (as was the case prior to the current crop cycle at the trial site in Bundaberg) are capable of generating sufficient N to supply the total needs of the ensuing sugarcane plant crop. This amount of N was presumably from mineralisation of N in the 'biological pool' that originated from legume fallow crops grown prior to previous crop cycles. This supports the opinion that the N from legume fallow crops is retained in the soil, and is not all subject to loss by leaching during the crops immediately after the fallow period. The release occurs over a relatively long timeframe.

Release of N from green cane trash blankets

- The first of two N x Farming Systems trials in Mackay showed that cane crops grown in long-term burnt and GCTB farming systems had similar response to applied N. There was no indication of greater N availability in the long-term GCTB system despite the retention of trash blankets between crops for over two decades. Productivity increases in the GCTB farming system was most likely due to soil moisture retention.

- The second N x Farming Systems trial in Mackay showed that ratoon crops following a soybean fallow did not acquire additional N in comparison to a bare fallow. There was evidence from the first ratoon crop that there may have been less N in the soil pool in the soybean fallow system due to lower sugarcane yield at the 0 kg N/ha rate. This was possibly due to the significantly reduced fertiliser N rate in the plant crop following the soybean fallow. Given this result, recommendations to apply 'normal' N rates to ratoon crops following a soybean fallow are justified, particularly if N applications are reduced in the plant crop to account for the legume N.

Comparison of EEFs to split applications of urea

- Nitrogen application rates and N fertiliser formulations did not have a significant effect on soil min-N values. Differences in soil min-N were most apparent to depth with evidence of leaching down the soil profile. This appeared to occur across the N treatments (including the control).

- There were no significant yield (tc/ha, CCS and ts/ha) responses to applied N, split applications or use of EEFs in the Bundaberg trial. The rainfall measured during the seasons Sep 2015 – Oct 2017 would not have resulted in excessively wet conditions at the trial site and may have contributed to the lack of responses to EEFs described above.

- Increased N-uptake by the crop, due to the use of N strategies away from the standard practice (use of EEFs or split applications of urea), improved NUE values based on crop N (fertiliser N uptake efficiency), but this did not always translate into any improvements in yield.

- The highest partial net returns in the plant and 1R crop corresponded to the control treatments. This was due to the lack of yield responses. Urea applied at the lower N rates in single applications resulted in the next best partial net returns in both crops. This appeared to be the most appropriate strategy to minimise risk to growers. The cost of EEF fertilisers negatively affected the partial net returns. DMPP-coated urea being more affordable than the poly-coated urea option.

Yield response to EEFs versus standard urea

- Trial results from a first ratoon crop on the clay soil in the Herbert district showed significant responses to applied N but no differences were apparent between the fertiliser formulations used (EEFs versus standard urea). The lack of response to EEFs was possibly due to the rainfall pattern during these particular seasons where rainfall was not sufficient to cause marked N losses due to waterlogging or leaching.

- Despite reports from other projects of reduced N losses and potential maintenance of sugarcane yields when EEFs were used at lower N application rates, the results from this trial indicated that an N rate of 120 kg N/ha would have been appropriate irrespective of the N fertiliser formulation (urea, DMPP-coated urea or PC-coated urea) applied.

- Increased crop N uptake that occurred in several of the trials due to higher N rates, use of EEFs, split N applications, etc, did not necessarily result in increased yields.

3. Nitrogen management guidelines that target in-field variability

Soil and yield maps illustrate variability within most sugarcane blocks. Some have suggested that variable rate fertiliser inputs should be used to target this variability. However, in terms of the SIX EASY STEPS program, we reiterate that:

- The SIX EASY SYTEPS N guidelines target a hierarchy of scales (region, district, soil, block and crop). Importantly, the N guidelines provided within STEP 4 of the SIX EASY STEPS are district and soil specific. STEPS 5 and 6 allow these N guidelines to be further adapted for specific circumstances at farm, block and with-in block scales. This is achievable via the cyclical learning and continuous improvement process within these two steps.
- Using simple yield-based parameters for determining N application rates are not appropriate because seasonal climatic conditions that interact particularly with soil type and position in the landscape have overriding effects on productivity from year to year.
- The use of on-farm nutrient management plans and tools within the SIX EASY STEPS TOOLBOX will enable nutrient inputs to be determined that are appropriate for specific on-farm and in-field circumstances within particular sugarcane farming enterprises. Identification of management strategies to alleviate constrained yields in particular blocks or parts of blocks will contribute to effective use of the N rates within the established SIX EASY STEPS guidelines.
- Harvester-derived yield data in combination with recorded N application rates (conventional or variable) may be used to develop maps showing areas of different NUE within and across blocks of cane. This provides a further tool for growers to identify areas within block that need specific management to improve yields and efficient and effective use of N fertiliser.
- Worth noting are the results from the Macknade N trials that showed that conventional and minimum/zero tillage treatments in permanent beds had no significant effect on N uptake by the crops in either trial (on different soil types) or in any of the seasons. Although similar

yields were produced at these two sites where zero N was applied, the response to applied N was greater and larger crops were produced at the higher rates of N on the River Bank silty loam than on the Clay Loam (which is in a lower position in the landscape) in both seasons. There was strong evidence that optimum N rates were affected by positions in the landscape and the interaction with seasonal climatic conditions.

4. Information to update the existing SIX EASY STEPS tools

The SIX EASY STEPS program is evolving with time, adapting to stakeholder (industry, government, community and environmental) needs, and remaining at the forefront of advances in research and development (R&D) and extension and adoption (E&A).

- Recognition as the BMP standard means that the SIX EASY STEPS program provides a mechanism for more innovative concepts to be tested and validated into the future. This is facilitated by the fundamental concepts of continuous improvement and cyclical learning in the program. STEPS 5 and 6 are aimed at providing such opportunities to researchers and users (growers and advisors).
- The project team proposed the establishment of the SIX EASY STEPS Advisory Committee (SESAC) to enable current and future R&D outputs to be assessed for compatibility with the intent of the SIX EASY STEPS program.
- The SESAC will also ensure that growers, extension providers and advisors have confidence in the SIX EASY STEPS 'tools' they choose, use and/or promote for specific on-farm circumstances.
- The project participants have played a key role in the development of the concept of a SIX EASY STEPS TOOLBOX.
- Results of investigations within this project have provided the additional information (as highlighted above) for updating the guidelines within the SIX EASY STEPS program.
- The various economic assessments showed that reductions in N rates below BMP standards, although environmentally desirable (due to improved NUEs), had the potential to reduce industry revenue and net returns to growers and millers.
- It is essential that the impacts of water quality targets on the sugar industry and the Great Barrier Reef are assessed using multi-facetted analyses that incorporate at least agronomic, socio-economic and environmental considerations. Assessments based on a single over-riding factor (e.g. when only agronomic, economic, social or environmental aspects are considered in isolation of the others) have the potential to produce a result that is biased towards a particular outcome.
- It is important that the sugar industry continues to commit to widespread adoption of BMPs. This dual awareness of economic and environmental sustainability will ensure that any water quality impacts on the sugar industry and the GBR are considered in a mutually beneficial way.

5. ASSCT and other journal papers, information sheets will be written, presented and communicated

A number of papers were published, with some of these presented at the ASSCT conferences. Communications also included articles in SRA CaneConnections and the Australian Canegrower magazines. A number of oral presentations were delivered by members of the project team in various forums, including stakeholder and government workshops, and meeting held as part of other projects.

3.2. Outcomes and Implications

Increased N-use efficiency and effectiveness by matching N supply and N demand of the crop through temporal and spatial adjustments to N inputs provides the opportunity to:

- Improve productivity in terms of increased cane and sugar yield, with more effective use of the N applied.
- Increased profitability for both the grower and milling sectors by lowering costs of production and minimising losses of applied fertiliser.
- Tailor inputs to the needs of the crop with more effective use of N applied, and
- Improve environmental outcomes by potentially reducing losses of N from cane paddocks.

The outcomes resulting from the project have shown that nutrient management within sustainable sugarcane production systems needs to be underpinned by optimised productivity, maintenance or improved profitability, environmental responsibility and social awareness. Multi-factored assessments of new and/or amended nutrient management strategies will prevent, or at least minimise bias or over-emphasis of one objective over others (Poggio *et al*., 2016). The standard SIX EASY STEPS N guidelines (within STEP 4), in combination with the continuous improvement and cyclical learning in STEPS 5 and 6, enable this approach to be achieved at enterprise, farm and/or in-field scales.

4. INDUSTRY COMMUNICATION AND ENGAGEMENT

4.1. Industry engagement during course of project

Several of the project team were actively involved in communicating details and information from, or associated with, this project to industry or other stakeholders including government via the following:

- Ongoing interaction and communication with David Calcino (SRA Adoption Unit).
- Barry Salter provided an update on the project and the N x Farming Systems trials at the Mackay Trial Information Day in Feb 2015.
- David Calcino and Bernard Schroeder. An oral presentation entitled “Tracking the success of the SIX EASY STEPS nutrient management program” at the International Society of Sugar Cane Technologists Agronomy, Agricultural Engineering and Extension Workshop, Salt Rock, South Africa in Aug 2015.
- Bernard Schroeder, Danielle Skocaj, Barry Salter, Alan Hurney and Andrew Wood. A poster entitled “Is it possible to reduce nitrogen input rates and increased nitrogen use efficiency in older ratoons within the sugarcane crop cycle?” at the International Society of Sugar Cane Technologists Agronomy, Agricultural Engineering and Extension Workshop, Salt Rock, South Africa in Aug 2015.
- Bernard Schroeder, Danielle Skocaj and Andrew Wood. An oral presentation entitled “SIX EASY STEPS N guidelines – what is possible, and what is not: Wet Tropics Cane Industry Focus Workshop – Nutrients and the Reef, Wet Tropics Sugar Industry Partnership (WTSIP) Mulgrave Mill, 3 Dec 2015.
- Bernard Schroeder and Troy Jensen. ABC interview with Belinda Sanders - NUE project (14 Dec 2015).
- Bernard Schroeder presented updates on N guidelines at CANEGROWERS, Edward street, Brisbane on 14 Jan 2016, to the Industry Cane Working Group at Wilmar Sugar, Queen Street, Brisbane prior to a meeting with Qld DEHP on 3 Feb 2016, and a meeting with SRA, Farmacist and MAPs on at SRA in Mackay 2 Mar 2016.

- Barry Salter provided an update on the project and the N x Farming Systems trials at the Mackay Trial Information Day in Feb 2016.
- Barry Salter provided an update and information about the project to the SRA Central Region Grower Update in March 2016.
- Bernard Schroeder delivered an oral presentation entitled "Apply N when and where you need it for a profitable business: SRA Research Forums 2016: Bundaberg (14 April 2016), Cairns (18 April 2016), Ayr (20 April 2016) and Mackay (22 April 2016).
- Bernard Schroeder presented an update on the SIX EASY STEPS N guidelines at the Nitrogen Management Workshop at the Rydges South Bank Convention Centre, Townsville, on 12 May 2016, and at the Wet Tropics Sugar Industry Partnership Extension Office Workshop at CANEGROWERS/Sugar Museum, Mourilyan on 16 May 2016.
- Bernard Schroeder delivered an oral presentation on aspects of EEFs at a workshop (Towards improved synchrony for controlled release fertilisers) on 24 May 2016 in Townsville.
- Bernard Schroeder and Danielle Skocaj represented the SIX EASY STEPS team at the WTSIP meeting held at Gordonvale on 27 June 2016.
- Bernard Schroeder represented the project and SIX EASY STEPS team at a meeting with Sunshine Sugar, Broadwater, NSW on 19 August 2016.
- Bernard Schroeder, Barry Salter, Danielle Skocaj and John Panitz met with the project 2014/075 (How much N does that crop need) team to discuss interaction between the two groups and how 2014/075 can contribute information/data for updating the SIX EASY STEPS N guidelines.
- Barry Salter presented an update on the SIX EASY STEPS at a Reef Catchments meeting/workshop in September 2016.
- Bernard Schroeder (on behalf of the project team) delivered a presentation entitled "Status of the SIX EASY STEPS" at the Queensland EHP Sugarcane NUE Workshop held in Brisbane on 27 October 2016.
- Barry Salter provided an update on the project and the N x Farming Systems trials at the Mackay Trial Information Day in February 2017.
- Barry Salter provided an update and information about the project to the SRA Central Region Grower Update in March 2017.
- Bernard Schroeder delivered an oral presentation entitled "Aspects of sugarcane production relevant to water quality during Sugar Tuesday that was held immediately prior to the ASSCT Conference in Cairns on 2 May 2017.
- Bernard Schroeder and Andrew Wood: an oral presentation entitled "Balancing sugarcane production with water quality targets" ASSCT Water Quality Workshop 4 May 2017.
- Barry Salter provided an update on the project and the N x Farming Systems trials at the Mackay Trial Information Day in February 2018.
- Bernard Schroeder and Danielle Skocaj: an oral presentation entitled "Crop nutrition – an update" New South Wales Productivity Services Conference, Ballina, 29 Nov 2017
- Bernard Schroeder and Andrew Wood: an oral presentation entitled "Nutrient management - balancing productivity, profitability and ecology" New South Wales Productivity Services Conference, Ballina, 29 Nov 2017.
- Danielle Skocaj: Update on project activities to SRA Board and RFU in Tully, Mar 2018
- Danielle Skocaj: Update on project activities at Tully sugar industry shed meetings, May 2018.

4.2. Industry communication messages

- The SIX EASY STEPS program is a comprehensive nutrient management system based on the principles of best management practice. It should be viewed as a continuous improvement

and cyclical learning process that will assist growers in fine-tuning the nutrient inputs for their specific circumstances.
- The SIX EASY STEPS program continues to aim at sustainable sugarcane production – profitability in combination with environmental responsibility, and is inextricably linked to best management practices.
- Best management practices need to be practical, cost effective, aim to maintain on-farm resources, and reduce the risk of losses of agricultural inputs.
- The content of the SIX EASY STEPS is not 'set in stone', it is continually growing and maturing. Any added components or fine-tuned aspects need to be based on credible scientific evidence.
- The proposed SIX EASY STEPS Advisory Committee will ensure that standards set within the SIX EASY STEPS program are upheld when any amendments are proposed.
- The SIX EASY STEPS TOOLBOX will provide a 'repository' for SIX EASY STEPS accredited nutrient management tools for use by growers and/or their advisors.
- Longer-term trials, such as those included in this project, have the ability to provide longer-term perspectives that are not possible when trials are conducted over one or two seasons. This is particularly relevant to N because of its dynamic nature.
- Continuation of the longer-term N trials within this project resulted in information pertaining to both nitrogen use efficiency and effectiveness. This related to the concept of 'balanced nutrition', influence of farming systems on N fertiliser requirements, and impacts of ratoon age on N fertiliser requirements. It also enabled multi-facetted (agronomic, economic and environmental) assessments of results.
- The combination of field trials and pot experiments that were conducted in semi-controlled environments, provided useful information on N uptake and clarity about where N resides in the different 'pools' within the crop and soil.
- The project contributed information about the release, availability and uptake of N from various sources including mineralisation of N during fallows, release of N from green cane trash blankets, and EEFs versus standard urea and split applications of urea. Once again, multi-faceted analyses provided balanced assessments of changing N strategies.
- The project aimed to provide a balanced approach to N management in the Australian sugar industry by recognising both spatial and temporal factors that could influence N use efficiency and effectiveness in sugarcane production.
- It is important that the sugar industry continues to commit to widespread adoption of BMPs.
- Some strategies that could help solve the conundrum of balancing sustainable sugarcane production and water quality N targets in the GBR lagoon.

5. METHODOLOGY

The project encompassed five interlinked activities:

- Re-evaluation of the basic tenets of various N management strategies
- Field investigations:
  - Continuing previously established long-term N rate trials (Tully, Herbert, Mackay and Bundaberg) to determine N uptake (N-use efficiency and effectiveness) in the field in order to set a base-line for the assessment of controlled-release formulations.
  - Assessing the most promising N fertiliser formulations to match N supply and N uptake in specifically established temporal N trials in the Herbert and Bundaberg regions.
  - Assessing in-field variation and the most appropriate means of managing N inputs at with-in block scales.
- Pot experiments conducted in semi-controlled environments to assess:
  - N-uptake of sugarcane varieties grown under ideal conditions.
  - Various EEF formulations to best match the N-uptake characteristics of sugarcane.
- Adjustments to the N guidelines (if appropriate) within the SIX EASY STEPS program based on the results of the field trials, pot experiments and any other information from previous or associated investigations.
- Development of a mechanism to provide information to growers, industry advisors and agri-business staff on a) the need for matching N supply with crop's N need b) how the SIX EASY STEPS can be updated to include future developments, and c) the use of N fertiliser formulations that increase N-use efficiency.

5.1. Re-evaluation of the basic tenets of various N management strategies

The re-evaluation process included three items:

1. Review of the principles and basic mechanisms that underpinned the various N management 'systems' that have been available for use in the industry (past approaches to N-management, SIX EASY STEPS and N-Replacement).
2. Determination of whether credible evidence existed for proposed modifications to the SIX EASY STEPS guidelines.
3. Assessment of three different N strategies [production-focused (risk adverse), sustainability-focused (SIX EASY STEPS) and environmentally-focused (reduced N rates) according to agronomic and environmental criteria using past trial data.

5.2. Nitrogen field trials

Several long-term N management field trials were included in this investigation and included:

1. Previously established N rate trials (Bundaberg (Bdb NxK), Mackay (Mky NxFS1 and Mky NxFS2), Herbert (Mkd NxFS1 and Mkd (NxFS2) and Tully (T1 and T3) that were continued and used as important resources for
   - Supporting the current N management guidelines contained in STEP 4 of the SIX EASY STEPS program.
   - Providing data/information for fine-tuning N requirements for specific circumstances.
   - Understanding the mineral N content of soils and N uptake by the crop following N fertiliser applications.
   - Determining the N-use efficiency and economics of different N application rates as a base-line for assessing the effectiveness of enhanced efficiency fertiliser (EEF) formulations.

2. Two new field trials namely Bdb TN and Hbt TN were established in the Bundaberg and Herbert districts respectively to assess the advantage of using N fertiliser within ‘temporal’ strategies i.e. split applications of urea and/or use of EEFs to supply N in a controlled manner.

5.2.1. Bundaberg N x K trial

5.2.1.1. Trial site

The long-term N x potassium (K) trial (Bdb NxK) was originally established in 2004 at Welcome Creek (Lat. 24.788°S, Lon. 152.297°E) north-north-west of Bundaberg on a Red Clay Loam (Schroeder *et al*., 2007a) of the Otoo series (Donnollan *et al*., 1988). Selected analysis results of soil samples (0 – 20 and 40 – 60 cm) collected across the site prior to establishing the trial (Aug 2004) and from the control plots (Nov 2008 and Dec 2012) are shown in Table 5-1. The Org C content of the topsoil was moderately low (about 1.0 %). The effective cation exchange capacity (ECEC) of the topsoil was low. The ECEC of the subsoil was lower than that of the topsoil despite an increase in clay (%) with depth. The higher ECEC in the topsoil was presumably due to the Org C content. The K reserve (Nitric K) was low and exchangeable K (Exch K) decreased with time.

In 2014, the third ratoon (3R) of the second crop cycle was harvested as part of a previous project. Although the trial was then assumed ready for inclusion in this project as an older ratoon crop, the regrowth was severely affected by soldier fly infestation. As a result, the ratooning sugarcane was destroyed by ploughing-out and spraying with weedicide (glyphosate). Fortunately no fertiliser treatments had been applied at that stage. As a pest reduction strategy, the entire site was left as a bare fallow for the ensuing year. Following conventional tillage, sugarcane (cv. Q183[A]) was planted across the site on 8 September 2015 with 50 kg P/ha applied as triple super phosphate in the planting furrow.

Table 5-1 Selected soil chemical and physical properties of the Bdb NxK trial site based on samples collected from control plots in 2003, 2008 and 2014.

Soil property		Sampling date and depth											
		Aug 2004				Nov 2008				Dec 2012			
Assay	Units	0 - 20 cm		40 – 60 cm		0 – 20 cm		40 – 60 cm		0 – 20 cm		40 – 60 cm	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
$pH_{(water)}$	-	5.50	0.26	4.92	0.28	5.75	0.25	4.58	0.13	6.15	0.06	4.88	0.15
[1] Org C	(%)	1.01	0.09	-	-	1.03	0.09	-	-	1.02	0.10	-	-
[2] ECEC	cmol(+)/kg	3.57	0.60	2.59	0.32	3.07	0.66	2.24	0.12	3.54	0.24	2.04	0.20
Nitric K	cmol(+)/kg	0.36	0.04	-	-	0.26	0.05	-	-	-	-	-	-
Exch K	cmol(+)/kg	0.27	0.02	0.05	0.01	0.07	0.01	0.03	0.01	0.13	0.02	0.04	0.01
Coarse sand	%	30		21		-`							
Fine sand	%	35		18		-							
Silt	%	11		9		-							
Clay	%	25		53		-							

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

5.2.1.2. Treatments, trial design and details

This project covered the plant crop (PC): 2015/16 and first ratoon (1R): 2016/17. Four rates of N (0, 75, 150 and 225 kg N/ha) as urea and four rates of K (0, 60, 120 and 180 kg K/ha) as muriate of potash were applied within a randomised factorial design layout containing four replicates (reps). The same treatment had been applied to the plots [7.32 m wide (4 rows wide with a row-spacing of 1.83 m) and 10 m long] since 2004. The outer rows in each plot were guard rows. Gaps of 1 m separated plots along the length of the cane rows. The N and K treatments were applied by hand adjacent to the emerging cane rows on 26 Nov 2015 (P crop) and 8 Oct 2016 (1R) followed by irrigation using a low-pressure lateral-boom irrigator.

5.2.1.3. Sampling, data collection, crop harvest and yields

Soil mineral N: Nitrate-N (NO_3^--N) and ammonium-N (NH_4^+-N) were determined on air-dried soil samples collected periodically during growth of the P and 1R crops in 20 cm increments to a depth of 80 cm from plots that had received 0, 75, 150 and 225 kg N/ha and where K was applied at 120 kg K/ha.

Leaf N: Total N [%N expressed on a dry matter (DM) basis] was determined on third leaf samples collected on 3/4 Mar 2016 (P crop) and 21/27 Mar 2017 (1R).

Crop N uptake: N uptake by the crop (kg N/ha) was determined from the N%DM of 6-stalk biomass samples (stalk, and leaves and tops) collected on 19 Sep 2016 (P crop) and 19 Sep 2017 (1R).

Yield: Sugarcane yields (tc/ha) and sugar yields (ts/ha) were determined by weighing the harvested billets from the two centre rows of each plot using an in-field weigh truck and collecting 6-stalk samples for commercial cane sugar (CCS) analysis. The P crop was harvested on 5 Oct 2016 and the 1R crop on 20 Sep 2017.

Rainfall: Monthly rainfall data for the period Sep 2015 to Sep 2017 [Bundaberg Aero Lat 24.91^{o}S, Lon 152.32^{O}E (Station 39128)] from the Bureau of Meteorology (BOM) website (http://www.bom.au).

Statistics: All trial data was analysed using Statistix Version 10.0

5.2.2. Mackay N x Farming Systems trials

5.2.2.1. Trial site

Two N x farming systems experiments (Mky NxFS1 and Mky NxFS2) were established on adjacent blocks at the Sugar Research Australia experiment station near Mackay (21^o 09’47.27’’ S, 149^o 06’46.71’’ E). The soil was a sandy clay loam (Chromosol) of the Pioneer series (Salter *et al*., 2015a). The experiments commenced in December 2011 and concluded in September 2017 when the fourth ratoon crop of sugarcane was harvested. This project covers the ratoon crops.

A background soil sample (0 – 20 cm) was collected from the site in September 2011. Analysis results showed that $pH_{(water)}$ = 4.9; Org C = 1.0 %; BSES P =40 mg/kg; ECEC = 3.59 cmol(+)/kg; colour – grey. Agricultural lime was applied at 2.5 t/ha on 21 September 2011 to ameliorate low soil pH.

The trials were established on a long-term experimental site where the crop residue (trash) was either burnt after harvest or retained on the soil surface as a green cane trash blanket (GCTB). The original experiment commenced in 1992 with trash management treatments maintained throughout the period. The site has previously been used for various experimental purposes (Chapman *et al.* 2001), including N response trials (Salter *et al.* 2010). Prior to the experiment reported here, sugarcane was last harvested at the site on 2 September 2010. A crop was not planted in 2011 due to extreme conditions associated with a La-Niña weather event that prevented appropriate site preparation. The site was managed as a bare fallow and received regular herbicide applications during this period.

In Mky NxFS1 row-spacing at the site was altered from 1.5 m spacing to 1.8 spacing in order to implement controlled traffic. This required a number of tillage operations. Beds were formed on a 1.8 m row spacing on 1 December 2011 with a bed renovator in preparation for planting a legume fallow crop. Unfortunately, seasonal conditions prevented the legume fallow from being planted.

Following the 2011-2012 wet season further tillage was required. The beds were reformed in June 2012. In Mky NxFS2, the 1.8 m beds established in the previous crop cycle were ripped with a bed ripper in Sep 2011 and the beds were reformed in Oct 2011 prior the planting of a soybean crop in Dec 2011 (see details below under "Treatments"). Sugarcane (cv. Q208) was planted across the two trial sites on 7 Aug 2012 using a double disc-opener planter followed by irrigation (50 mm) applied in each of two events in Sep and Nov 2012.

5.2.2.2. Treatments, trial design and details

Mky NxFS1: Trash management (burnt trash or GCTB) treatments were maintained throughout the trial period, based on the historical design. This included four replicated strips of burnt trash and GCTB, either 6 or 7 rows wide. Crop residues were burnt within two weeks of the previous crop harvest.

Nitrogen treatments were not imposed in the plant crop. During sugarcane planting all plots received 18.1 N, 18.4 P, 0 K and 12.8 S (kg/ha). On 25 October 2012 all plots received an additional 120 kg N/ha and 109 kg K /ha. Nitrogen rate treatments were imposed on the following ratoon crops (1R-4R) using urea. Rates were established in sub-plots within the larger trash management treatments, as a split plot design. Plot size was 25 m x 6 or 7 rows. Rates were as follows:

- First ratoon (1R): 0, 95, 150 and 200 kg N/ha
- Second ratoon (2R): 0, 95, 150 and 200 kg N/ha
- Third ratoon (3R): 0, 75, 150 and 200 kg N/ha
- Fourth ratoon (4R): 0, 75, 150 and 200 kg N/ha

The 150 kg N/ha treatment was based on the SIX EASY STEPS nutrient management guidelines (Schroeder *et al.* 2005). The 95 kg N/ha treatment, which changed to 75 kg N/ha later in the crop cycle, was broadly based on the N-Replacement strategy where the previous crops yield was used to determine N rate (Thorburn *et al.* 2003a). The 0 and 200 kg N/ha rates allowed the development of N response curves and calculation of NUE parameters.

Mky NxFS2: The experimental design of this farming systems experiment, specifically fallow management treatments, were reported previously (Salter *et al.* 2015b). Briefly, these included soybean (SF) or bare fallow (BF) followed by zonal (ZT) or no tillage (NT). Soybean (cv. Leichhardt) was planted on 20 Dec 2011. Two soybean rows were established on each planting bed. The soybean crop was terminated on 18 Apr 2012 with the application of glyphosate. Soybean grain was not harvested. Soybean crop biomass was 22.4 (fresh t/ha) or 6.1 (dry t/ha) with an estimated N contribution (including root biomass) of 169 kg N/ha. Beds in the ZT treatment were tilled (30 Jul 2012) with one pass of a wavy (scalloped)-disc cultivator following termination of the soybean crop. Plot size was 50 m x 6 rows, with four replicates, arranged as a split plot design with tillage as the main plot and fallow system as the sub-plot.

During sugarcane planting all plots received 18.1 N, 18.4 P, 0 K and 12.8 S (kg/ha). On 25 Oct 2012 plots following the bare fallow treatment received an additional 120 kg N/ha as urea. All plots also received 100 kg K/ha, which also occurred for all sugarcane crops in the crop cycle. This established plots following bare fallow that received 138 kg N/ha of N fertiliser and plots following soybean fallow that received 18 kg N/ha of N fertiliser. These rates were in line with the industry's SIX EASY STEPS nutrient management guidelines for both bare and soybean fallow farming systems.

In the 1R crop, plots were split (25 m x 6 rows) to include two fertiliser N rates (0 and 150 kg N/ha). This was done in order to investigate whether N from a soybean fallow was available to early ratoon crops in the sugarcane crop cycle. These treatments were maintained in the 2R crop. As there did not appear to be any influence of fallow management on crop N response in the 1R and 2R first and second ratoon crops, the trial was altered in the 3R crop to investigate the influence of previous N management on crop N response. Plots either received 0 or 150 kg N /ha following a history of 0 kg N/ha or received 0 or 150 kg N/ha following a history of 150 kg N/ha. These N rate treatments were maintained in the 4R crop.

Treatments were applied to Mky NxFS1 and Mky NxFS2 on 22 Oct 2013 (1R), 14 Oct 2014 (2R), 20 Oct 2015 (3R) and 31 Oct 2016 (4R) using a calibrated 'stool splitter' fertiliser applicator.

5.2.2.3. Sampling, data collection, crop harvest and yields

Soil mineral N: NO_3^--N and NH_4^+-N were determined on air-dried soil samples collected periodically to a depth of 80 cm (0-10, 10-30, 30-50 and 50-80 cm) from the shoulders of the beds in each plot in two replicates of each trial during growth of the 1R, 2R, 3R and 4R crops. Bulk density for the soils were assumed to be 1.3, 1.4, 1.5 and 1.5 g/cm^3 for the four depth increments, respectively. This was based on previous experimental work at the trial site (Page *et al.*., 2013).

Leaf N: Total N [%N expressed on a dry matter (DM) basis] was determined on third leaf samples collected on 25 Feb 2015 (2R), 29 Feb 2016 (3R) and 1 Mar 2017 (4R).

Crop N uptake: N uptake by the crop (kg N/ha) was determined from the N%DM of biomass samples (stalk, and leaves and tops) collected at 3, 6, 9 and 12 months after harvest (MAH) of the preceding crop.

Yield: Sugarcane yields (tc/ha) and sugar yields (ts/ha) were determined by weighing the harvested billets from the two centre rows of each plot using an in-field weigh-tipper and collecting 6-stalk samples for commercial cane sugar(CCS) analysis. The harvest dates were: 25 Aug 2014 (1R), 2 Sep 2015 (2R), 29 Sep 2016 (3R) and 24 Aug 2017 (4R).

Rainfall: Data for the trial period was sourced from the Bureau of Meteorology station located at Dumbleton Rocks (Station 033300).

5.2.3. Macknade N x Farming Systems trials

5.2.3.1. Trial sites

Two long-term N x farming systems (FS) trials were originally established at Macknade (Lat. 18.586^{o}S, Lon. 146.249^{o}E) north east of Ingham in 2008 as part of a previous project. The one trial (Mkd NxFS1) was located on a silty loam River Bank soil (Wood *et al*., 2003) of the Macknade series (Wilson and Baker, 1990) and the other (Mkd NxFS2) on a heavier Clay Loam soil (Wood *et al*., 2003) of the Leach series (Wilson and Baker, 1990). Selected analysis results of soil samples (0 – 20) collected across the sites prior to establishing the trials (Aug 2007) are shown in Table 5-2. These data include baseline NO_{3-}N, NH_4^+-N and Min-N values.

In the first crop cycle of these trials (prior to this project), five rates of N (0, 40, 80, 120 and 160 kg N/ha) were applied annually as urea to two FS treatments [conventional tillage with a row-spacing of 1.55 m, and pre-formed beds (minimum tillage) with a row-spacing of 1.85 m] within a randomised split-plot design layout. Mkd NxFS1 contained four replicates (reps) and Mkd NxF2 contained six reps. Each plot in the conventional tillage treatments was 6 rows (9.3 m) wide and 20 m long. The plots that contained the preformed beds were also 6 rows wide (11.1 m) and 20 m long.
The 3R crops of the above mentioned crop cycle (2008 – 2012) of trials Mkd NxFS1 and Mkd NxFS2 were harvested in Aug 2012. Regrowth after the 3R crop at each trial site was sprayed-out with glyphosate on 29 Sep 2012. The cropping zones in the 1.85 m permanent beds at the Mkd NxFS1 site were lightly tilled on 7 Nov 2012 with a single pass of a set of wavy discs. The permanent beds in Mkd NxFS2 were not tilled (zero till). The conventional tillage treatment areas in both trials were

tilled over the period 1 to 6 Nov 2012 with four passes of a bed renovator that had six off-set discs and three ripper legs. A soybean fallow crop was planted on 7 Jan 2013 across both sites. Biomass samples of the soy bean were collected on 11 Apr 2013 from 1.85 m^2 areas in each of the farming systems treatments (conventionally tilled and permanent beds) within the previous sugarcane rep areas. The contributions of N (kg N/ha) by the soy bean fallow crop (sprayed out with glyphosate on 14 Apr 2013) were calculated from the dry biomass and N%DM values (Table 5-3).

Table 5-2 Selected soil chemical and physical properties and initial nitrate, ammonium and mineral n values for the Mkd NxFS1 and Mkd NxFS2 trial sites.

Soil property (0 - 20 cm)		Trial site: Aug 2007			
		Mkd NxFS1		Mkd NxFS2	
Assay	Units	0 - 20 cm		0 - 20 cm	
		Mean	SD	Mean	SD
$pH_{(water)}$	-	5.7	0.1	5.9	0.2
[1] Org C	(%)	0.78	0.10	0.87	0.04
[2] ECEC	cmol(+)/kg	6.32	0.22	9.88	0.13
NO_3^--N	mg/kg	0.73	0.40	0.93	0.38
NH_4^+- N	mg/kg	4.33	0.74	3.23	0.12
Min-N	mg/kg	5.07	1.05	4.17	0.35
Estimated coarse sand	%	20		22	
Estimated fine sand	%	54		31	
Estimated silt	%	14		20	
Estimated clay	%	12		27	

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

Table 5-3 Details of soy bean fallow biomass prior to the second crop cycle in trials Mkd NxFS1 and Mkd NxFS2.

Trial	FS treatment	Fresh biomass (t/ha)		Dry biomass (t/ha)		N content (N%dm)		N contribution (kg N/ha)	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
Mkd NxFS1	Conventional tillage	25.3	2.9	5.3	0.7	3.5	-	188	23
	Permanent beds	15.5	5.4	3.2	1.0	3.7	-	119	37
Mkd NxFS2	Conventional tillage	21.9	5.3	4.6	1.1	3.5	-	160	39
	Permanent beds	16.7	6.1	3.7	1.5	3.5	-	130	51

5.2.3.2. Treatments, trial design and details

Sugarcane cultivars Q208 and MQ239 were planted across the Mkd NxFS1 and Mkd NxFS2 sites on 7 and 19 June 2013 respectively. A dual row double disc whole stalk planter was used on the permanent beds and a single row double disc whole stalk planter was used in the conventionally tilled plots. Muriate of potash (100 kg K/ha) was applied to all plots on 28 June 2013. The N fertiliser treatments (0, 40, 80, 120, 160 kg N/ha as urea) were applied to the P crop adjacent to the cane rows in the relevant plots in Mkd NxFS1 and Mkd NxFS2 on 21 Nov 2013 and 26 Nov 2013 respectively. The trial design and layout remained as before. The N treatments (0, 50, 100, 150 and 200 kg N/ha) were applied by hand to the relevant plots (adjacent to the rows of emerging cane) during the ensuing ratoons crops as follows – Mkd NxFS1: 10 Nov 2014 (1R), 19 Nov 2015 (2R), 14 Dec 2016 (3R); Mkd NxFS2: 12 Nov 2014 (1R) and 21 Nov 2015 (2R).

5.2.3.3. Sampling, data collection, crop harvest and yields

Soil mineral N: NO_3^--N and NH_4^+-N were determined on air-dried soil samples collected periodically to a depth of 80 cm (0-20, 20-40, 40-60 and 60-80 cm) from the shoulders of the beds in each plot in two replicates of each trial during growth of the plant and ratoon crops of both trials. Separate composite soil samples were also collected regularly during the cropping seasons for mineral N determinations. The samples were in 20 cm increments to a depth of 80 cm from the uncropped plots adjacent to the trials.

Leaf N: Total N [%N expressed on a dry matter (DM) basis] was determined on third leaf samples collected from Mkd NxFS1 on 26 Feb 2014 (PC), 10 April 2015 (1R), 31 March 2016 (2R) and 21 March 2017 (3R), and from Mkd NxFS2 on 20 Feb 2014 (PC), 10 Apr 2015 (1R), 1 Apr 2016 (2R).

Crop N uptake: Crop N uptake: N uptake by the crop (kg N/ha) was determined from the N%DM of biomass (stalk, and leaves and tops) collected during growth of the ratoon crops of Mkd NxFS1 – 1R: 18 Dec 2014. 25 May 2015, 2R – 8 Jan 2016, 24 Mar 2016, 24 May 2016 and 25 Aug 2016; 3R – 13 Jan 2017, 6 Jun 2017 and 21 Aug 2017; and Mkd NxFS2: 1R: 22 Dec 2014, 26 May 2015, 2R – 11 Jan 2016, 29 Mar 2016, 25 May 2016 and 26 Aug 2016.

Yield: The ratoon crops were harvested on the following dates using a mechanical harvester:

- Mkd NxFS1: 29 Sep 2015 (1R), 5 Sep 2016 (2R) and 24 Aug 2017 (3R)
- Mkd NxFS2: 30 Sep 2015 (1R) and 6 Sep 2016 (2R).

Sugarcane yields (t cane/ha) were determined by weighing harvested billets from the two centre rows of each plot using a tractor-drawn in-field weigh-tipper with load-cells. Prior to harvest 6-stalk samples were collected from each plot to determine CCS. Sugar yield (t sugar/ha) were calculated from the sugarcane yield and CCS values. Whereas trial Mkd NxFS1 continued after the 3R crop in a subsequent project (SRA2017/004), Mkd NxFS2 was sprayed out on 21 Oct 2016 so that the trial site could be used for other purposes in another project (SRA2017/009)**.**

Rainfall: Rainfall data for the period Sep 2014 to Sep 2017 was accessed for Macknade Lat -18.5867°, Lon 146.2547° (Station 32032) from the Bureau of Meteorology (BOM) website (http://www.bom.au).

Statistics: All trial data was analysed using Statistix Version 10.0.

5.2.4. Tully rates of N trials

5.2.4.1. Trial site

Two small-plot N response trials T1 (Lat. 17°58’42.3912”S, Long. 145°55’29.0886”E) and T3 (Lat. 18°0’7.1634”S, Long. 145°57’52.1994”E) were established in 1R crops of sugarcane cultivar Q208 in the Tully mill area in 2010 as part of a previous project (STU073). Both trials were located on Grey Dermosols (Isbell 1996) of the Bulgun series (Cannon *et al.* 1992). Selected analysis results of soil samples (0 – 20 cm) collected across the sites after harvesting the plant crop but prior to establishing the experiment in the 1R crop (25 and 26 August 2011) are shown in Table 5.4. These data include baseline NO_3^--N, NH_4^+-N and total mineral N values. Ratoon crops 1R, 2R and 3R were included in project STU073. This project (SRA2014/045) covers the ratoon crops subsequent to 3R.

Table 5-4 Selected soil chemical and physical properties and initial nitrate, ammonium and mineral N values for the T1 and T3 trial sites based on samples collected prior establishment (2011).

Soil property (0 - 20 cm)		Trial site 2011			
Assay	Units	T1		T3	
		Mean	SD	Mean	SD
$pH_{(water)}$	-	4.6	0.08	4.37	0.07
[1] Org C	(%)	1.71	0.21	1.41	0.15
[2] ECEC	cmol(+)/kg	3.45	0.29	3.43	0.03
NO_3^--N	mg/kg	2.82	6.69	2.38	0.46
NH_4^+-N	mg/kg	9.91	0.94	17.14	4.52
Min-N	mg/kg	12.73	7.13	19.52	4.41
Estimated coarse sand	%	8		13	
Estimated fine sand	%	33		32	
Estimated silt	%	32		26	
Estimated clay	%	27		29	

[1]Walkley and Black (1934); [2]Effective Cation Exchange capacity

5.2.4.2. Treatments, trial design and details

Twelve rates of N (0, 30, 60, 75, 90, 105, 120, 135, 150, 180, 210 and 240 kg N/ha) were applied to the same plot locations each year as urea within a randomised complete block design layout containing four replicates. Each plot was 6 rows (9.6 m) wide and 30 m long. Gaps of 1 m separated plots along the length of the cane rows. Treatment applications were applied subsurface to each side of the emerging cane row on the following dates – T1: 2 Oct 2014 (4R), 26 Oct 2015 (5R) and 15 Nov 2016 (6R); T3: 3 Oct 2014 (4R) and 29 Oct 2015 (5R). Nutrients other that N were applied according to the results of soil tests.

5.2.4.3. Sampling, data collection, crop harvest and yields

Soil mineral N: NO_3^--N and NH_4^+-N were determined on air-dried soil samples collected to a depth of 80 cm (0-10, 10-30, 30-50 and 50-80 cm) from the shoulders of the rows in each plot in two replicates (reps 1 and 3) of each trial. The sampling dates were as follows:

- T1: 1 Dec 2014 (3 mth 4R), 25 Jun 2015 (9mth 4R), 13 Oct 2015 (12 mth 4R); 15 Dec 2015 (3 mth 5R), 3 Mar 2016 (6 mth 5R), 10 Jun 2016 (9 mth 5R), 14 Oct 2016 (12 mth 5R) and 22 Sep 2017 (12 mth 6R).
- T3: 2 Dec 2014 (3 mth 4R), 26 Jun 2015 (9mth 4R), 15 Oct 2015 (4R), 16 Dec 2015 (3 mth 5R), 8 Jun 2016 (9 mth 5R), 13 Oct 2016 (12 mth 5R).

Leaf N: Total N [%N expressed on a dry matter (DM) basis] was determined on third leaf samples collected from T1 on 19 Mar 2015 (4R), 6 Apr 2016 (5R), 20 March 2017 (6R) and T3 on 20 Mar 2015 (P4), 6 Apr 2016 (5R).

Crop N uptake: N uptake by the crop (kg N/ha) was determined from the N%DM of biomass (stalk, and leaves and tops) collected during growth of the ratoon crops:

- T1 – 4R: 27 Nov 2014 (3 month), 24 Jun 2015 (9 month) and 17 Sep 2015 (12 month); 5R: 7 Dec 2015 (3 month), 29 Feb 2016 (6 month), 31 May 2016 (9 month) and 21 Sep 2016 (12 month); and 6R: 26 Jan 2017 (3 month) and 8 Jun 2017 (9 month) (6R).
- T3 – 4R: 28 Nov 2014 (3 month), 23 Jun 2015 (9 month) and 18 Sep 2015 (12 month); and 5R: 8 Dec 2015 (3 month), 6 Jun 2016 (9 month) and 22 Sep 2016.

Yield: The ratoon crops were harvested on the following dates – T1: 17 Sep 2015 (4R), 21 Sep 2016 (5R) and 8 Sep 2017 (6R); and T3: 18 Sep 2015 (4R) and 22 Sep 2016 (5R). Sugarcane yields (t cane/ha) were determined by weighing harvested billets from the two centre rows of each plot using an in-field weigh tipper haul-out truck fitted with a load-cell. At harvest, 6-stalk samples were randomly collected from each plot to determine CCS content. Sugar yield (t sugar/ha) were calculated from the sugarcane yield and CCS values.

Rainfall: Rainfall data for the period Sep 2014 to Sep 2017 was accessed for Tully Sugar Mill Lat -17.9364°, Lon 145.9253° (Station 32042) from the Bureau of Meteorology (BOM) website (http://www.bom.au).

Statistics: All trial data was analysed using Statistix Version 10.0.

5.2.5. Bundaberg temporal N trial

5.2.5.1. Trial site

The temporal N trial (Bdb TN) was established in 2015 at Welcome Creek (Lat. 24.788°S, Lon. 152.297°E) north-north-west of Bundaberg on a Red Clay Loam soil (Schroeder *et al*., 2007a) of the Otoo series (Donnollan *et al*., 1988). This soil is located in a well-drained position and is moderately permeable. Selected analysis results of soil samples (0 – 20cm) collected across the site prior to establishing the trial are shown in Table 5-5. Prior to establishment, the site was used for commercial cane production.

Table 5-5 Selected soil chemical and physical properties of the trial site (Bdb TN) based on samples collected on 15 May 2015.

Soil property		Value
Assay	Units	0 - 20 cm
$pH_{(water)}$	-	5.8
[1] Org C	(%)	1.1
[2] ECEC	cmol(+)/kg	3.3
Texture	-	Light clay

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

5.2.5.2. Treatments, trial design and details

In this trial, two rates of N (120 and 160 kg N/ha) applied as DMPP-coated and poly-coated urea (DMPP-urea and PC-urea respectively) were compared to urea applied as split applications that totalled either 120 kg N/ha or 160 kg N/ha (Table 5-6). A control treatment was included. A randomised complete block design layout was used containing four replicates. Each plot was 10.98 m wide (6 rows wide with a row-spacing of 1.83 m) and 30 m long. Gaps of 1 m separated plots along the length of the cane rows. Prior to establishment, the site was used for commercial cane production. The block was planted on 9 Sep 2015 (cv. Q183) with di-ammonium phosphate (DAP) fertiliser applied in the planting furrow. This was necessary due to the P requirement indicated by a soil test. The N treatments (that included the N in the DAP) were applied according to the schedule in Table 5-6. The side-dressings were applied by hand on the shoulder of the cane rows in each plot. Irrigation was applied shortly after the treatment applications.

The N treatments to the 1R crop (120 and 160 kg N/ha) were applied as before using DMPP-coated, poly-coated urea and urea as split applications were applied according to the schedule in Table 5-7. Irrigation was applied shortly after the treatment applications.

Table 5-6 N treatments applied to the plant crop in the temporal N trial (Bdb TN) at Welcome Creek near Bundaberg.

Treatment	Fertiliser formulation applied during side-dressing	N applications (kg N/ha)				Total N applied (kg N/ha)
		Initial as DAP[1] (9 Sep 2015)	Side-dressings			
			1st (25 Nov2015)	2nd (30 Dec 2015)	3rd (28 Jan 2016)	
12	Control	40	0	0	0	40
2	Urea	40	40	20	20	120
1	Urea	40	40	40	0	120
6	Urea	40	80	0	0	120
8	DMPP-urea	40	80	0	0	120
10	Poly-urea	40	80	0	0	120
4	Urea	40	80	40	0	160
3	Urea	40	80	20	20	160
11	Urea	40	40	40	40	160
7	Urea	40	120	0	0	160
5	DMPP-urea	40	120	0	0	160
9	Poly-urea	40	120	0	0	160

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

Table 5-7 N treatments applied to the 1R crop in the temporal N trial (Bdb TN) at Welcome Creek near Bundaberg.

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

5.2.5.3. Sampling, data collection, crop harvest and yields

Soil mineral N: Nitrate-N and NH_4^+-N were determined on air-dried soil samples collected periodically from the shoulders of the rows in all plots in reps 1 and 3 of the P and 1R crops. The samples were collected in 20 cm increments to a depth of 80 cm.

Leaf N: Total N [%N expressed on a dry matter (DM) basis] was determined on third leaf samples collected from all plots in Mar 2016 (PC) and Mar 2017 (1R).

Crop N uptake: Crop N uptake: N uptake by the crop (kg N/ha) was determined from the N%DM of biomass (stalk, and leaves and tops) collected during growth of the plant and 1R crops.

Yield: Sugarcane yields (tc/ha) and sugar yields (ts/ha) were determined by weighing hand harvested cane from two centre rows of each plot using an in-field weigh platform. Six-stalk samples were collected for CCS analysis. The P crop was harvested on 21/22 Sep 2016 and the 1R crop on 28 Sep 2017.

Rainfall: Monthly rainfall data for the period Sep 2015 to Sep 2017 [Bundaberg Aero Lat 24.91°S, Lon 152.32°E (Station 39128)] from the Bureau of Meteorology (BOM) website (http://www.bom.au).

Statistics: All trial data was analysed using Statistix Version 10.0.

5.2.6. Herbert temporal N trial

5.2.6.1. Trial site

The temporal N trial (Hbt TN) was established at Tara (Lat. 18°35’22’’S, Lon. 146°19’35’’E) in the Herbert district north of Ingham in 2015 on a Clay soil (Wood *et al*., 2003) of the Hamleigh series (Wilson and Baker, 1990). It is located in a poorly drained position in the landscape and is subject to seasonally high water tables. Selected analysis results of soil samples (0 – 20cm) collected across the site prior to stablishing the trial are shown in Table 5.8. Prior to establishment, the regrowth following the commercially harvested ratoon cane that was harvested in Oct 2014 was sprayed out and then disced in. The area was left as a grass fallow until planting. During this period agricultural lime was surface applied at 2.4 t/ha on 1 July 2015 and then incorporated. Commercial fertiliser GF320 134 kg/ha (20 kg P, 7 kg/ha S, 22 kg/ha Ca) was applied across the site prior to planting. Following the PC, commercial fertiliser GF320 (20 kg P, 7 S, 22 Ca) was applied at a rate of 139 kg/ha across the site on 11 Nov 2016 followed by 100 kg/ha of muriate of potash on 14 Nov 2016.

Table 5-8 Selected soil chemical and physical properties of the trial site (Hbt TN) based on samples collected on 15 May 2015.

Soil property		Value
Assay	Units	0 - 20 cm
$pH_{(water)}$	-	5.3
[1] Org C	(%)	2.15
[2] ECEC	cmol(+)/kg	7.8
Texture	-	Medium clay

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

5.2.6.2. Treatments, trial design and details

The block was planted on 14 Aug 2015 with sugarcane cultivar Q208. An initial light irrigation was applied on 18 Aug 2015 due to the prevailing dry soil conditions. Five rates of N (0, 60, 120, 160, 200 kg N/ha) applied by hand as urea, DMPP-urea and PC-urea on 7 – 9 Dec 2015 within a randomised complete block design layout containing three replicates. This was followed by ‘hilling- up’ of the cane rows. Each plot was 10.08 m wide (6 rows wide with a row-spacing of 1.67 m) and 29 m long. The outer rows in each plot were guard rows. Gaps of 1 m separated plots along the length of the cane rows. The N treatments ((0, 60, 120, 160, 200 kg N/ha) as urea, DMPP-urea and PC-urea were applied to the appropriate plots on 15-17 Nov 2016 using a single row stool splitter fertiliser box.

5.2.6.3. Sampling, data collection, crop harvest and yields

Soil mineral N: Initial NO_3^--N and NH_4^+-N values were determined on soil samples were collected to a depth of 1 m in 20 cm increments from the shoulders of the rows of some of the intended treatments plots [i.e. where urea (0 kg N/ha), urea (60 kg N/ha), urea (120 kg N/ha), and urea (160 kg N/ha) were to be applied] in all the designated replicate areas on 31 Aug 2015. Further samples were collected in the same way to a depth of 80 cm from each plot in reps 1 and 3 on 10 Oct 2016

Leaf N: Total N [%N expressed on a dry matter (DM) basis] was determined on third leaf samples collected from each plot on 8 Apr 2016 (PC) and 22 Mar 2017 (1R).

Crop N uptake: N uptake by the crop (kg N/ha) was determined from the N%DM of biomass (stalk, and leaves and tops) collected during growth of the ratoon crops:

- PC: 8 Jan 2016, 19 May 2016 and at harvest on 24 Aug 2016.
- 1R: 17 Jan 2017 and 17 Jun 2017.

Yield: Sugarcane yields (tc/ha) were determined by weighing hand harvested cane from pre-determined areas within the two centre rows of each plot – PC: 24 Aug 2016 with the remaining cane in each plot harvested mechanically on 8 Sep 2016; 1R: 27 Jun 2017 with the remaining cane in each plot harvested on 5 Aug 2017. Sugar yields (ts/ha) were calculated from yield data and CCS values determined from the 'six-stalk' samples collected at harvest.

Rainfall: Rainfall data for the period Sep 2015 to Sep 2017 was accessed for Macknade Lat -18.5867°, Lon 146.2547° (Station 32032) from the Bureau of Meteorology (BOM) website (http://www.bom.au).

Statistics: All trial data was analysed using Statistix Version 10.0.

5.3. Pot experiments conducted in semi-controlled environments

5.3.1. N-uptake by sugarcane

Two pot were conducted to quantify N uptake by young cane plants to establish whether this could be a factor in the enhanced efficiency fertiliser (EEF) trials described above.

5.3.1.1. Pot experiment USQ1

Details: The pot experiment trial was conducted from November 2014 to March 2015 in a temperature-controlled glasshouse at the University of Southern Queensland (USQ) in Toowoomba. It was laid out in a randomised block design that included three sugarcane cultivars (Q200, Q208 and Q240), five harvest times and four replicates. The 9L pots were filled to 50 mm from the top of pot with a 50:50 mix by volume of coarse grade perlite and vermiculite. The pots were watered regularly to estimated field capacity and any leachate was captured in a saucer and returned to the pot. Three pre-germinated old single-eyed sugarcane setts were planted in each pot. Nutrients were applied at rates assumed to be non-limiting for plant growth (equivalent of 200 kg N/ha, 30 kg P/ha, 150 kg K/ha and 150 kg Mg/ha). a second N fertiliser application (50 kg N/ha) was made at week 9 in case there was insufficient urease in the growth medium to enable full utilisation of urea-N by the plants.

Harvest procedure and N uptake: Harvests occurred at 4, 8, 11, 14 and 16 weeks after planting. Four plants of each variety of the seedlings were also harvested to determine the N content of the potted plants. Plants were partitioned into above ground and below ground parts. The plant parts from all three plants per pot were combined into one sample. Total N [%N expressed on a dry matter (DM) basis] was determined for the above, and below ground components of the harvested plants.

5.3.1.2. Pot experiment USQ2

Details: A second pot experiment was established at USQ in Nov 2015 to understand the pattern of N uptake over a longer period than the 16-week period assessed in USQ1. This time the trial was located outdoors, included only cv.Q208, and used a soil and sand growth-medium. Plants (cv Q208) were grown from pre-germinated one-eyed setts planted on 17 Dec 2015 in a replicated experiment with two N strategies (high and low) within different sized pots (9 – 26 L) depending on the length of the growth period. There were five sequential and destructive harvests. The growth medium was a 2/3 to 1/3 sand:clay mixture (i.e. 67% sand, 33% clay), hereafter referred to as 'sandy soil'. The 'sandy soil' was used to minimise the contribution of mineralisable soil N and maximise the contribution of applied fertiliser N to the plant throughout the experiment

Nitrogen was applied as urea to two treatment groups of plants. The 'High N' group received a high N rate of 350 kg/ha applied with 150 kg/ha applied at planting and the remainder throughout the experimental period (Table 5-9). The 'Lower N' group received 200 kg N/ha with applications of 50 kg/ha starting from 5 weeks after planting. A zero N rate was not included because the growth medium would not have supported the plants through to harvest. In total over the 21 weeks, P was applied at 210 kg/ha, K at 150 kg/ha, S at 143 kg/ha, Ca at 396 kg/ha and Mg at 150 kg/ha. Trace elements were also applied at label rates. The timing and products used to apply the nutrients are listed in Table 5.9.

All plants were watered regularly by hand using mains tap water. Leachate was not captured and was allowed to drain from the pots. Despite receiving 1026 mm of irrigation plus 299 mm of rain over the 21 weeks of the trial, the surface of the pots fell to 64% of estimated field capacity by 'Harvest 5'.

Table 5-9 Products and rates of N, P, K and S applied to each treatment in pot experiment USQ2.

Treatment	"High N'				'Lower N'				Products applied
Rates applied (kg/ha)	N	P	K	S	N	P	K	S	
At planting	150	30	150	104	0	30	150	104	Urea, superphosphate, potassium sulphate, dolomite
3.5 weeks after planting (11/01/2016)		30		39		30		39	superphosphate
5 weeks, not applied to H1 pots (21/01/2016)	50	30			50	30			Urea, phosphoric acid (liquid), trace elements (Yates trace chelates)
10 weeks to all plants (25/02/2016)		30				30			Phosphoric acid (liquid)
12 weeks, not applied to H2 pots (11/03/2016)	50	30			50	30			Urea, phosphoric acid (liquid),
15 weeks, not applied to H3 pots (01/04/2016)	50	30			50	30			Urea, phosphoric acid (liquid),
18 weeks, not applied to H4 pots (21/04/2016)	50	30			50	30			Urea, phosphoric acid (liquid),
Total	350	210	150	143	200	210	150	143	

Harvest procedure and N uptake: Pots of plants were destructively harvested at 6 (H1), 12 (H2), 15 (H3), 18 (H4) and 21 (H5) weeks after planting. Total N content as a percentage of dry matter was determined for all harvested plant samples.

5.3.2. Supply and uptake of N when enhanced efficiency fertilisers are used.

5.3.2.1. Pot experiment Bdb1.

An N fertiliser formulations pot experiment was conducted in a glasshouse at SRA, Bundaberg. It was established on 2 September 2015. The aim was to understand aspects of N uptake and NUE in young sugarcane plants when different temporal N options were used. The pot experiment provided supporting information for the field trial (Bdb TN) conducted at Welcome Creek (see section 5.2.5). Soil for the experiment was sourced from that trial site and the sugarcane cultivars were Q200 and Q208. The treatments that were applied are shown in Table 5-10. There were four replications within a randomized block design layout. The intention was to maintain the soils in the pots at field capacity using an semi-automated dripper irrigation system. However, any excess water that leached to the saucers was returned to the appropriate pot. The above ground plants were harvested in mid-Dec 2015. The plant material from each pot was partitioned into stalk, and leaves and tops, and then placed in a drying oven at 65°C. The dry mass was determined. Samples were then prepared and submitted to the laboratory for N analyses.

Table 5-10 Details of treatments applied to the N fertiliser formulations pot experiment conducted in Bundaberg (Bdb1).

Treatment No.	Sugarcane variety	N treatment including formulation at equivalent rate of N applied
1	Q208	PC-coated urea 150kg N/ha
2	Q200	DMPP-coated urea 75 kg N/ha
3	Q208	PC-coated urea 75kg N/ha
4	Q208	DMPP-coated urea 0 kg N/ha
5	Q200	PC-coated urea 225 kg N/ha
6	Q200	DMPP-coated urea 150 kg N/ha
7	Q208	DMPP-coated urea 225 kg N/ha
8	Q200	Urea 225 kg N/ha
9	Q208	PC-coated urea 225 kg N/ha
10	Q208	Urea 225 kg N/ha
11	Q208	PC-coated urea 0 kg N/ha
12	Q200	PC-coated urea 150kg N/ha
13	Q208	DMPP-coated urea 150 kg N/ha
14	Q208	Urea 150 kg N/ha
15	Q200	Urea 150 kg N/ha
16	Q200	Urea 0 kg N/ha
17	Q208	Urea 75 kg N/ha
18	Q200	PC-coated urea 75kg N/ha
19	Q208	DMPP-coated urea 75 kg N/ha
20	Q208	Urea 0 kg N/ha
21	Q200	DMPP-coated urea 225 kg N/ha
22	Q200	PC-coated urea 0 kg N/ha
23	Q200	Urea 75 kg N/ha
24	Q200	DMPP-coated urea 0 kg N/ha

5.3.2.2. Pot experiments Bdb2

A second N fertiliser formulations / temporal N pot experiment was established at SRA Bundaberg in July 2016. The N treatments (urea and EEFs) and plot plan are shown in Figure 5-1. Two irrigation treatments were used: I1 (soil retained at field capacity) and I2 (soils retained at field capacity plus three simulated ‘downpour’ events). The trial was harvested on 19 Dec 2016 with leaves and tops per pot weighed separately to the harvested stalks. The samples were prepared and sent to the laboratory for analysis.

Trt	Nitrogen treatments
N1	Agromaster 225 kg N/ha
N2	Agromaster 150kg N/ha
N3	Urea 75 kg N/ha
N4	Entec 75 kg N/ha
N5	Urea 150 kg N/ha
N6	Entec 150 kg N/ha
N7	Agromaster 75kg N/ha
N8	Urea 225 kg N/ha
N9	Entec 225 kg N/ha
N10	Agromaster 0 kg N/ha
N11	Urea 0 kg N/ha
N12	Entec 0 kg N/ha

Trt	Irrigation treatments
I1	Field capacity
I2	Field capacity plus 3 'downpour' events

						Row	Rep
91	92	93	94	95	96	16	4
N11	N2	N12	N8	N2	N5		
85	86	87	88	89	90	15	
N6	N4	N10	N10	N3	N9		
79	80	81	82	83	84	14	
N3	N1	N5	N4	N11	N12		
73	74	75	76	77	78	13	
N7	N8	N9	N7	N6	N1		
67	68	69	70	71	72	12	3
N7	N8	N10	N6	N3	N2		
61	62	63	64	65	66	11	
N2	N5	N11	N4	N9	N5		
55	56	57	58	59	60	10	
N9	N3	N6	N7	N10	N11		
49	50	51	52	53	54	9	
N1	N4	N12	N1	N8	N12		
43	44	45	46	47	48	8	2
N9	N10	N3	N1	N11	N3		
37	38	39	40	41	42	7	
N12	N4	N2	N5	N7	N2		
31	32	33	34	35	36	6	
N8	N1	N6	N4	N10	N9		
25	26	27	28	28	30	5	
N5	N7	N11	N6	N12	N8		
19	20	21	22	23	24	4	1
N10	N12	N2	N6	N5	N1		
13	14	15	16	17	18	3	
N8	N5	N6	N9	N2	N4		
7	8	9	10	11	12	2	
N4	N1	N11	N3	N10	N12		
1	2	3	4	5	6	1	
N3	N9	N7	N11	N8	N7		

Variety: Q208	
Trial established: 22 Aug 2016	
'Down pour' event 1: 15/09/2016	
'Down pour' event 2: 12/10/2016	Doorway into glasshouse
'Down pour' event 3: 16/11/2016	
Trial harvested: 19/12/2016	

Figure 5-1 Second N fertiliser formulations pot experiment conducted in Bundaberg (Bdb2) – treatments and plot plan.

5.4. Spatial aspects of the PA and Bdb NxK trial sites

The previous Precision Agriculture (PA) site used within SRRD/SRA project CSE022 (Bramley *et al.*, 2014) provided a resource to investigate spatial aspects of this project. The site is located at Welcome Creek near Bundaberg (Figure 5-2). This site has been well characterised because of extensive soil and crop sampling that was undertaken within previous Sugar Research and Developments Corporation (SRDC)/SRA funded projects BSS232, BSS268 and CSE022. The NxK trial site (Bdb NxK) lies within this site. Its perimeter is shown by the red outline in Figure (5-2). ArcGIS was used to produce visual images.

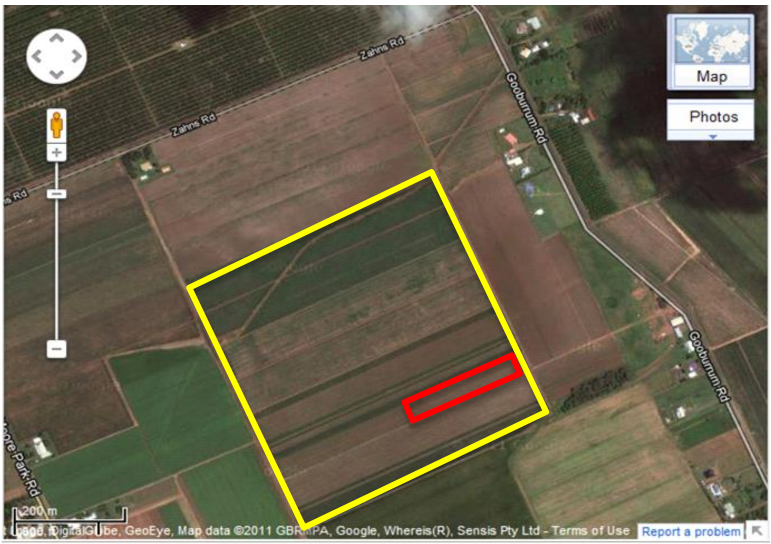


Figure 5-2 PA site at Welcome Creek near Bundaberg.
The perimeter of the site is shown in yellow. The location of the NxK factorial trial (Bdb NxK) is shown in red.

5.5. Adjustments to the N guidelines (if appropriate) within the SIX EASY STEPS program

Data/information from the trials and experiments described above and from other sources were collated and assessed on several occasions to determine whether there were any implications for adjusting the N guidelines within the SIX EASY STEPS program.

A project review and planning meetings was used to formulate a strategy for dealing with adjustments to the nutrient guidelines within the SIX EASY STEPS program.

5.6. Development of an updated SIX EASY STEPS short course

The SIX EASY STEPS short course was reviewed by the project team within in a specially-convened workshop. Necessary changes were identified, particularly in relation to outcomes and outputs from the activities described in 5.4. Information and slides were updated subsequent to the initial workshop. A further meeting was held during which the updated SIX EASY STEPS short course was presented to the project team and invited guests. Further changes were identified, again with particular reference to the activities in highlighted in Section 5.4.of this report. A second updating of the short course followed. Other implication from Section 6 of this report were discussed.

6. RESULTS AND DISCUSSION

6.1. Re-evaluation of the basic tenets of various N management strategies

6.1.1. Review of the principles and basic mechanisms that underpin the various N management 'systems' available to, or used in, the Australian sugar industry

A review of the principles and mechanisms of the various N management 'systems' was included in Chapter 2 (Schroeder *et al*., 2015) of the "Review of nitrogen-use efficiency (NUE) in sugarcane in Australia" (Bell, 2015). A summary of some of that information is provided/reproduced below for completeness of this report.

Schroeder *et al*. (2009b) recognised that the overall farming system used generally across the Australian sugar industry changed over the years according to the following progression:

- 'Historical approach' of the 1960s and 1970s (sugarcane grown as a plant crop and two ratoons with a fallow period between crop cycles and burning of cane prior to harvest),
- 'Cane-on-cane' period of the 1980s and 1990s (sugarcane grown in cycles of plant crop and three ratoons with limited bare fallow areas),
- 'Improved system' of the 2000s (sugarcane grown as a plant crop and four ratoons with break crops grown between sugarcane crop cycles, green-cane trash retention widely used in most areas, and increasing adoption of controlled traffic and minimum tillage operations).

During the 'cane-on-cane' period, N inputs increased substantially from a previous average of 115 kg N/ha for plant cane and 120 kg N/ha for ratoon cane, to 150 kg N/ha for plant cane and 170 kg N/ha for ratoon cane (Schroeder *et al*, 2009b). This upward trend in N usage occurred despite the existence of general and somewhat 'generous' N rates (Table 6-1) that were based on BSES-derived production functions (Chapman, 1994) and contained in the Australian Sugarcane Nutritional Manual (Calcino, 1994). Growers appeared to favour applying higher N rates than these guidelines and often adopted their own N management strategies to mitigate against productivity losses (Thorburn *et al*., 2003b). It was estimated from surveys that 80% of growers applied N to plant crops (following a fallow) in excess of the BSES N rates, 45% applied N to replant cane in excess of the recommendations, and 44% applied N to ratoon cane in excess of the recommendations (Schroeder *et al*., 2002, Calcino *et al*., 2010).

Table 6-1 Traditional N rates that were based on general production functions (Calcino, 1994).

Soil	Crop	Nitrogen fertiliser recommendations (kg N/ha)	
		Burdekin	All other regions
All soil types	Fallow plant	135 -150	120 – 150
	Replant and ratoons	210 – 250	160 – 200
		All regions	
Richland	Fallow plant	80	
	Replant and ratoons	120	

Recognition of the need for sustainable sugarcane production (i.e. profitability in combination with environmental responsibility) in the mid-1990s necessitated modifications to the past nutrient management strategies (Schroeder *et al*., 1998). This led to the development of two new approaches to N management i.e. the SIX EASY STEPS nutrient management principles and program (Schroeder *et al*., 2006) and the N-Replacement strategy (Thorburn *et al*., 2011).

6.1.1.1. SIX EASY STEPS nutrient management program

The "SIX EASY STEPS" is a comprehensive, integrated and science-based nutrient management program developed by and for the Australian sugar industry. It is recognised as the basis for developing, promoting and adopting nutrient BMPs in sugarcane production (Schroeder *et al*., 2015). As mentioned in the Introduction, the SIX EASY STEPS program consists of six logical steps that are intended for cyclical learning and continuous improvement as illustrated in Figure 6.1. The program focuses on profitable sugarcane production without adverse influences on soil fertility or off-farm effects. It promotes balanced nutrition and sustainable soil/nutrient management by considering all essential nutrients for sugarcane production. Importantly it recognises the range of districts, soil types and soil properties mentioned above. It is a nutrient management system that enables identification and adoption of nutrient management options for specific on-farm circumstances. The goal is to optimise conditions for effective, economic and efficient use of nutrients in the soil and those added by fertiliser/ameliorant applications

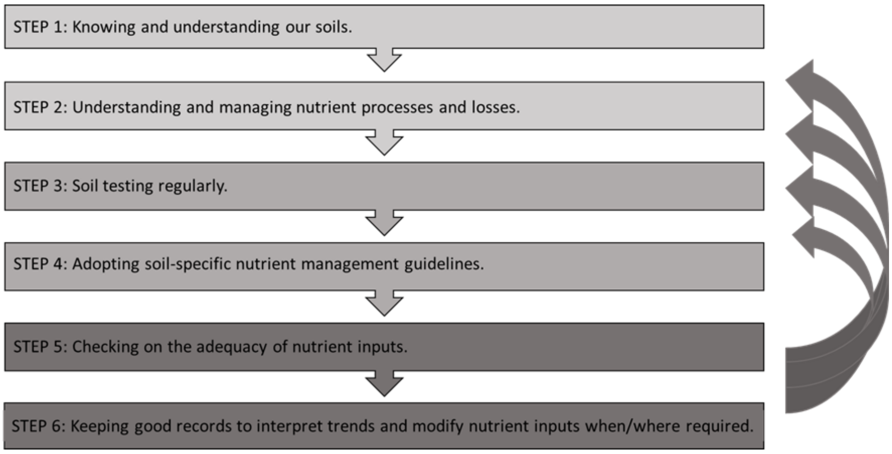


Figure 6-1 The six logical steps that are used for cyclical learning and continuous improvement within the SIX EASY STEPS program (as illustrated by the curved arrows).

The SIX EASY STEPS program has resulted from an eleven-stage framework (Table 6-2) used to refine the previous generalised nutrient recommendations into soil-specific nutrient management guidelines (Schroeder et al., 2008a). The process integrated knowledge and information about chemical, physical and morphological properties of major soil types within districts, with results from a number of laboratory, glasshouse and field investigations (Schroeder et al., 2006).

The framework was initially applied to the Herbert and Bundaberg districts and progressively introduced across the industry (Queensland Wet Tropics to northern New South Wales). Much attention was, and continues to focus on N management.

Nitrogen guidelines within the SIX EASY STEPS program are based on a suite of concepts, namely, the district yield potential (DYP), an 'N requirement multiplier' (to determine the baseline N application rate for each district) and a soil N mineralisation index to take account of soil type (Schroeder et al., 2005). Nitrogen from various sources of N within the sugarcane cropping system is discounted against the N rates contained in the guidelines. The individual 'concepts' are explained in more detail below.

The DYP for individual districts were determined from the best possible yield averaged over all soil types within a district over the period of 1990 to 2008. It was defined as the estimated highest average annual district yield (EHAADY) multiplied by a factor of 1.2 (Schroeder et al., 2010a). The multiplier accounts for the fact that some farms/blocks yield higher than EHAADY particularly in seasons characterised by favourable/well-distributed rainfall patterns. The overall concept is well documented in various papers (Schroeder *et al*., 2005, 2007b, 2008b, 2009a). The EHAADY and DYP values for the different districts are summarised in Table 6-3.

Table 6-2 Eleven-stage framework used for developing the SIX EASY STEPS nutrient management program (after Schroeder *et al*., 2008b).

Stage	Description
1. General assessment	Review existing technical information.
2. Identify major soil types in a district	Use existing soil maps and local expertise.
3. Establish soil reference sites	Assess chemical, physical & morphological properties of a typical soil at each geographically referenced site.
4. Consider and review current information	Review existing nutrient management information and re-interpret data where appropriate.
5. Conduct field, glasshouse and/or laboratory experiments	Conduct experiments and investigations linked to soil reference sites.
6. Infer nutrient management strategies	Develop preliminary / modified nutrient management guidelines from the above information.
7. Develop tools to support these strategies	Develop district-specific nutrient management guidelines, and promote soil testing, leaf analysis, etc.
8. Validate nutrient management strategies	Conduct further field trials to confirm the validity of modified guidelines.
9. Present the nutrient management package to users	Develop and present short-courses and other promotional material.
10. Demonstrate advantages of nutrient management strategies	Establish on-farm replicated strip-trials, etc. to demonstrate maintained / improved productivity, profitability and/or environmental responsibility.
11. Identify innovative approaches to enhance the system	Use results of on-going investigations to further refine the system.

Table 6-3 Estimated highest average annual district yields (EHAADY) and district yield potentials (DYP) used within the SIX EASY STEPS program (Schroeder *et al*., 2010a)

Region	District	EHAADY (t cane/ha)	DYP (t cane/ha)
Wet Tropics	Cairns (Mulgrave / Mossman)	100	120
	Innisfail / Babinda and Tully	100	120
Herbert (moist tropics)	Herbert	100	120
Mareeba / Dimbulah	Mareeba / Dimbulah	125	150
Burdekin	Lower yielding areas	125	150
	Higher yielding areas	150	180
Mackay – Whitsundays (Central)	Proserpine	110	130
	Mackay	110	130
	Plane Creek	100	120
Southern	Bundaberg / Isis / Maryborough	100	120

The concept of DYP was used to determine the baseline N application rate for replant and ratoon cane using a multiplier of 1.4 kg N per tonne of cane up to a cane yield of 100 tonnes and 1.0 kg N per tonne of cane thereafter (Keating *et al*., 1997). The baseline N application rate for districts with a DYP of 120 t cane/ha is therefore (100 x 1.4) + (20 x 1.0) = 160 kg N/ha.

Baseline N application rates within the SIX EASY STEPS program were adjusted within each region to take account of soil type. This was done using an N mineralisation index (Schroeder and Wood, 2001) based on soil organic C (Walkley and Black, 1934). A combination of the baseline N application rate and the N mineralisation index, and a discount in terms of plant cane following bare or grass fallows, were used to determined N rates for the different regions (Table 6-4).

Table 6-4 Nitrogen requirement for plant and ratoon crops (Schroeder et al., 2010b).

Crop	Soil organic carbon (%)						
	0 – 0.4	0.4 – 0.8	0.8 – 1.2	1.2 – 1.6	1.6 – 2.0	2.0 – 2.4	> 2.4
Wet Tropics, Herbert, Plane Creek, Bundaberg/Isis, Maryborough (district yield potential = 120 t cane/ha)							
Replant cane and ratoon after replant	160	150	140	130	120	110	100
Plant cane after a grass/bare fallow	140	130	120	110	100	90	80
Proserpine and Mackay (district yield potential = 130 t cane/ha)							
Replant cane and ratoon after replant	170	160	150	140	130	120	110
Plant cane after a grass/bare fallow	150	140	130	120	110	100	90
Burdekin (district yield potential = 150 t cane/ha)							
Replant cane and ratoon after replant	190	180	170	160	150		
Plant cane after a grass/bare fallow	150	140	130	120	110		
Burdekin (district yield potential = 180 t cane/ha)							
Replant cane and ratoon after replant	220	210	200	190	180		
Plant cane after a grass/bare fallow	180	170	160	150	140		

As mentioned above, the SIX EASY STEPS program recognises sources of N other than that supplied by fertiliser applications [legume fallow / break crops, mill by-products, irrigation water, and residual mineral N remaining after small/vegetable rotational crops (Schroeder *et al*., 2005)]. In particular, the amount of N available to the succeeding sugarcane crop is dependent on the legume type, how well it was grown, and whether the grain was harvested (Garside and Bell, 2001). The SIX EASY STEPS program provides estimates of the amounts of N being returned to the soil by legume crops (Table 6-5) and the adjustments in the amount of N fertiliser required following different legume fallows.

The SIX EASY STEPS program also recognises that "nutrient use efficiency" should be viewed as a term that focuses on maximising yield per unit of nutrient applied. Is is considered a product of recovery and utilisation (Wood and Kingston, 1999):

Yield/unit nutrient applied = (unit nutrient taken up/unit nutrient applied) x (yield/unit nutrient taken up)

As such, increases in nutrient use efficiency aim to yield more with the same amount of nutrient applied, the same yield with less nutrient applied or greater yield with less nutrient applied.

Based on the above, the best expression of N-use efficiency from a grower perspective is:

Fertiliser N-use efficiency (t cane/kg N) = yield (t cane/ha) / N applied (kg N/ha)

In this equation, no account is taken of yield at nil applied N and hence, Bell *et al*. (2015) referred to this index as the "Apparent Agronomic Efficiency of Fertiliser N".

Fertiliser guidelines such as the SIX EASY STEPS program aim to improve NUE by ensuring that the "fertiliser N-use efficiency" is as high as possible. The proviso is that productivity and profitability are not negatively affected.

Table 6-5 Estimates of N contributions from fallow legume crops based on information from the Sugar Yield Decline Joint Venture (Schroeder *et al*., 2005).

Legume crop	Fallow crop dry mass (t/ha)	N (% of crop dry mass)	N content above ground (tops)	N content below ground (roots)	Total N contribution	N removed in harvested grain	N contribution if grain harvested
			(kg/ha)				
Soybean	8	3.5	280	80	360	240	120
	6		210	60	270	180	90
	4		140	40	180	120	60
	2		70	20	90	60	30
Cowpea	8	2.8	225	65	290	190	100
	6		170	50	220	145	75
	4		110	35	145	95	50
	2		55	15	70	45	25
Lablab	8	2.3	185	55	240	160	80
	6		140	40	180	120	60
	4		90	30	120	80	40
	2		45	15	60	40	20

6.1.1.2. N-Replacement strategy

The N-Replacement strategy targeted the concept that sugarcane crops get a relatively small amount of N directly from fertiliser, usually about 30-40% of the total N requirement (Chapman, 1994; Vallis *et al*., 1996), with the balance supplied by mineral N in the soil profile and/or that from mineralised organic matter. Although much of applied N fertiliser is immobilised by microbes in soil organic matter, it is subsequently available to crop through the process of mineralisation.

The N-Replacement strategy aimed to provide a framework for aligning N fertiliser applications to the actual amount of sugarcane grown on a field or farm, rather than the potential yields that could be achieved. A basic aspect of the N-Replacement strategy was that the amount of N removed in a harvested crop needed to be determined. This was done using an estimate of the N concentration of harvested cane [0.6 kg N/t cane (Thorburn *et al*., 2011)], and the actual harvested cane yield within a block. If crops were burnt, the amount of N volatilised through burning trash also needed to be considered. From the N concentration of trash and the amount of trash relative to cane, it was estimated that 0.3 kg N/t cane was usually lost through burning trash (Thorburn *et al*., 2011). The final attribute that needed to be considered was the proportion of N fertiliser immobilised in soil organic matter and/or unavoidably lost to the environment relative. This was estimated to be 0.4 kg N/t cane (Thorburn *et al*., 2011). Thus, to 'replace' the N lost from a field (in harvested cane, to the environment and, where applicable, due to burning), the amount of fertiliser N required by the N-Replacement concept was either 1 kg N/t cane with green cane trash retention, or 1.3 kg N/t cane in burnt systems.

It was also necessary for cane farmers to keep good record to determine the average yield over a period so that the N fertiliser application rates can be determined.

As well as N from fertiliser, N from fallow legumes and/or mill mud could be accounted for in the N-Replacement calculations (Park *et al*., 2010; Thorburn *et al*., 2008).

6.1.1.3. Conclusions from the review process

- The importance of appropriate nutrient management in sugarcane production has been recognised in the Australian sugar industry since the early 1900s.
- Nitrogen, in particular, has been the subject of ongoing RD&E over the ensuing period. In the mid-1990s there was realisation that nutrient management should focus on sustainability rather than production *per se*.
- Attention was directed towards better understanding the factors that controlled losses and uptake of N.
- This was accompanied by recognition that nutrient guidelines be based on soil properties and processes, and the interaction of nutrients with soils.
- This led to the development of two new approaches to N management - the SIX EASY STEPS nutrient management principles and program, and the N-Replacement concept.
- The SIX EASY STEPS program was developed using a logically-based 'systems' framework that enables further evolution as further research results emerge.
- The SIX EASY STEPS program has been delivered to industry through various mechanisms, including a widely run short-course program, the ongoing development of district-specific soil/nutrient management booklets, and on on-line nutrient management package.
- The N-Replacement concept was more environmentally-focused. However, with its reduced N-input strategy, maintenance and/or increases in sugarcane productivity and profitability were considered less likely. This strategy was not as well-tested as the SIX EASY STEPS program. It has therefore not been used or promoted as an applicable system within the industry.
- Soil and district-specific N guidelines, developed in the SIX EASY STEPS program, are based on DYP, a multiplier of 1.4 kg N per tonne of cane up to a cane yield of 100 tonnes and 1.0 kg N per tonne thereafter, and an N mineralisation index. This system continues to be aimed at profitable sugarcane production in combination with environmental responsibility.
- The on-going developments (since the early 1900s) have ensured continuing improvements in NUE. However, it is important that improvements in NUE not be isolated from economic effectiveness.
- The SIX EASY STEPS N guidelines form the basis of current industry best management practice (BMP). They are focuses on all nutritional requirements not just N.
- The following topics were identified within the review process as needing R&D attention in the short to medium term:
  - Impact of climate variability on cane yield and appropriate N application rates - improving NUE in this way should be evaluated on a wider range of soil types and sugarcane growing districts.
  - Any changes to the DYP values used within the SIX EASY STEPS program to calculate N fertiliser requirements should be well-researched and not based on anecdotal evidence. These investigations should not focus on historical yields alone, but also aim at determining yield potential of the upcoming season to ensure crop N demand is not restricted.
  - Development of SIX EASY STEPS guidelines for Precision Agriculture (PA) would need to target in-field variability.
  - Temporal N needs of sugarcane would need to focus on matching N supply to crop N uptake.
- The following general requirements were noted:

- The most appropriate (efficient and economically effective) N inputs need to be used within the sugarcane production system in Australia to ensure sustainable sugarcane production.
- The combination of the SIX EASY STEPS program and the integrated framework that underpins the program provides a suitable mechanism for future RD&E in sugarcane nutrient management.

6.1.2. Determination of whether credible evidence existed for proposed modifications to the SIX EASY STEPS guidelines.

In particular, evidence for proposed modifications was sourced to answer the following questions:

- Was it possible to modified DYP as the basis for N guidelines within the SIX EASY STEPS program?
- Was there evidence to modify the N guidelines following application of mill mud or mud/ash?
- Was there evidence to modify the N guidelines following legume fallow crops?

6.1.2.1. Was it possible to modify DYP as the basis for the SIX EASY STEPS N guidelines?

As indicated previously, the N guidelines within the SIX EASY STEPS program are based on a combination of:

- DYP calculated from the 'highest average annual district yield' determined from mill data over a 20-year period multiplied by a factor of 1.2.
- A multiplier of 1.4 kg N/tonne of cane up to a cane yield of 100 t/ha and 1 kg N/t cane thereafter to determine the baseline N application rate.
- An N mineralisation index (based on soil Org C) to take soil type into consideration.

There was mounting pressure from outside the SIX EASY STEPS program to replace DYP with block yield potential (BYP) for determining N application rates. The SIX EASY STEPS team was supportive of investigations to determine how the N guidelines could be adapted for within-block soil and yield variation. However, there was strong opinion that any changes should be based on a sound scientific evidence that included data from longer-term field trials, relevant commercial operations and/or appropriate investigations (e.g. pot experiments, glasshouse trials, data interrogation studies).

As a result, several possibilities for determining N rate based on BYP concepts (as suggested by others) were investigated. This was done using commercial yield data sourced from farms (Farms 1 – 6), and higher-yielding blocks of cane on Tully and Lugger soils (Blocks T1-T7 and L1-L6) in the Tully district. The suggested BYPs included:

a. An average farm yield potential (FYP) for each block on the farm. The N rate was determined by multiplying FYP by 1.4 kg N/t cane up to 100 tc/ha and 1.0 kg N/t cane thereafter.
b. BYP_1: 10-year average block yield plus 1xSD. N rate was calculated by multiplying BYP_1 by 1.4 kg N/t cane.
c. BYP_2: 10-year average block yield plus two standard deviations. N rate was calculated by multiplying BYP_2 by 1.4 kg N/t cane.

In all three cases, the proponents of BYP apparently did not include discounts for N mineralisation based on soil Org C (as is the case with the SIX EASY STEPS approach).

The average farm yields for Farms 1 – 6 for the period 2004 to 2013 are shown in Figure 6-2. The highest average farms yields and therefore the estimated current FYPs occurred in various years: Farm

1: 103 t cane/ha (2004); Farm 2: 108 t cane/ha (2008); Farm 3: 130 t cane/ha (2004); Farm 4: 109 t cane/ha (2005); Farm 5: 111 t cane/ha (2005); and Farm 6: 126 t cane/ha (2010).

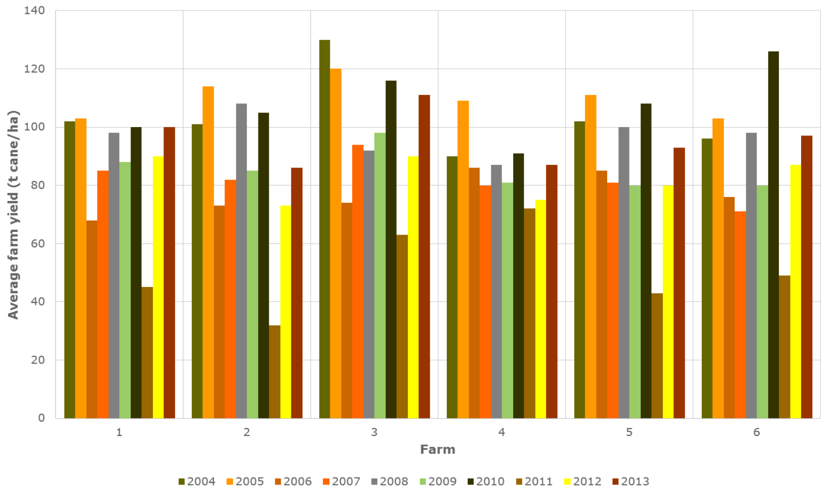


Figure 6-2 Average farm yields for six Tully farms for the period 2004 – 2013. FYPs are indicated by the highest annual farm yield for each farm during that 10-year period.

Based on the FYPs shown above and the multipliers indicated in dot point a) above, the calculated N application rates for each block on Farm 1 to Farm 6 would be 143, 154, 170, 149, 151 and 166 kg N/ha respectively, with an average of 155 kg N/ha. The SIX EASY STEPS N rates (for ratoon cane) would vary between 120 and 140 kg N/ha for the soil types and Org C values found on these farms.

The BYP1 and BYP2 values for blocks T1-T7 and L1-L6 are shown in Table 6.6. The calculated N rates based on BYP1 ranged from 136 to 170 kg N/ha, with a mean of 160 kg N/ha for blocks T1-T7, and 152 kg N/ha for blocks L1-L6. The calculated N rates based on BYP2 ranged from 152 to 200 kg N/ha, with a mean of 185 kg N/ha for blocks T1-T7, and 182 kg N/ha for blocks L1-L6. In contrast, the SIX EASY STEPS N rates (for ratoon cane) would vary between 130 and 140 kg N/ha. The growers reported using rates of 120 to 130 Kg N/ha since 2006.

Table 6-6 Ten-year average farm block yields, SDs, 2xSDs, BYPs and N rate for 13 commercial higher-yielding block in the Tully district.

Block	Average yield	SD	BYP_1			BYP_2	
			Average yield + SD	N rate	2xSD	Average yield + 2xSD	N rate
	(tc/ha)	(tc/ha)	(tc/ha)	(kg N/ha)	(tc/ha)	(tc/ha)	(kg N/ha)
T1	93	20	113	158	40	133	186
T2	103	17	121	169	34	138	193
T3	93	22	114	160	43	136	190
T4	99	22	121	169	44	143	200
T5	90	16	106	148	32	121	170
T6	90	16	106	148	32	121	170
T7	109	12	121	170	24	134	187
Mean: T	**97**	**18**	**114**	**160**	**36**	**132**	**185**
L1	90	26	116	163	53	143	200
L2	86	24	110	154	48	134	188
L3	90	25	115	162	50	140	197
L4	88	21	109	152	42	130	182
L5	85	11	97	136	23	108	152
L6	82	21	103	144	41	124	173
Mean: L	**87**	**21**	**108**	**152**	**43**	**130**	**182**

6.1.2.2. Was there evidence to modify the N guidelines following mill by-products?

The SIX EASY STEPS N guidelines (as in 2014) indicated that the amount of N applied needed to the discounted for up to 3 years after application of mill by-products. The amount of N to be subtracted from N application rates following the use of mud and mud/ash mixture is shown in Table 6-7.

Table 6-7 Amounts of N to be subtracted from N application rates following the use of mill by-products (Salter *et al*., 2015).

Product	Application rate	To be subtracted from the appropriate N application rate		
		Plant crop	First ratoon	**Second ratoon**
Mill Mud	150 wet t/ha	80 kg N/ha	40 kg N/ha	20 kg N/ha
Mud/Ash	150 wet t/ha	50 kg N/ha	20 kg N/ha	10 kg N/ha

Moody *et al.* (2014) suggested that a total estimated contribution of 35% of the total N applied as mill mud/mud ash was available in the first crop after application. Therefore, the amount discounted from the plant crop could have been increased to 90 kg N/ha rather than the currently suggested 80 kg N/ha within the SIX EASY STEPS program. Although Moody *et al*. (2014) also suggested that the discounts to the first and second ratoon crops could be reduced, no definitive amounts were provided.

6.1.2.3. Was there evidence to modify the N guidelines following legume fallow crops?

The SIX EASY STEPS N guidelines (as in 2014) indicated the following (based on information from Bell *et al*., 2003; Garside and Bell, 2001; Schroeder *et al*., 2005): “Unlike N held in soil organic matter, legume N is readily available for plant uptake and should be treated the same way as fertiliser N for the purposes of calculating N requirement. Information published by scientists working in the Yield Decline Joint Venture has provided details on how to estimate the amount of legume N being returned to the soil from a legume crop. The amount of N available to the succeeding sugarcane crop will be dependent on the type of legume, how well it was grown and whether the grain was harvested.”

A summary of the calculations for various legume fallows is shown in Table 6-8. This information is used to adjust the amount of N fertiliser required for the different soils following different legume fallows. The values shown in BOLD in Table 6-8 are used as examples in Table 6-9.

Anecdotal evidence suggested previously that N discounts following legume fallow crop could be increased due to perceived amounts of N remaining in soil in subsequent sugarcane crop cycles. However, a previous crop cycle in the N x K factorial trial at Welcome Creek near Bundaberg (describe in Section 5.2.1 of this report) provided some important insights. Nitrogen response curves based on the PC to 2R yield data (part of a previously funded project) and 3R yield data (this project) are presented in Figure 6-3. Despite a good legume crop grown as a fallow (7.4 t/ha soybean biomass) prior to the plant crop (2010/2011), significant responses to applied N have been noted throughout the crop cycle. This was unusual, but explained by the uncharacteristically large rainfall events (> 500 mm of rain) in December 2010 after the legume fallow crop and during the early growth of the sugarcane plant crop. Rainfall post the legume crop had a substantial effect on the amount of N available to subsequent plant and ratoon crops. The uncertainty of the amount of N remaining in the soil after the plant crop following heavy rains means that it is difficult to estimate the amount of N remaining in the system.

Table 6-8 Calculation of N contribution from a fallow legume as supplied by the Sugar Yield Decline Joint Venture (see Schroeder *et al*., 2005).

Legume crop	Fallow crop dry mass (t/ha)	N (%)	Total N contribution (kg N/ha)	N contribution if grain harvested (kg/ha)
Soybean	8	3.5	360	120
	6		**270**	**90**
	4		180	60
	2		90	30
Peanut*	8	3	n/a	125
	6			100
	4			65
	2			25
Cowpea	8	2.8	290	100
	6		220	75
	4		145	50
	2		**70**	25
Lablab	8	2.3	240	80
	6		180	60
	4		120	40
	2		60	20

* MJ Bell (2007)

Table 6-9 Effect of fallow management on N requirement (Schroeder *et al*., 2005).

Crop	N mineralisation index						
	VL	L	ML	M	MH	H	VH
Replant cane and ratoon after replant	170	160	150	140	130	120	110
Plant cane after a grass/bare fallow	150	140	130	120	110	100	90
Plant cane after a poor legume crop (e.g. 2 t/ha cowpea green manure: N rate minus **70** kg N/ha)	100	90	80	70	60	50	40
Plant cane after a good legume crop (e.g. 6 t/ha soybean: N rate minus **270** kg N/ha)	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Plant cane after a good legume crop harvested for grain (e.g. 6 t/ha soybean: N rate minus **90** kg N/ha)	80	70	60	50	40	30	20
First ratoon after a good legume crop*	170	160	150	140	130	120	110
Second ratoon after a good soybean/cowpea crop	170	160	150	140	130	120	110

***** Data from the Yield Decline Joint Venture and BSES trials suggest that N applied to the first ratoon sugarcane crop after a good legume crop can possibly be reduced. The reduction in N applied will depend on several factors which include legume residue management, soil type, climate and tillage practices.

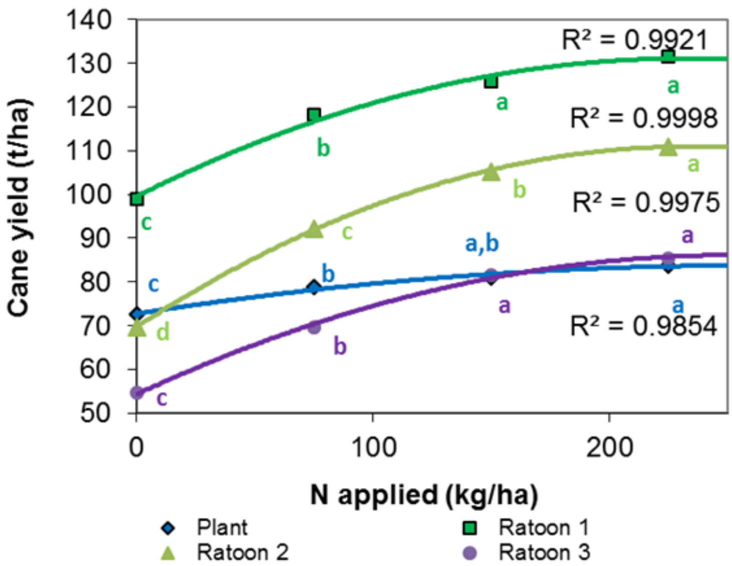


Figure 6-3 Yield response curves (tc/ha versus N applied) for the Bundaberg trial site (2010 – 2014). The data points and curve relating to the third ratoon are specific to the current project.

6.1.2.4. Conclusions: evidence for modifying N guidelines

- Changing DYP to other finer-scale alternatives (e.g. FYP or BYP) within the SIX EASY STEPS N guidelines is not as easy as it sounds. Trial and commercial data indicate that there could be a perverse outcome and the resulting N rates would not reflect, or be supported by, trial results.
- Due to the variable nature of mill by-products there is little practical information that may be used to tailor advice for reducing N rates following mill mud or mud/ash mixtures. The current SIX EASY STEPS guidelines still appear to be appropriate for general circumstances. More tailored advice will need to be based on specific information, data, analysis results, etc.
- The variability of legume crops and the uncertainty of weather conditions between the fallow crop and the ensuing sugarcane plant and 1R crops make it difficult to formulate general guidelines covering a range of circumstances. However, the development of a 'decision support tree' may be the best option for providing specific guidance for growers and/or their advisors who want to add additional precision to their N management strategies.

6.1.3. Assessment of the agronomic and economic implications of the different N management strategies?

Sugarcane yield data from the N x FS trial at Macknade but pre-Mkd NxFS1 (as described in Section 5.2.3) were used to quantify agronomic, economic/social and environmental implications of different N management strategies. The data covered the period 2001/02 (PC) to 2005/06 (4R) and 2008/09 (PC) to 2011/12 (3R).

6.1.3.1. Implications of changing the basis of N Opt from 95% to 90% of the maximum yield

In the initial crop cycle (2001 – 2006), the maximum attainable sugarcane yields determined from the yield response curves (quadratic functions), ranged from 85 to 138 t cane/ha (Figure 6-4) with a mean of 116 t cane/ha, and a standard error (SE) and standard deviation (SD) of 8.6 and 19.3 t cane/ha, respectively. The optimum N rate for each crop (determined as 95% of the maximum attainable yield) are indicated by the downward arrows associated with each of the response curves in Figure 6-4). The SIX EASY STEPS N rate was previously set at 150 kg N/ha for this soil type (based on a DYP of 120 t cane/ha and a soil organic C value of 0.7%) and indicated by the small green arrow in Figure 6-4. The amount and cost of N applied, the cane and sugar yield, and the revenue from sugar and the industry net return over the crop cycle for the SIX EASY STEPS N rate and the N rates required to produce 95% of the maximum yield are shown in Table 6-10. In relation to the SIX EASY STEPS N rate (150 kg N/ha annually), 750 kg N/ha would have been applied over the crop cycle and would have produced 554 t cane/ha. This would have resulted in an industry net return (calculated as the price received for sugar per ha minus the cost of N fertiliser per ha) of $24,795/ha over that five-year period. The N-rate strategy aimed at 95% of the maximum yield would have been similar and produced 549 t cane/ha and an industry net return of $24,625/ha over the five-year period.

The effect of reducing N rates to achieve 90% of the maximum cane yield for each of the crops in the crop cycle is shown in Figure 6-5. The N rates would have decreased in all seasons and resulted in a total N input of 560 kg N/ha applied over the crop cycle (Table 6-10). The overall result would have been a yield of 522 t cane/ha and an industry net return of $23,605 over the five year period, about $1,000 lower that the N rate aimed at 95% of the maximum yield (Table 6.-10). Examples of the effects of further decreases in N application rates (to attain 85 and 80% of the maximum yield) are shown in the lower section of Table 6-10). Although such strategies would presumably be more environmentally acceptable with the NUE indicators dropping from about 1.3 kg N/t cane to 0.85 and 0.67 kg N/t cane respectively (Table 6-10), productivity and profitability would also have decreased markedly (Table 6-10).

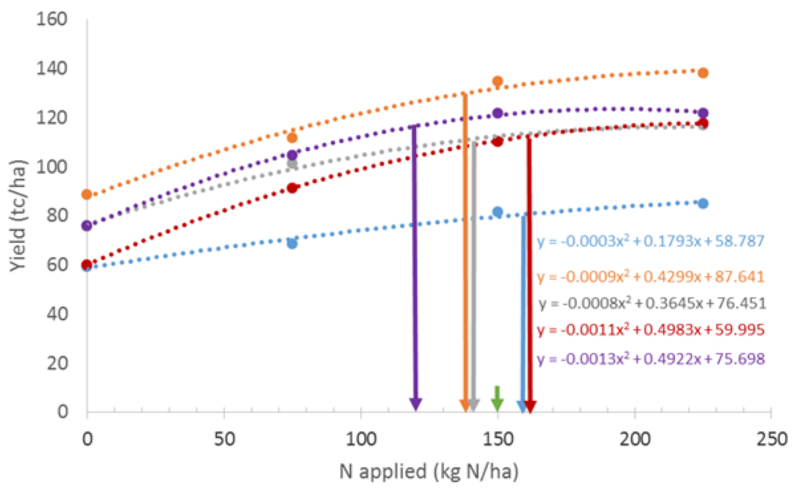


Figure 6-4 Yield response curves (quadratic functions) from a replicated small plot rates of applied N trial conducted over a crop cycle.

The sugarcane P crop is shown in blue, the 1R in orange, the 2R in grey, the 3R in red and the 4R in purple. The vertical lines indicate the 'optimum N rate' corresponding to 95% of the maximum attainable yield in each crop. The small green arrow indicates the SIX EASY STEPS N rate (150 kg N/ha) for this soil type.

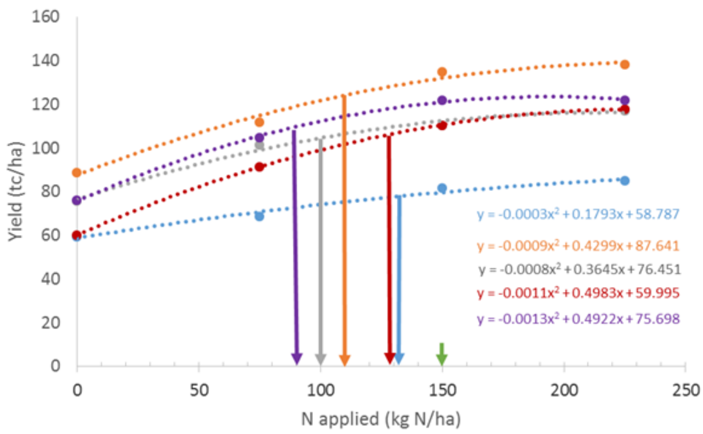


Figure 6-5 Yield response curves (quadratic functions) from a replicated small plot rates of applied N trial conducted over a crop cycle.

The sugarcane P crop is shown in blue, the 1R in orange, the 2R in grey, the 3R in red and the 4R in purple. The vertical lines indicate an 'environmentally-friendly N rate' corresponding to 90% of the maximum attainable yield in each crop. The small green arrow indicates the SIX EASY STEPS N rate (150 kg N/ha) for this soil type.

Table 6-10 Sugar and cane yield for a crop cycle, revenue and industry nett returns for different N rates based on varying percentage difference from the maximum yields associated with the response curves shown in Figures 6-4 and 6-5.

N rate determined as:	N applied over a crop cycle[1]	Cost of N fertiliser[2]	Cane yield over a crop cycle[1]	Expressions of nitrogen use efficiency		Yield over a crop cycle[1]	Revenue from sugar[3]	Industry net return[4]	Industry net return for a 70 ha farm
	(kg N/ha)	($/ha)	(t/ha)	(tc/kg N)	(kg N/tc)	(t sugar /ha)	($/ha)	($/ha)	($/year)
SIX EASY STEPS rate	750	1,125	554	0.74	1.35	72.0	25,920	24,795	347,130
95% of the max. yield	720	1,080	549	0.76	1.31	71.4	25,705	24,625	344,750
90% of the max. yield	560	840	522	0.93	1.07	67.9	24,445	23,605	330,470
Difference (95% - 90%)	160	240	27	0.17	0.24	3.5	1,260	1,020	14,280
85% of the max. yield	420	630	492	1.17	0.85	64.0	23,040	22,410	313,740
Difference (95%- 85%)	300	450	57	0.41	0.46	7.4	2,665	2,215	31,010
80% of the max. yield	310	465	464	1.50	0.67	60.3	21,708	21,243	297,402
Difference (95% - 80%)	410	610	85	0.74	0.64	11.1	3,997	3,382	47,348

[1]Crop cycle: a plant crop and four ratoons; [2]Unit price of fertiliser assumed to be AU$1.50/kg N; [3]Price of sugar assumed to be AU$360/tonne of sugar; [4]Industry net return = Price received for sugar per ha minus the cost of N fertiliser per ha

6.1.3.2. Assessing different N management strategies

The yield response curves (quadratic functions) for the second crop cycle covering the period 2008/09 (PC) to 2011/12 (3R) are shown in Figure 6-6. The lack of yield response to applied N in the plant crop (harvested in 2009) was due to the 'good' legume fallow crop that was grown at the site between the crop cycles and prior to establishment of the trial in 2008. An on-farm strategy of applying zero N would be in line with the SIX EASY STEPS N guidelines for such circumstances.

In the ratoon crops, the maximum attainable sugarcane yields were 109 t cane/ha, 46 t cane/ha and 80 t cane/ha for the 1R (2009/10), 2R (2010/11) and 3R (2011/12) crops, respectively (Table 6-11). As indicated previously, the SIX EASY STEPS N rate was set at 150 kg N/ha for this particular soil (indicated by the green downward pointing arrow in Figure 6-6). The optimum N rate (required to produce 95% of the maximum yield) was 160 kg N/ha for the 1R, 120 kg N/ha for the 2R and 100 kg N/ha for the 3R (Figure 6-6). The response curves provided the ability to assess three different N management strategies aimed at the following: 1) Production-focus (risk adverse): 180 kg N/ha, 2) Sustainability-focus (SIX EASY STEPS: 150 kg N/ha), and 3) Environment-focus (120 kg N/ha). The first and third strategies are indicated by the upward-pointing small black arrows in Figure 6-6. Nitrogen inputs, yield data and partial net returns (based on a generalised grower cane pay formula) for each strategy are presented in Table 6-11. In addition, estimated on-farm losses in revenue at the farm, district and industry scales and the industry as a whole, if environmentally-focused strategies are chosen by growers over production-focused strategies are also shown.

The 1R crop grew in a season that experienced well-distributed and near average rainfall for the Hebert District (Figure 6-7). These good growing conditions were reflected in the sugarcane yields obtained with the various N management strategies (Table 6-11). The yield of 106 t cane/ha was obtained using the production-focused approach (180 kg N/ha applied). The grower partial net return was $4,645/ha and the NUE was 0.59 t cane/kg N. The SIX EASY STEPS approach resulted in a sugarcane yield of 103 t cane/ha, a grower partial net return of $4,527 and an NUE of 0.69 t cane/kg N. Although the environment-focused approach produced the best NUE (0.82 t cane/kg N), the yield was 98 t cane/ha with a grower net return of $4,336/ha, substantially lower than both the production-focused and SIX EASY STEPS strategies (Table 6-11).

The 2R crop was produced in a season that had high rainfall (and presumably low radiation) especially during February and March (Figure 6-7). As a result yields were markedly lower than the previous season. Yields across the various N strategies were similar (about 44 t cane/ha). The grower partial net return for the production-focused strategy was lower than the other two approaches despite the slightly better commercial cane sugar (CCS) content (Table 6-11). As expected, the NUE values were low, but increased as the rate of N deceased.

Improved yields, grower partial net returns and NUEs occurred in the 3R compared to the 2R crop (Table 6-11), primarily due to the season not being as wet as the previous year. Although the yields were similar across the various N strategies (about 77 t cane/ha), the grower partial net return for the production-focused strategy ($2,493/ha) was lower than both the sustainability- and environment-focused strategies ($2,606/ha and $2,646/ha respectively) due to a slightly lower CCS and lower N inputs.

When the overall ratoon crops (1R to 3R) were considered, a total of 226 t cane/ha were produced from both the production- and sustainability-focused strategies and 219 t cane/ha from the environment-focused strategy (Table 6-11). However, on average the environment-focused approach resulted in a $90/ha loss in revenue compared to the production-focused approach (Table 6-11). On the assumption that the River Bank soil is an average soil for the sugar industry (i.e. not the poorest, nor the best) and that the seasons covered a range of rainfall patterns, these figures were scaled-up to reflect farm, district and industry circumstances. Estimated losses were calculated as $10,800/yr, $4,680,000/yr and $32,200,000/yr respectively. Based on the assumption that growers and millers receive revenue from sugar in a ratio of 0.67:0.33, the loss to industry due to a systematic change of fertiliser inputs was estimated as $51,300,000/yr (Table 6-11).

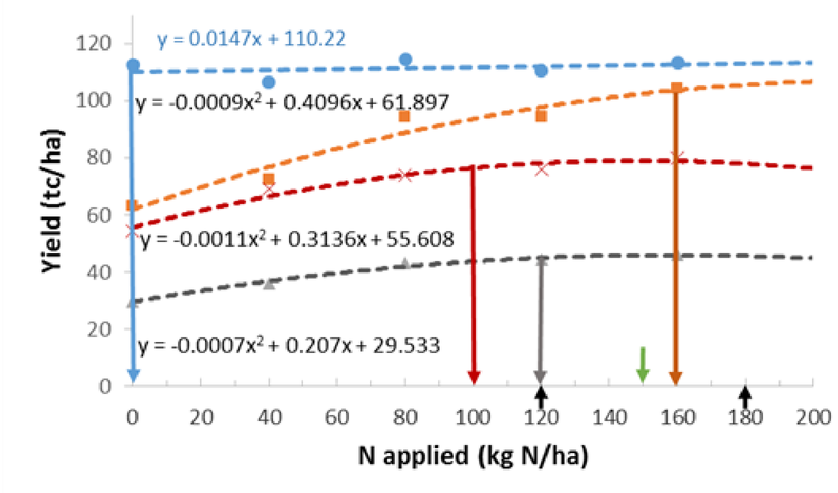


Figure 6-6 Yield response curves (quadratic functions) from a replicated small plot rates of applied N trial conducted over a crop cycle (2008/09 to 2011/12).

The sugarcane PC is shown in blue, the 1R in orange, the 2R in grey and the 3R in red. The vertical lines indicate the ‘optimum N rate’ corresponding to 95% of the maximum attainable yield. No yield response to applied n occurred in the plant crop due to the preceding fallow legume crop. The small green arrow indicates the SIX EASY STEPS N rate for the ratoon crops (150 kg N/ha) for this soil type.

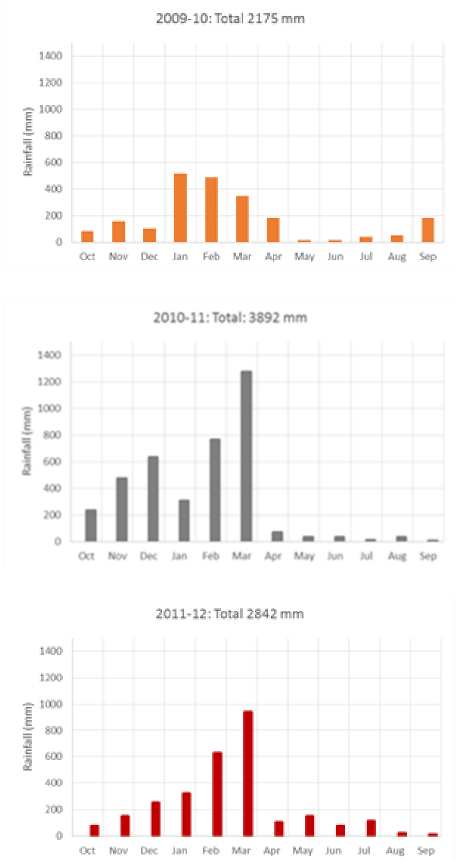


Figure 6-7 Rainfall data for the Macknade trial site during the sugarcane growing seasons (Oct – Sep) of the 1R, 2R and 3R crops (2009/10, 2010/11 and 2011/12, respectively).

Table 6-11 Yield data and calculated partial net returns for the different N strategies.
Production-focused, sustainability-focused (SIX EASY STEPS) and environment-focused; and estimated losses to industry (production-focused strategy minus environmental-focused strategy).

	N management strategy		
	Production-focused (Risk-adverse)	Sustainability-focused (SIX EASY STEPS)	Environment-focused (Reduced N rate)
N input (kg N/ha)	180	150	120
1R (cost of N: $1.30/kg; sugar price: $525/t; maximum attainable yield: 109 tc/ha[1])			
Cane yield (tc/ha)	106	103	98
CCS (%)	15.69	15.69	15.69
Grower partial net return ($/ha)	$4,645	$4,527	$4,336
NUE (tc/kg N applied)	0.59	0.69	0.82
2R (cost of N: $1.40/kg; sugar price: $530/t; maximum attainable yield: 46 tc/ha[1])			
Cane yield (tc/ha)	44	45	44
CCS (%)	16.40	16.32	16.25
Grower partial net return ($/ha)	$1,941	$2,003	$2,003
NUE (tc/kg N applied)	0.24	0.30	0.37
3R (cost of N: $1.79/kg; sugar price: $430/t; maximum attainable yield: 80 tc/ha[1])			
Cane yield (tc/ha)	76	78	77
CCS (%)	15.96	15.99	15.99
Grower partial net return ($/ha)	$2,493	$2,606	$2,646
NUE (tc/kg N applied)	0.42	0.52	0.64
1R to 3R			
Cane yield (tc/ha)	226	226	219
Grower partial net return ($/ha)	$9,262	$9,136	$8,985
Production-focused strategy minus environmental-focused strategy			
Annual loss of on-farm revenue [($9,262 - $8,985)/3 = $92/ha/yr]			$90/ha/yr
Extrapolated loss of on-farm revenue for a 120 ha farm			$10,800/yr
Extrapolated loss of on-farm revenue across the Herbert District (52,000 ha)[2]			$4,680,000/yr
Extrapolated loss of on-farm revenue across the industry (380,000ha)			$34,200,000/yr
Extrapolated loss of industry revenue[3]			$51,300,000/yr

[1]Determined from the yield response curves shown in Figure 5
[2]Based on the assumption that the River Bank soil represents an ‘average’ for the district
[3]Based on the assumption that growers and millers receive revenue from sugar in a ratio of 0.67:0.33

6.1.3.3. Conclusions: agronomic, economic and environmental assessments

- It is not unrealistic to expect that the close proximity of much of the Australian sugar industry and the Great Barrier Reef will result in mutual impacts, and that certain land-based activities, especially N applications, could affect the quality of water in the GBR Lagoon due to losses from crop production activities.
- The development, delivery and adoption of sugarcane BMPs are aimed at ensuring that such effects are minimised, or at least curbed. Water quality targets aim at similar objectives, but have the potential to impact land-based agricultural activities.
- The agronomic analyses based on response curves from replicated rates of N trials have shown that optimum N rates produced yields comparable to maximum attainable yield in various seasons.
- It was most apparent, and not unexpected, that the rainfall within different seasons have the greatest effect on cane productivity.

- The various economic assessments showed that reductions in N rates below BMP standards, although environmentally desirable (due to improved NUEs), had the potential to reduce industry revenue and net returns to growers and millers.
- The estimation of potential losses to farming enterprises, districts and the industry when N rates are adjusted for external reasons or a systematic reduction in inputs (e.g. to meet water quality targets rather than based on agronomic principles) provided an initial benchmark for further consideration.
- It is essential that the impacts of water quality targets on the sugar industry and the Great Barrier Reef are assessed using multi-facetted analyses that incorporate at least agronomic, socio-economic and environmental considerations.
- Assessments based on a single over-riding factor (e.g. when only agronomic, economic, social or environmental aspects are considered in isolation of the others) have the potential to produce a result that is biased towards a particular outcome.
- Current DIN reduction targets, although environmentally favourable, have the potential to cause negative effects on cane productivity and profitability, and viability of mills and regional economies.
- Notwithstanding this, it is equally important that the sugar industry continues to commit to widespread adoption of BMPs. This dual awareness will ensure that any water quality impacts on the sugar industry and the GBR are considered in a mutually beneficial way.
- The following strategies could contribute to solving the conundrum of balancing sustainable sugarcane production and water quality N targets in the GBR lagoon:
    - All stakeholders recognise that the proximity of much of the Australian sugar industry and the GBR results on mutual impacts.
    - Robust relationships between DIN targets and N rates be quantified so that those setting the targets and those expected to meet the targets have common goals.
    - Recognition in DIN models that improving farming practices (aimed at maximising cane yield) will improve NUE and lower N available for off-site impacts.
    - Changes in N management practices be assessed using multi-facetted analyses (agronomic, social, economic and environmental) as suggested by Poggio *et al*. (2016).
    - Use of BMPs to guide N inputs on-farm will enable profitable and environmentally responsible sugarcane production. This is best achieved through well-considered and implemented farm-specific nutrient management plans.
    - Credit be given to those growers who are striving for profitable sugarcane production in combination with environmental responsibility.
    - Growers who are yet to practice BMPs on their farms are encouraged to do so in a positive and supportive manner.
    - Future projects should include multi-faceted analyses to provide unbiased outcome.

6.2. Nitrogen field trials

Results of the long-term N trials conducted during the period covered by this project are presented sequentially, followed by the results of the first two seasons of the temporal N trials.

6.2.1. Bundaberg N x K trial: Bdb NxK

6.2.1.1. Rainfall

The monthly and annual rainfall data from the Bundaberg Aero met site and the estimated amounts of irrigation applied to the trial site for the period July Sep 2015 to Oct 2017 are presented in Figure 6-8. This period included the plant crop from establishment (Sep 2015) to harvest (Oct 2016) and the first ratoon crop from Oct 2016 to Sep 2017. The 2015/16 cropping season (Oct to Sep) in Bundaberg was wetter (1041 mm of recorded rainfall) than the 734 mm of recorded rainfall during the 2016/17 season. The rainfall patterns during those seasons differed from each other and from the long-term pattern (Figure 6-8). Both crops were irrigated during the high-growth period (Jan – May each year), but the first ratoon received 100 mm more than the plant crop. The total rainfall and irrigation for each of the crops were therefore not dissimilar and were in line with, or higher than, the long-term mean annual rainfall. Although temporary periods of moisture 'stress' were possible, overall water availability should not have been an overriding factor in crop growth and therefore should not have influenced the results of the N and N x K investigations.

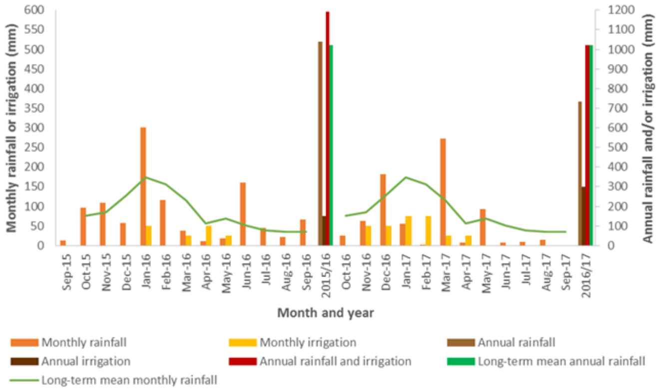


Figure 6-8 Monthly and annual recorded rainfall from the Bundaberg Aero met site and details of irrigation relevant to the N x K trial at Welcome Creek (Sep 2015 – Sep 2017).

6.2.1.2. Soil mineral N

Mean soil NO_3^--N, NH_4^+-N and total mineral N (min N) (NO_3^--N + NH_4^+-N) values for the 0, 75, 150 and 225 kg N/ha treatments where K had been applied at 120 K/ha for the are presented for the plant and 1R crops in Tables 6-12 and 6-13 respectively. As expected these values where generally highest with the first sampling (15 Dec 2015) in the plant crop. The values then generally declined through the growing and ripening season (Feb 2015 to Sep 2016). The mean NO_3^--N and min N values associated with the Dec 2015 samples generally reflected the amounts of N applied on 26 Nov 2015 with P<0.001 and P<0.01 respectively. However, this did not apply to the NH_4^+-N, with no significant differences across the rates of N applied. Significant difference in NO_3^--N, NH_4^+-N and min-N were evident down the soil profile with evidence of movement to lower soil depths (P<0.001, P<0.01 and P<0.001 respectively). This trend (significant differences in the various N values and movement down the soil profile) continued through the season (Table 6-12). This also contributed to the continued significant differences in NO_3^+-N and min N (associated with the amount of N applied) and to the significant N x depth interactions.

There was some evidence of net mineralisation of N during the spring of 2016 with increased $NH4_+^-$-N and min N values in the soil samples collected on 29 Sep 2016 (Table 6-12). Although this was also apparent in the NO_3^--N and min N in the samples collected on 21 Nov 2016 (Table 6-13), there were no significant differences among the various soil N values, neither by rate of N applied nor with soil depth. However, the NO_3^--N and min-N values in the soil samples collected on 19 Jan 2017 (Table 6-13) again reflected the rates of N applied to the 1R crop (8 Oct 2016) with P<0.001 in both cases. Although the significant differences in NO_3^--N and min-N (by rate of N applied and by depth) persisted until the winter of 2017, these values were markedly lower than those measured the previous year. By 4 Aug 2017, there were no significant differences in the mean N values according to N applied, although significant differences still existed down the soil profile (Table 6-13).

The heavier rainfall that occurred in Jan 2016 appears to have had a marked effect on the amount and location of the various mineral N components in the soil. Once this reserve of N had been lost from the system, additional N applied to the following crop (irrespective of the rate) was insufficient to restore the amount of residual N in the soil profile.

Table 6-12 Soil nitrate-N, ammonium-N and total mineral N concentrations associated with the PC and the various N application rates to a depth of 80 cm in increments of 20 cm in the N x K trial at Welcome Creek. The samples were collected from plot that had received 120 kg K/ha.

Date	Depth	N applied (kg/ha)														
		0	75	150	225		0	75	150	225		0	75	150	225	
		Soil N (mg/kg)														
		Nitrate-N				Mean	Ammonium-N				Mean	Mineral-N				Mean
2 Dec 15	0 – 20	4.4	5.7	6.6	6.6	5.8^{C}	2.5	4.5	2.8	3.2	3.2^{A}	6.9	10.2	9.4	9.8	9.1^{B}
	20 – 40	6.8	7.3	13.3	14.5	10.5^{A}	2.8	3.9	2.6	2.6	3.2^{A}	9.5	11.2	15.9	18.1	13.7^{A}
	40 – 60	7.9	9.3	10.5	9.3	9.2^{AB}	1.9	1.9	1.7	1.7	1.8^{B}	9.8	11.2	12.2	11.0	11.0^{B}
	60 – 80	6.7	8.2	8.2	7.9	7.8^{BC}	1.6	1.8	1.5	1.5	1.6^{B}	8.3	10.0	9.7	9.4	9.4^{B}
	Mean	6.4^{B}	7.6^{AB}	9.6^{A}	9.6^{A}		2.2^{A}	3.0^{A}	2.1^{A}	2.5^{A}		8.6^{B}	10.6^{AB}	11.8^{A}	12.1^{A}	
	Tukey HSD$^{0.05}$	*N = 2.2 (P<0.001)* *Depth = 2.2 (P<0.001)* *N x Depth = 5.9 (P<0.05)*					*N = ns (P=0.28)* *Depth = 1.3 (P<0.01)* *N x Depth = ns (P=0.94)*					*N = 2.6 (P<0.01)* *Depth = 2.6 (P<0.001)* *N x Depth = ns (P=0.10)*				
24 Feb 16	0 – 20	2.1	2.6	2.6	2.6	2.4^{BC}	1.7	1.7	2.1	2.1	1.9^{A}	3.8	4.2	4.6	4.6	4.3^{B}
	20 – 40	1.8	1.9	2.4	2.4	2.1^{C}	1.6	1.7	2.1	1.8	1.8^{A}	3.4	3.6	4.5	4.1	3.9^{B}
	40 – 60	1.2	3.0	6.7	9.4	5.1^{B}	1.3	1.5	1.4	1.0	1.3^{B}	2.6	4.5	8.1	10.4	6.4^{B}
	60 – 80	1.7	5.4	13.8	14.6	8.9^{A}	1.3	1.2	1.2	1.0	1.2^{B}	3.0	6.5	15.0	15.6	10.0^{A}
	Mean	1.7^{B}	3.2^{B}	6.4^{A}	7.2^{A}		1.5^{AB}	1.5^{AB}	1.7^{A}	1.4^{B}		3.2^{B}	4.7^{B}	8.0^{A}	8.7^{A}	
	Tukey HSD$^{0.05}$	*N = 2.6 (P<0.001)* *Depth = 2.6 (P<0.001)* *N x Depth = 7.1 (P<0.001)*					*N = 0.2 (P<0.05)* *Depth = 0.2 (P<0.001)* *N x Depth = 0.6 (P<0.05)*					*N = 2.7 (P<0.001)* *Depth = 2.7 (P<0.001)* *N x Depth = 7.3 (P<0.001)*				
6 May 16	0 – 20	2.7	3.4	3.2	3.2	3.1^{BC}	1.6	2.1	2.2	1.6	1.9^{A}	4.3	5.6	5.4	4.8	5.0^{B}
	20 – 40	1.9	1.9	1.7	2.3	1.9^{C}	1.7	1.9	2.0	1.5	1.8^{AB}	3.6	3.7	3.7	3.8	3.7^{B}
	40 – 60	1.4	2.1	3.3	7.2	3.5^{B}	1.3	1.2	1.6	1.1	1.3^{B}	2.7	3.3	4.9	8.2	4.8^{B}
	60 – 80	2.0	2.8	7.1	12.6	6.1^{A}	1.3	1.2	1.6	1.O	1.3^{B}	3.2	4.0	8.7	13.6	7.4^{A}
	Mean	2.0^{C}	2.6^{BC}	3.8^{B}	6.3^{A}		1.5^{AB}	1.6^{AB}	1.9^{A}	1.3^{B}		3.5^{C}	4.2^{C}	5.7^{B}	7.6^{A}	
	Tukey HSD$^{0.05}$	*N = 1.5 (P<0.001)* *Depth = 1.5 (P<0.001)* *N x Depth = 4.1 (P<0.001)*					*N = 0.5 (P<0.05)* *Depth = 0.5 (P<0.05)* *N x Depth = ns (P=0.99)*					*N = 1.5 (P<0.001)* *Depth = 1.5 (P<0.001)* *N x Depth = 4.0 (P<0.001)*				
15 Jun 16	0 – 20	1.9	1.9	1.8	1.8	1.8^{B}	0.9	0.9	1.1	0.9	0.9^{A}	2.7	2.8	2.9	2.7	2.8^{B}
	20 – 40	1.4	1.4	1.3	1.6	1.4^{B}	0.7	0.7	0.9	0.8	0.8^{B}	2.1	2.1	2.2	2.4	2.2^{B}
	40 – 60	1.1	1.4	1.9	6.6	2.8^{B}	0.7	0.8	0.7	0.7	0.7^{B}	1.8	2.2	2.6	7.3	3.5^{B}
	60 – 80	0.7	2.9	4.7	13.1	5.4^{A}	0.8	0.7	0.6	0.6	0.7^{B}	1.5	3.6	5.3	13.8	6.0^{A}
	Mean	1.3^{B}	1.9^{B}	2.4^{B}	5.8^{A}		0.8^{A}	0.8^{A}	0.8^{A}	0.7^{A}		2.0^{B}	2.7^{B}	3.2^{B}	6.5^{A}	
	Tukey HSD$^{0.05}$	*N = 1.9 (P<0.001)* *Depth = 1.9 (P<0.001)* *N x Depth = 5.1 (P<0.001)*					*N = ns (P=0.28)* *Depth = 0.1 (P<0.001)* *N x Depth = ns (P=0.94)*					*N = 1.9 (P<0.001)* *Depth = 1.9 (P<0.001)* *N x Depth = 5.1 (P<0.001)*				
29 Sep 16	0 – 20	1.7	1.6	1.5	1.6	1.6^{B}	1.7	2.0	1.9	1.7	1.8^{A}	3.4	3.5	3.4	3.2	3.4^{AB}
	20 – 40	1.9	1.5	1.4	1.4	1.5^{B}	1.7	1.9	1.8	1.7	1.8^{AB}	3.6	3.4	3.1	3.1	3.3^{AB}
	40 – 60	1.1	1.0	1.6	2.4	1.5^{B}	1.4	1.6	1.6	1.6	1.6^{BC}	2.5	2.6	3.2	4.0	3.1^{B}
	60 – 80	1.1	0.9	2.9	7.0	3.0^{A}	1.5	1.5	1.4	1.5	1.5^{C}	2.6	2.4	4.3	8.5	4.5^{A}
	Mean	1.4^{B}	1.2^{B}	1.8^{AB}	3.1^{A}		1.6^{A}	1.7^{A}	1.7^{A}	1.6^{A}		3.0^{B}	3.0^{B}	3.5^{AB}	4.7^{A}	
	Tukey HSD$^{0.05}$	*N = 1.2 (P<0.01)* *Depth = 1.2 (P<0.01)* *N x Depth = 3.4 (P<0.01)*					*N = ns (P=0.25)* *Depth = 0.2 (P<0.01)* *N x Depth = ns (P=0.83)*					*N = 1.3 (P<0.01)* *Depth = 1.3 (P<0.05)* *N x Depth = 3.6 (P<0.001)*				

^{A,B,C} Means with the same letter in a group are either “not significantly” or “not highly significantly” different

Table 6-13 Soil nitrate-N, ammonium-N and total mineral N concentrations associated with the 1R crop and the various N application rates to a depth of 80 cm in increments of 20 cm in the N x K trial at Welcome Creek. The samples were collected from plot that had received 120 kg K/ha.

Date	Depth	N applied (kg/ha)														
		0	75	150	225		0	75	150	225		0	75	150	225	
		Soil N (mg/kg)														
		Nitrate-N				Mean	Ammonium-N				Mean	Mineral-N				Mean
21 Nov 16	0 – 20	2.3	2.6	2.8	3.0	2.7^{A}	1.3	1.7	1.5	1.4	1.5^{A}	3.6	4.3	4.3	4.4	4.1^{A}
	20 – 40	0.9	1.4	1.6	1.8	1.4^{A}	1.1	2.4	1.3	1.2	1.5^{A}	2.1	3.8	2.9	3.0	2.9^{A}
	40 – 60	0.6	4.2	1.6	2.3	2.2^{A}	0.7	3.0	0.9	0.9	1.4^{A}	1.2	7.2	2.5	3.2	3.5^{A}
	60 – 80	0.5	2.4	4.2	6.8	3.4^{A}	0.7	1.1	0.9	1.0	0.9^{A}	1.2	3.5	5.1	7.8	4.4^{A}
	Mean	1.1^{A}	2.7^{A}	2.6^{A}	3.4^{A}		1.0^{A}	2.0^{A}	1.1^{A}	1.1^{A}		2.0^{A}	4.7^{A}	3.7^{A}	4.6^{A}	
	Tukey $HSD^{0.05}$	*N = ns (P=0.08) Depth = ns (P=0.16) N x Depth = ns (P=0.34)*					*N = ns (P=0.08) Depth = ns (P=0.51 N x Depth = ns (P=0.85)*					*N = ns (P=0.15) Depth = ns (P=0.66) N x Depth = ns (P=0.53)*				
19 Jan 17	0 – 20	4.7	5.8	6.4	7.0	6.0^{A}	2.1	2.5	2.4	2.4	2.4^{A}	6.8	8.4	8.8	9.4	8.3^{A}
	20 – 40	2.9	4.7	5.9	5.0	4.6^{AB}	2.1	2.5	2.3	1.8	2.2^{A}	5.0	7.2	8.2	6.8	6.8^{AB}
	40 – 60	1.5	3.6	5.3	5.0	3.9^{B}	1.7	1.8	1.5	1.2	1.5^{B}	3.2	5.3	6.9	6.2	5.4^{B}
	60 – 80	1.0	3.4	8.8	8.6	5.4^{AB}	1.4	1.4	1.2	1.5	1.4^{B}	2.4	4.8	10.0	10.1	6.8^{AB}
	Mean	2.5^{C}	4.4^{BC}	6.6^{A}	6.4^{AB}		1.8^{A}	2.0^{A}	1.9^{A}	1.7^{A}		4.3^{B}	6.4^{AB}	8.5^{A}	8.1^{A}	
	Tukey $HSD^{0.05}$	*N = 2.1 (P<0.001) Depth = 2.1 (P<0.05) N x Depth =ns (P=0.12)*					*N = ns (P=0.19) Depth = 0.5 (P<0.001) N x Depth = ns (P=0.53)*					*N = 2.1 (P<0.001) Depth = 2.1 (P<0.01) N x Depth = ns (P=0.12)*				
18 Apr 17	0 – 20	2.6	3.0	2.6	3.5	2.9^{A}	1.3	1.4	1.7	1.4	1.4^{A}	3.9	4.4	4.2	4.9	4.3^{A}
	20 – 40	1.6	1.8	2.0	2.3	1.9^{B}	0.6	0.9	1.2	0.9	0.9^{B}	2.3	2.7	3.1	3.1	2.8^{B}
	40 – 60	0.9	0.8	1.7	2.9	1.6^{B}	0.6	0.8	0.9	0.7	0.7^{B}	1.5	1.6	2.6	3.5	2.3^{B}
	60 – 80	1.0	0.8	2.7	4.7	2.3^{AB}	0.6	0.7	0.6	0.7	0.7^{B}	1.6	1.5	3.3	5.4	2.9^{B}
	Mean	1.5^{B}	1.6^{B}	2.2^{B}	3.3^{A}		0.8^{B}	0.9^{AB}	1.1^{A}	0.9^{AB}		2.3^{C}	2.5^{BC}	3.3^{B}	4.2^{A}	
	Tukey $HSD^{0.05}$	*N = 0.8 (P<0.001) Depth = 0.8 (P<0.001) N x Depth = 2.3 (P<0.01)*					*N = 0.24 (P<0.05) Depth = 0.24 (P<0.001) N x Depth = ns (P=0.80)*					*N = 0.9 (P<0.001) Depth = 0.9 (P<0.001) N x Depth = 2.4 (P<0.05)*				
29 May 17	0 – 20	1.8	2.6	2.5	2.8	2.4^{A}	1.5	1.3	1.3	1.6	1.4^{A}	3.2	3.9	3.7	4.3	3.8^{A}
	20 – 40	1.0	1.2	1.5	1.8	1.4^{B}	1.0	0.7	0.8	1.0	0.9^{B}	2.0	1.9	2.3	2.8	2.2^{B}
	40 – 60	0.5	0.5	0.7	1.8	0.9^{B}	0.7	0.7	0.6	0.7	0.7^{C}	1.2	1.2	1.3	2.4	1.5^{B}
	60 – 80	0.5	0.6	1.2	2.6	1.2^{B}	0.7	0.7	0.7	0.7	0.7^{C}	1.2	1.3	1.9	3.3	1.9^{B}
	Mean	0.94^{B}	1.2^{B}	1.5^{B}	2.2^{A}		0.9^{A}	0.8^{A}	0.8^{A}	1.0^{A}		1.9^{B}	2.1^{B}	2.3^{B}	3.2^{A}	
	Tukey $HSD^{0.05}$	*N = 0.7 (P<0.001) Depth = 0.7 (P<0.001) N x Depth = ns (P=0.50)*					*N = ns (P=0.15) Depth = 0.2 (P<0.001) N x Depth = ns (P=0.84)*					*N = 0.8 (P<0.001) Depth = 0.8 (P<0.001) N x Depth = ns (P=0.81)*				
4 Aug 17	0 – 20	0.9	1.2	1.0	1.0	1.0^{A}	2.5	4.2	2.4	2.1	2.8^{A}	3.4	5.4	3.3	3.0	3.8^{A}
	20 – 40	1.8	1.0	0.9	0.7	1.1^{A}	1.2	2.0	3.0	1.6	1.9^{AB}	3.0	2.9	3.8	2.3	3.0^{AB}
	40 – 60	0.7	0.5	0.5	0.5	0.5^{B}	1.2	1.1	1.4	1.1	1.2^{B}	1.8	1.6	1.9	1.6	1.7^{C}
	60 – 80	0.5	0.9	0.5	1.2	0.8^{AB}	1.0	1.1	0.9	2.2	1.3^{B}	1.5	2.0	1.4	3.4	2.1^{BC}
	Mean	0.9^{A}	0.9^{A}	0.7^{A}	0.9^{A}		1.4^{A}	2.1^{A}	1.9^{A}	1.7^{A}		2.4^{A}	3.0^{A}	2.6^{A}	2.6^{A}	
	Tukey $HSD^{0.05}$	*N = ns (P=0.36) Depth = 0.4 (P<0.01) N x Depth = 0.4 (P<0.05)*					*N = ns (P=0.36) Depth = 1.0 (P<0.001) N x Depth = ns (P=0.09)*					*N = ns (P=062) Depth = 1.1 (P<0.001) N x Depth = ns (P=0.06)*				

^{A,B,C} Means with the same letter in a group are either "not significantly" or "not highly significantly" different

6.2.1.3. Third leaf N

The total N (%) values of third leaf samples collected from the plant and 1R crops on 2/3 Mar 2016 and 21/27 Mar 2017 respectively are presented in Table 6-14. Not unsurprisingly, no significant differences were evident in relation to either the rate of N or K applied. Experience with N field trials has shown in the past that responses to applied N do not often occur in plant cane. In this particular instance the plant crop followed an extended fallow period that would have resulted in the accumulation of N from mineralisation processes that would have occurred without crop uptake. This was confirmed by the soil NO_3^--N, NH_4^+-N and min-N values in the zero N plots at the site in Dec 2015 (Table 6-12).

In contrast to the lack of response to applied N in third leaf N values in the plant crop, significant differences (P<0.001) occurred in the 1R crop (Table 6-14). The mean values ranged from 1.38 %N for the control (zero N applied) to 1.68 %N with 225 kg N/ha. The established critical value for third-leaf N for samples collected in March is 1.7%N. As expected, third leaf N values did not respond to applied K.

Table 6-14 Third leaf N concentration (%DM) as influenced by N and K application rates for the plant and 1R crops in the N x K trial at Welcome Creek.

Crop	K applied (kg/ha)	Third leaf N values (%DM)				
		N applied (kg/ha)				Means for K applied
		0	75	150	225	
Plant	0	1.86	1.89	1.95	1.97	1.92^{A}
	60	1.85	1.84	1.95	1.89	1.88^{A}
	120	1.85	1.90	1.86	1.95	1.89^{A}
	180	1.87	1.92	1.98	1.70	1.87^{A}
	Means for N applied	1.86^{A}	1.89^{A}	1.93^{A}	1.88^{A}	
	Tukey HSD$^{0.05}$: N = ns (P=0.38); K = ns (P=0.73); N x K = ns (P=0.21)					
1R	0	1.41	1.59	1.59	1.64	1.55^{A}
	60	1.38	1.57	1.63	1.70	1.57^{A}
	120	1.35	1.55	1.57	1.70	1.54^{A}
	180	1.38	1.55	1.71	1.70	1.59^{A}
	Means for N applied	1.38^{C}	1.57^{B}	1.62^{B}	1.68^{A}	
	Tukey HSD$^{0.05}$: N = 0.06 (P<0.001); K = ns (P=0.20); N x FS = ns (P=0.15)					

^{A,B,C} Means with the same letter in a group are either “not significantly” or “not highly significantly” different

6.2.1.4. N uptake

Nitrogen uptake by the plant and ratoons crops (kg N/ha) based on the 12-month dry biomass samples and their N content are presented in Table 6-15. The N uptake by the plant crop when zero N was applied was relatively high (132.9 kg N/ha). This was not surprising due to the preceding long bare fallow and the amount of mineral N in the soil at the start of the crop cycle (Table 6-12). N-uptake did increase with increased rate of N applied and reached a maximum of 175 kg N/ha when 225 kg N/ha was applied. In the 1R crop the N uptake at zero N applied was markedly lower (79.4 kg N/ha) compared to 132.9 kg N/ha in the plant crop. As in the plant crop, N uptake increased significantly with the amount of N applied. Once again the maximum uptake was 175 kg N/ha at the highest N application rate (225 kg N/ha).

Table 6-15 Effect of N and K application rates on crop N uptake (kg N/ha) 12 months after planting (PC) or 12 month after harvest of the PC for the 1R crop.

Crop	K applied (kg/ha)	Crop N uptake (kg N/ha)				
		N applied (kg/ha)				Means for K applied
		0	75	150	225	
Plant	0	137.5	152.5	164.2	161.9	154.1^{A}
	60	123.9	161.5	150.5	184.3	155.0^{A}
	120	141.9	140.3	132.1	192.9	151.8^{A}
	180	128.2	130.4	172.3	161.4	148.1^{A}
	Means for N applied	132.9^{B}	146.2^{B}	154.8^{AB}	175.1^{A}	
	Tukey $HSD^{0.05}$: N = 26.9 (P<0.01; K = ns (P=0.88); N x K = ns (P=0.24)					
1R	0	72.4	136.7	126.9	135.9	118.0^{A}
	60	80.7	106.7	185.1	171.7	136.0^{A}
	120	67.4	130.3	130.0	188.2	128.9^{A}
	180	97.1	104.7	128.7	200.4	132.7^{A}
	Means for N applied	79.4^{C}	119.6^{B}	142.7^{B}	174.0^{A}	
	Tukey $HSD^{0.05}$: N = 24.1 (P<0.001); K = ns (P=0.20); N x K = 67.6 (P<0.01)					

^{A,B,C} Means with the same letter in a group are either "not significantly" or "not highly significantly" different

6.2.1.5. Yield and CCS

Sugarcane yields (tc/ha) associated with the plant and 1R crops are presented in Table 6-16. Sugarcane yields were more or less constant across the rates of N applied with no significant differences. This supports the previous statement made in relation to the third leaf N values that suggested that no response to applied N was expected. However, there was a significant yield response to applied K. This is the result of run-down of K in plots with zero/low K application rates over an extended period (since 2004). Interestingly, in the previous crop cycle in this trial (not reported here), interactive effects of NxK had occurred and suggested that actual responses to applied K *per se* were imminent. These interactive effects were now no longer evident (Table 6-16).

Sugarcane yields were significantly affected by N fertiliser applications in the 1R crop (Table 6-16) increasing from 62.2 tc/ha (zero N applied) to 85.3 tc/ha (at an application rate of 75 kg N/ha). This indicated that an appropriate N rate for this 1R crop following the extended fallow period prior to the plant crop was close to 75 kg N/ha. A quadratic response curve fitted to the yield data (not shown here) indicated that the optimum N rate for the 1R crop (based on 95% of the maximum yield) was 100 kg N/ha. Sugarcane yields were significantly affected by K applied. This re-iterated the importance of applying K fertiliser when needed. In the absence of K, sugarcane and sugar yields were negatively affected. At zero K applied, the plant crop yielded a mean of 96 tc/ha (across N rates). The mean yield increased to 104 tc/ha at intermediate rates of N (60 and 120 kg K/ha) and 112 tc/ha when K was applied at 180 kg K/ha. Similar trend occurred in the 1R crop. These results reinforce the concept and importance of "balanced nutrition".

The CCS values associated with samples collected from the plant and 1R crops (Table 6-17) showed no significant response to applied N in the plant crop. However, the CCS values decreased significantly with applied N in the 1R crop. Significant effects of applied K on CCS were evident, but are not discussed further here. As with cane yield, sugar yields were unaffected by the rate of N applied in the plant crop (Table 6-18), but were affected significantly by N fertiliser applications in the 1R crop increasing from 11.38 (at zero N applied to 15.71 when 75 kg N was applied. Sugar yield were also markedly affected by K fertiliser applications and supported the need for K to be applied in this case.

Table 6-16 Effect of N and K application rates on sugarcane yield (tc/ha).

Crop	K applied (kg/ha)	Sugarcane yield (tc/ha)				
		N applied (kg/ha)				Means for K applied
		0	75	150	225	
Plant	0	89.6	99.3	98.6	97.3	96.2^{C}
	60	105.2	101.9	105.6	96.3	102.3^{B}
	120	105.3	112.4	104.6	98.6	105.3^{B}
	180	111.9	111.7	111.1	112.2	111.7^{A}
	Means for N applied	103.0^{A}	106.3^{A}	105.0^{A}	101.1^{A}	
	Tukey HSD$^{0.05}$: N = ns (P=0.09); K = 5.7 (P<0.001); N x K = ns (P=0.09)					
1R	0	57.9	78.8	75.1	76.1	72.0^{C}
	60	63.3	85.5	91.9	86.5	81.8^{B}
	120	64.9	86.6	94.0	90.8	84.1^{AB}
	180	62.7	90.4	97.5	100.7	87.8^{A}
	Means for N applied	62.2^{B}	85.3^{A}	89.6^{A}	88.5^{A}	
	Tukey HSD$^{0.05}$: N = 6.0 (P<0.001); K = 6.0 (P<0.001); N x K = ns (P=0.11)					

^{A,B,C} Mean values accompanied by the same letter in a group are "not significantly" different

Table 6-17 Effect of N and K application rates on CCS (%).

Crop	K applied (kg/ha)	Commercial cane sugar (%)				
		N applied (kg/ha)				Means for K applied
		0	75	150	225	
Plant	0	15.79	14.99	15.27	15.38	15.36^{B}
	60	16.51	15.72	16.36	15.62	16.05^{A}
	120	16.19	16.16	15.41	15.88	15.91^{A}
	180	15.39	15.66	15.98	15.63	15.67^{AB}
	Means for N applied	15.97^{A}	15.63^{A}	15.75^{A}	15.63^{A}	
	Tukey HSD$^{0.05}$: N =ns (P=0.16); K = 0.45 (P<0.001); N x K = 1.23 (P<0.05)					
1R	0	18.72	18.57	18.44	18.07	18.45^{A}
	60	18.27	18.41	18.63	18.13	18.36^{A}
	120	18.28	18.55	18.02	17.84	18.17^{A}
	180	18.04	18.20	17.28	16.97	17.62^{B}
	Means for N applied	18.33^{A}	18.43^{A}	18.10^{AB}	17.75^{B}	
	Tukey HSD$^{0.05}$: N = 0.49 (P<0.01); K = 0.49 (P<0.001); N x K = ns (P=0.46)					

^{A,B,C} Mean values accompanied by the same letter in a group are "not significantly" different

Table 6-18 Effect of N and K application rates on sugar yield (ts/ha).

Crop	K applied (kg/ha)	Sugar yield (ts/ha)				
		N applied (kg/ha)				Means for K applied
		0	75	150	225	
Plant	0	14.14	14.87	15.10	14.95	14.76^{C}
	60	17.36	15.98	17.28	15.06	16.42^{B}
	120	17.05	18.17	16.14	15.67	16.76^{AB}
	180	17.18	17.50	17.75	17.54	17.49^{A}
	Means for N applied	16.43^{A}	16.63^{A}	16.56^{A}	15.80^{A}	
	Tukey HSD$^{0.05}$: N = ns (P=0.11); K = 0.97 (P<0.001); N x K = 2.65 (P<0.05)					
1R	0	10.83	14.63	13.84	13.75	13.26^{B}
	60	11.54	15.73	17.12	15.68	15.02^{A}
	120	11.84	16.04	16.93	16.22	15.25^{A}
	180	11.32	16.45	16.81	17.09	15.42^{A}
	Means for N applied	11.38^{B}	15.71^{A}	16.17^{A}	15.68^{A}	
	Tukey HSD$^{0.05}$: N = 1.13 (P<0.001); K = 1.13 (P<0.001); N x K = ns (P=0.35)					

^{A,B,C} Mean values accompanied by the same letter in a group are "not significantly" different

6.2.1.6. NUE and economics

A range of NUE indicators (Table 6-19) were calculated using sugarcane yields (Table 6-16) and N uptake data (Table 6-15). As expected, NUE expressed as tc/kg N applied decreased as the rate of N increased in both the plant and 1R crops. The values showed that N was 'more efficiently' used in the 1R crop than the plant crop due to the marked crop N uptake at zero N applied (Table 6-19). As indicated previously, this source of N was due primarily to the extended fallow period that preceded the plant crop. The agronomic NUE (Agron Eff_{fert}(kg N/additional TCH) values were high or could not be calculated because there was no significant increase in yield with increased N applied. The different patterns in crop N uptake in the plant and ratoon crops (as described in section 6.2.14) resulted in more fertiliser N being taken up by the 1R compared with the P crop. This again indicated improved NUE in the ratoon crop and was reflected in the NupEfert (%) values. Nitrogen use efficiency values for the Opt N and SIX EASY STEPS rates were included in Table 6-19. These rates provided a balanced option with intermediate crop N and NUE indicator values.

Costs of N fertilisers and yields enabled the calculation economic indicators for the N application rates included in the trial and for the Opt N and SIX EASY STEPS N rates for the soil at the trial site (Table 6-20). In the P crop, the best economic returns (grower partial net return of $3135/ha and an industry net return of $5,049/ha) occurred when zero N was applied. An assumed SIX EASY STEPS N rate of 100 kg N/ha provided favourable returns of $2,987 and $e956 respectively, despite the N input being greater than the actual requirement (that could only be determined after the season). In the 1R crop the SIX EASY STEPS N rate for this site (140 kg N/ha) resulted in the best economic returns ($3,235 and $5,000 for grower and industry net returns respectively). The economic returns were less at both higher and lower N application rates.

Table 6-19 Effect of N and K application rates on NUE.

Crop	Yield and efficiency factors	N applied (kg N/ha)					
		0	75	150	225	Opt N = 0	6ES = 100?
Plant crop	Mean yield (tc/ha)	103.0	106.3	105.0	101.1	103	105
	tc/kg N applied	-	1.42	0.70	0.45	-	1.05
	kg N applied/tc	-	0.70	1.43	2.22	-	0.95
	Agron Eff_{fert} (kg N/additional TCH)	-	22.7	75.0	-	-	50.0
	Crop N uptake (kg N/ha)[1]	132.9	146.2	154.8	175.1	132.9	150.0
	NUtE (TCH/kg crop N)[1]	0.78	0.73	0.68	0.58	0.78	0.70
	Fertiliser N uptake (kg N/ha)	-	13.3	21.9	42.2	-	17.1
	NUpEfert (additional kg N uptake/kg fert applied) %	-	17.7	14.6	18.8	-	16.3
						Opt N = 100	6ES = 140
1R	Mean yield (tc/ha)	62.2	85.3	89.6	88.5	87	92
	tc/kg N applied	-	1.14	0.60	0.39	0.87	0.66
	kg N applied/tc	-	0.88	1.67	2.56	1.15	1.52
	Agron Eff_{fert} (kg N/additional TCH)	-	3.25	5.47	8.56	4.03	4.70
	Crop N uptake (kg N/ha)[1]	79.4	119.6	142.7	174.0	126.5	142.6
	NUtE (TCH/kg crop N)[1]	0.78	0.71	0.63	0.51	0.69	0.65
	Fertiliser N uptake (kg N/ha)	-	40.2	63.3	94.6	47.1	63.2
	NUpEfert (additional kg N uptake/kg fert applied) %		53.6	42.2	42.0	47.1	45.1

[1]Calculated on final yield and N uptake at 12 months after planting or twelve months after previous harvest.

Table 6-20 Effect of N and K application rates on mean input, yield and economics parameters.

Crop	Inputs, yield and economic parameters	N applied (kg N/ha)					
		0	75	150	225	Opt N[1] = 0	6ES = 100?
Plant crop	Cost of N fertiliser($/ha)	0	98	195	173	0	130
	Mean cane yield (tc/ha)	103.0	106.3	105.0	101.1	103	105
	ccs (%)	15.97	15.63	15.75	15.63	15.97	15.7
	Mean sugar yield (ts/ha)	16.43	16.63	16.56	15.80	16.63	16.5
	Grower partial net return[2] ($/ha)	$3,135	$3,018	$2,924	$2,670	$3,135	$2,987
	Industry net return[2] ($/ha)	$5,049	$4,993	$4,882	$4,553	$5,049	$4,956
1R						Opt N[1] = 100	6ES = 140
	Cost of N fertiliser($/ha)	0	98	195	173	130	182
	Mean cane yield (tc/ha)	62.2	85.3	89.6	88.5	87	91
	ccs (%)	18.33	18.43	18.10	17.75	18.3	18.1
	Mean sugar yield (ts/ha)	11.38	15.71	16.17	15.68	15.98	16.46
	Grower partial net return[2] ($/ha)	$2,509	$3,121	$3,220	$2,851	$3,209	$3,235
	Industry net return[2] ($/ha)	$3,748	$4,748	$4,990	$4,523	$4,911	$5,000

[1]Optimum N = N rate corresponding to 95% of the maximum yield calculated from a response curve.
[2]Assumptions: Sugar price = $370/ts, harvesting and levies = $10/tc, cost of fertiliser = $1.30/kg N

6.2.1.7. Conclusions: Bdb NxK trial

- The SIX EASY STEPS program already recognises that sugarcane plant cane grown after a bare fallow requires less N fertiliser than replant cane (sugarcane grown without a fallow period between crop cycles).
- However, the long uncropped fallow period that occurred prior to the plant crop at this site (even though the zero N plots had received no fertiliser N for two crop cycles, except from previous legume fallow crops prior to previous crop cycles) supplied sufficient N to produce no response to applied N. The amount of N supplied in this way (presumably by mineralisation) exceeded 133 kg N/ha (the amount of N contained in the crop at harvest).
- This amount of mineralised N is unlikely to have been generated solely by the inherent soil organic matter [Org C = 1.0% (Table 5.1)], but suggests continuing mineralisation of N from preceding legume fallow crops. This supports the opinion that the N from such legume fallow crops is retained in the soil, and is not all subject to loss by leaching during the crops immediately after the fallow period.
- The response to applied K in this case was due to the insufficiency of K in plots that received zero or below removal rates over an extended period. This illustrate the importance of applying K when it is required and re-iterates the need for “balanced nutrition”.
- Soil $N0_3^-$-N and min-N values (following the N fertiliser applications and into the growing season) generally reflected the amounts of N applied. This was not the case with soil NH_4^+-N.
- Significant differences in NO_3^--N, NH_4^+-N and min-N, and evidence of movement of N down the soil profile continued as the seasons progressed.
- Occurrences of high rainfall events had a marked effect on soil mineral N concentration and location in the soil profile due to leaching.
- The lower soil mineral N values in the ratoon crop compared with those associated with the plant crop indicated run-down of the N reserve that presumably occurred due to the long fallow period.
- Third leaf N values reflected the relatively high N status of the plant crop and supported the lack of yield response to applied N in that crop.
- Third leaf N values associated with the 1R crop reflected the N status of the cane that was due to the rates of N applied.

- The various NUE indicators confirmed that the N fertiliser applied to the 1R crop was used more efficiently than the plant crop. This was due to the substantial amounts of N mineralised during the long fallow period.
- The SIX EASY STEPS N rate in the 1R crop provided a balance between being economically most appropriate and being environmentally responsible (due to intermediate NUE values).

6.2.2. Mackay N x Farming Systems trials

6.2.2.1. Rainfall

Rainfall data for the trial period from the Bureau of Meteorology station (0333300) located at Dumbleton Rocks (4.5 km away from the trial site) are presented in Figure 6-9.

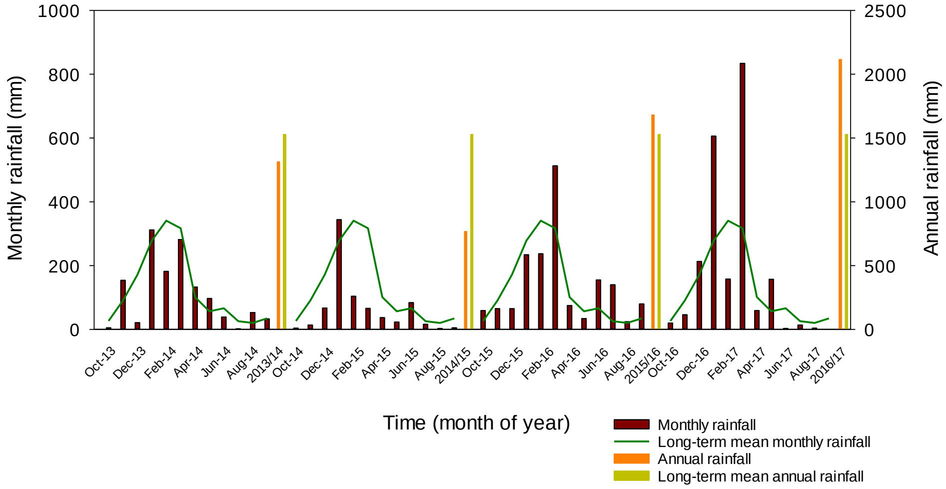


Figure 6-9 Monthly and annual recorded rainfall from the Dumbleton met site relevant to the Mackay N x Farming systems trials at the Mackay SRA station (Oct 2013 – Sep 2017).

Annual rainfall for all crops was calculated for the periods from October – September each year as this corresponded well with crop harvesting times (Figure 6-9). Rainfall for the 1R crop was slightly below average (1528 mm) at 1313 mm, well below average for the 2R crop at 767 mm, slightly above average for the 3R crop at 1681 mm and above average for the 4R crop at 2115 mm. Despite below average rainfall conditions during the 2R crop, December rainfall exceeded the long-term monthly average. Significant rainfall events were also experienced in March 2016 during the 3R crop, January 2017 and March 2017 during the 4R crop. The 4R crop was also impacted by Cyclone Debbie (March 2017) which resulted in crop lodging and some damage. This affected sampling activities during the 4R crop and increased variability. No irrigation was applied to ratoon crops.

6.2.2.2. Soil mineral N

Mky NxFS1:

Analysis of soil mineral N during the second ratoon crop revealed few statistically significant effects (Table 6-21). Mineral N decreased with soil depth at all sampling times. This was due to fertiliser application at ~ 10 cm and increased levels of soil org C and associated mineralisation near the soil surface. The lack of statistically significant effects may be due to very high variability as a result of sampling near the fertiliser band, and potentially the low number of replicates sampled. An example of this can be seen at 3 months in the 0-10 cm depth increment. Clearly, fertiliser N was collected during the sampling process, and the concentration in the soil sample was dependent on random factors (sampling location in respect to fertiliser application) rather than rate of product applied. The data show the presence of mineral N at 3 months after harvesting which is associated with fertiliser application. There was also evidence of elevated mineral N at 6 months, although this was mostly linked to one very high value (0-10 cm depth, Burnt, 200 kg N/ha). At 9 and 12 months mineral N values were low. There were no clear differences between farming systems at any time.

Similar observations were present in the third ratoon crop (Table 6-22). Soil mineral N decreased with sampling depth as discussed above. Soil mineral N concentrations were clearly elevated at 3 months due to N fertilisation and to a lesser extent at 6 months. Mineral N levels at 9 and 12 months were low. At 3 months there was a significant N rate by depth interaction (not shown). Soil mineral N in the 200 kg N/ha rate was significantly higher than the 150 kg N/ha rate which was significantly higher than both the 0 and 75 kg N/ha rate in the 0-10 cm increment. This effect was also evident to a lesser extent in the 10-30 cm increment but there was no difference in soil mineral N among N rates in the 30-50 and 50-80 cm increments. At 3 months, there was significantly higher soil mineral N in the Burnt than GCTB farming system. This could potentially be attributed to immobilisation of N in the GCTB farming system. However, a more likely explanation is that a sample was taken from closer to the fertiliser band in one system than the other by chance. No other difference in soil mineral N due to farming system were evident in the third ratoon crop.

Soil samples collected at the commencement and after harvesting of the fourth ratoon crop showed that soil mineral N was low at both times (Table 6-23)and the only statistically significant effect was due to sample depth (as discussed above).

Table 6-21 Soil mineral-N concentrations (mg/kg) associated with the second ratoon crop, N application rates and farming systems to a depth of 80 cm in the trial at Mackay (Mky NxFS1).

Crop	Time	Soil Depth (D) (cm)	Farming system (FS)										Overall mean Depth
			Burnt					GCTB					
			N applied (kg/ha)				Mean	N applied (kg/ha)				Mean	
			0	95	150	200	Depth	0	95	150	200	Depth	
2R	0	0-10	4.3	4.4	2.8	5.1	4.1	3.6	4.2	5.7	5.5	4.7	4.4
		10-30	4.3	3.2	3.7	3.6	3.7	5.1	3.9	3.3	5.3	4.4	4.1
		30-50	2.2	2.3	2.5	2.5	2.4	1.7	2.6	2.1	2.5	2.2	2.3
		50-80	1.9	2.2	2.6	2.4	2.3	1.8	2.3	1.5	2.2	1.9	2.1
		Mean N applied	3.2	3.0	2.9	3.4	3.1	3.0	3.3	3.1	3.9	3.3	
		$LSD^{0.05}$: FS ns (P=0.86); D 0.7 (P<0.01); FS x N ns (P=0.54); FS x D ns (P=0.30); FS x N x D ns (P=0.28)											
	3	0-10	4.1	7.1	301.8	11.8	81.2	3.6	56.4	8.1	48.4	29.1	55.2
		10-30	2.6	10.6	21.0	5.6	9.9	2.4	44.8	4.1	23.6	18.7	14.3
		30-50	1.5	3.8	1.9	3.4	2.6	2.8	12.8	3.1	8.2	6.7	4.7
		50-80	1.7	5.3	1.9	3.4	3.1	1.6	7.2	2.0	10.6	5.3	4.2
		Mean N applied	2.5	6.7	81.6	6.0	24.2	2.6	30.3	4.3	22.7	15.0	
		$LSD^{0.05}$: FS ns (P=0.79); D ns (P=0.19); FS x N ns (P=0.39); FS x D ns (P=0.56); FS x N x D ns (P=0.39)											
	6	0-10	2.8	4.3	3.4	44.6	13.7	4.5	5.3	6.2	6.8	5.7	9.7
		10-30	3.3	3.2	3.2	13.2	5.7	2.3	2.7	2.3	2.3	2.4	4.0
		30-50	1.7	1.8	1.5	3.2	2.0	1.0	2.1	1.1	2.4	1.7	1.9
		50-80	1.9	2.4	2.0	1.7	2.0	2.3	1.2	1.2	2.0	1.7	1.8
		Mean N applied	2.4	2.9	2.5	15.6	5.9	2.5	2.8	2.7	3.4	2.9	
		$LSD^{0.05}$: FS ns (P=0.16); D 2.9 (P<0.01); FS x N ns (P=0.06); FS x D 4.1 (P=0.04); FS x N x D 9.4 (P<0.01)											
	9	0-10	1.8	2.0	4.5	1.7	2.5	1.8	2.3	2.7	2.4	2.3	2.4
		10-30	1.8	1.5	1.6	1.3	1.5	1.5	1.5	1.3	1.7	1.5	1.5
		30-50	1.2	1.1	1.5	1.4	1.3	1.0	1.0	1.2	1.3	1.1	1.2
		50-80	1.1	0.9	1.2	1.2	1.1	0.8	1.2	0.8	1.1	1.0	1.0
		Mean N applied	1.5	1.4	2.2	1.4	1.6	1.3	1.5	1.5	1.7	1.5	
		$LSD^{0.05}$: FS ns (P=0.62); D 0.4 (P<0.01); FS x N 0.4 (P=0.02); FS x D ns (P=0.97); FS x N x D ns (P=0.44)											
	12	0-10	2.4	2.5	2.2	2.9	2.5	2.2	2.0	2.2	2.3	2.2	2.3
		10-30	1.7	1.9	1.5	2.3	1.8	1.7	1.6	1.9	1.9	1.7	1.8
		30-50	1.3	2.0	1.5	1.8	1.6	1.6	1.4	1.6	1.9	1.6	1.6
		50-80	1.4	2.0	1.3	1.7	1.6	1.2	1.6	1.2	1.6	1.4	1.5
		Mean N applied	1.7	2.1	1.6	2.2	1.9	1.7	1.7	1.7	1.9	1.7	
		$LSD^{0.05}$: FS ns (P=0.52); D 0.2 (P<0.01); FS x N ns (P=0.39); FS x D ns (P=0.56); FS x N x D ns (P=0.39)											

Table 6-22 Soil mineral-N concentrations (mg/kg) associated with the third ratoon crop, N application rates and farming systems to a depth of 80 cm in the trial at Mackay (Mky NxFS1)

Crop	Time	Soil Depth (D) (cm)	Farming system (FS)										Overall mean Depth
			Burnt					GCTB					
			N applied (kg/ha)				Mean Depth	N applied (kg/ha)				Mean Depth	
			0	75	150	200		0	75	150	200		
3R	0	0-10	2.4	2.5	2.2	2.9	2.5	2.2	2.0	2.2	2.3	2.2	2.3
		10-30	1.7	1.9	1.5	2.3	1.8	1.7	1.6	1.9	1.9	1.7	1.8
		30-50	1.3	2.0	1.5	1.8	1.6	1.6	1.4	1.6	1.9	1.6	1.6
		50-80	1.4	2.0	1.3	1.7	1.6	1.2	1.6	1.2	1.6	1.4	1.5
		Mean N applied	1.7	2.1	1.6	2.2	1.9	1.7	1.7	1.7	1.9	1.7	
		$LSD^{0.05}$: FS ns (P=0.52); D 0.2 (P<0.01); FS x N ns (P=0.39); FS x D ns (P=0.56); FS x N x D ns (P=0.39)											
	3	0-10	3.4	11.4	46.0	64.5	31.3	2.8	4.1	14.3	67.7	22.2	26.8
		10-30	2.4	2.6	11.4	7.4	5.9	1.8	2.0	5.0	12.6	5.4	5.7
		30-50	2.2	2.7	1.9	3.5	2.6	1.9	1.4	2.0	1.6	1.7	2.2
		50-80	1.8	1.4	1.5	2.4	1.8	1.5	1.6	1.3	1.6	1.5	1.6
		Mean N applied	2.4	4.5	15.2	19.5	10.4	2.0	2.3	5.7	20.9	7.7	
		$LSD^{0.05}$: FS 1.5 (P=0.03); D 4.4 (P<0.01); FS x N ns (P=0.23); FS x D ns (P=0.14); FS x N x D ns (P=0.16)											
	6	0-10	0.9	4.5	4.1	16.9	6.6	3.3	3.4	4.3	5.2	4.1	5.3
		10-30	1.7	2.1	2.3	2.6	2.2	1.5	2.4	2.1	2.7	2.2	2.2
		30-50	1.5	3.0	2.1	3.3	2.5	2.3	2.1	2.7	2.1	2.3	2.4
		50-80	1.3	2.0	3.4	3.2	2.5	1.8	1.7	1.5	1.9	1.7	2.1
		Mean N applied	1.4	2.9	3.0	6.5	3.4	2.2	2.4	2.6	3.0	2.6	
		$LSD^{0.05}$: FS ns (P=0.57); D ns (P=0.06); FS x N ns (P=0.45); FS x D ns (P=0.75); FS x N x D ns (P=0.74)											
	9	0-10	1.3	1.5	1.9	1.3	1.5	1.6	3.3	2.6	2.3	2.4	2.0
		10-30	1.1	1.5	1.4	1.5	1.4	1.2	1.6	2.0	1.7	1.6	1.5
		30-50	1.6	1.8	1.3	1.1	1.4	1.8	1.3	1.3	1.2	1.4	1.4
		50-80	1.3	0.8	1.2	1.7	1.2	1.0	1.4	0.9	1.3	1.1	1.2
		Mean N applied	1.3	1.4	1.4	1.4	1.4	1.4	1.9	1.7	1.6	1.6	
		$LSD^{0.05}$: FS ns (P=0.58); D 0.4 (P<0.01); FS x N ns (P=0.52); FS x D 0.6 (P=0.05); FS x N x D ns (P=0.72)											
	12	0-10	1.7	2.2	2.2	2.0	2.0	2.2	3.3	2.1	3.0	2.6	2.3
		10-30	1.0	2.4	1.8	1.9	1.8	3.1	1.5	2.2	2.5	2.3	2.0
		30-50	0.7	1.7	1.1	1.3	1.2	1.6	2.3	1.5	1.2	1.7	1.4
		50-80	1.1	1.1	1.2	1.5	1.2	1.0	1.1	1.2	1.4	1.2	1.2
		Mean N applied	1.1	1.8	1.6	1.7	1.5	2.0	2.1	1.7	2.0	1.9	
		$LSD^{0.05}$: FS ns (P=0.22); D 0.6 (P<0.01); FS x N ns (P=0.71); FS x D ns (P=0.60); FS x N x D ns (P=0.52)											

Table 6-23 Soil mineral-N concentrations (mg/kg) associated with the fourth ratoon crop, N application rates and farming systems to a depth of 80 cm in the trial at Mackay (Mky NxFS1)

Crop	Time	Soil Depth (D) (cm)	Farming system (FS)										Overall mean Depth
			Burnt					GCTB					
			N applied (kg/ha)				Mean Depth	N applied (kg/ha)				Mean Depth	
			0	75	150	200		0	75	150	200		
4R	0	0-10	1.7	2.2	2.2	2.0	2.0	2.2	3.3	2.1	3.0	2.6	2.3
		10-30	1.0	2.4	1.8	1.9	1.8	3.1	1.5	2.2	2.5	2.3	2.0
		30-50	0.7	1.7	1.1	1.3	1.2	1.6	2.3	1.5	1.2	1.7	1.4
		50-80	1.1	1.1	1.2	1.5	1.2	1.0	1.1	1.2	1.4	1.2	1.2
		Mean N applied	1.1	1.8	1.6	1.7	1.5	2.0	2.1	1.7	2.0	1.9	
		$LSD^{0.05}$: FS ns (P=0.22); D 0.6 (P<0.01); FS x N ns (P=0.71); FS x D ns (P=0.60); FS x N x D ns (P=0.52)											
	12	0-10	1.4	2.1	3.5	2.5	2.4	2.3	1.6	2.9	2.6	2.3	2.4
		10-30	0.8	1.5	1.0	1.7	1.2	1.5	1.6	2.0	2.0	1.8	1.5
		30-50	1.6	1.3	1.2	0.7	1.2	0.9	1.6	0.8	1.2	1.1	1.2
		50-80	1.5	1.6	2.9	3.8	2.4	1.6	3.4	2.5	3.3	2.7	2.6
		Mean N applied	1.3	1.6	2.1	2.2	1.8	1.6	2.0	2.1	2.2	2.0	
		$LSD^{0.05}$: FS ns (P=0.11); D 0.5 (P=0.02); FS x N ns (P=0.82); FS x D ns (P=0.90); FS x N x D ns (P=0.94)											

Mky NxFS2:

Soil mineral N values relating to the 2R crop are shown in Table 6-24. There was a significant decline in mineral N with depth as highlighted in Mky NxFS1. Farming system (bare or soybean fallow) had no effect on soil mineral N in the second ratoon crop. Despite the application of 150 kg N/ha prior to sampling at 3 months, there was no statistically significant difference in soil mineral N due to N rate at any of the sampling times. Despite the lack of statistical significance, there was some indication of increased soil mineral N at 6 months in the 150 kg N/ha rate. Soil mineral N at 9 and 12 months was low.

Treatments were altered to investigate the effect of past fertiliser history in the third ratoon crop (Table 6-25). The sample depth effect was significant at all sampling times. Few other statistically significant effects were found. As outlined previously, this may be due to high levels of variation and the low number of replicates. Despite the lack of statistical significance, there appeared to be higher soil mineral N at 3 months where 150 kg N/ha was applied to the crop. N rate history did not have any statistically significant effect on soil mineral N at any sampling time.

Table 6-24 Soil mineral-N concentrations (mg/kg) associated with the second ratoon crop, N application rates and farming systems to a depth of 80 cm in the trial at Mackay (Mky NxFS2).

Crop	Time	Soil depth (D) (cm)	Farming system (FS)						Overall mean depth
			Bare			Soybean			
			N applied (kg/ha)		Mean Depth	N applied (kg/ha)		Mean Depth	
			0	150		0	150		
2R	0	0-10	4.7	6.2	5.5	5.8	3.2	4.5	5.0
		10-30	3.3	4.8	4.1	4.2	3.4	3.8	3.9
		30-50	3.9	3.6	3.7	2.5	2.8	2.7	3.2
		50-80	2.4	2.9	2.7	3.1	3.6	3.3	3.0
		Mean N applied	3.6	4.4	4.0	3.9	3.2	3.6	
		$LSD^{0.05}$: FS ns (P=0.68); D 1.0 (P<0.01); FS x N ns (P=0.07); FS x D ns (P=0.23); FS x N x D ns (P=0.07)							
	3	0-10	2.3	3.4	2.9	4.2	6.6	5.4	4.1
		10-30	2.1	2.3	2.2	2.6	2.7	2.6	2.4
		30-50	1.7	1.3	1.5	1.8	2.8	2.3	1.9
		50-80	0.7	0.8	0.7	1.2	1.5	1.3	1.0
		Mean N applied	1.7	2.0	1.8	2.4	3.4	2.9	
		$LSD^{0.05}$: FS ns (P=0.27); D 1.0 (P<0.01); FS x N ns (P=0.75); FS x D ns (P=0.15); FS x N x D ns (P=0.82)							
	6	0-10	4.4	5.4	4.9	4.3	14.0	9.1	7.0
		10-30	1.8	1.8	1.8	2.4	3.6	3.0	2.4
		30-50	2.7	1.8	2.3	3.0	2.2	2.6	2.4
		50-80	1.1	0.9	1.0	1.6	2.6	2.1	1.6
		Mean N applied	2.5	2.5	2.5	2.8	5.6	4.2	
		$LSD^{0.05}$: FS ns (P=0.28); D 3.7 (P=0.03); FS x N ns (P=0.18); FS x D ns (P=0.69); FS x N x D ns (P=0.33)							
	9	0-10	2.2	2.3	2.2	2.6	1.9	2.3	2.3
		10-30	1.7	1.8	1.7	2.0	1.4	1.7	1.7
		30-50	1.1	1.2	1.2	1.5	1.2	1.3	1.3
		50-80	1.0	0.4	0.7	1.1	0.9	1.0	0.9
		Mean N applied	1.5	1.4	1.5	1.8	1.4	1.6	
		$LSD^{0.05}$: FS ns (P=0.63); D 0.3 (P<0.01); FS x N ns (P=0.34); FS x D ns (P=0.78); FS x N x D ns (P=0.23)							
	12	0-10	3.4	2.0	2.7	3.0	2.9	2.9	2.8
		10-30	1.9	1.8	1.8	2.2	2.3	2.2	2.0
		30-50	1.4	1.2	1.3	2.0	1.7	1.8	1.6
		50-80	1.9	1.2	1.5	1.7	1.9	1.8	1.7
		Mean N applied	2.2	1.5	1.9	2.2	2.2	2.2	
		$LSD^{0.05}$: FS ns (P=0.34); D 0.8 (P=0.02); FS x N ns (P=0.36); FS x D ns (P=0.98); FS x N x D ns (P=0.79)							

Soil samples collected at the commencement and after harvesting of the 4R crop showed that crop soil mineral N was low at both times (Table 6-26). The change in soil mineral N with depth was not statistically significant in the fourth ratoon crop. However, mean values were consistent with a decline with soil depth. While a significant N rate history by soil depth interaction was found at the commencement of the fourth ratoon crop, differences were small and likely to be of little consequence. This effect could be due to a Type 1 error where a significant effect is detected when it does not exist.

Table 6-25 Soil mineral-N concentrations (mg/kg) associated with the third ratoon crop, N application rates and N rate history to a depth of 80 cm in the trial at Mackay (Mky NxFS2)

Crop	Time	Soil depth (D) (cm)	N rate history (kg/ha)						Overall mean depth
			0			150			
			N applied (kg/ha)		Mean Depth	N applied (kg/ha)		Mean Depth	
			0	150		0	150		
3R	0	0-10			3.2			2.4	2.8
		10-30			2.0			2.0	2.0
		30-50			1.7			1.4	1.6
		50-80			1.8			1.6	1.7
		Mean N applied			2.2			1.9	
		LSD$^{0.05}$: NH ns (P=0.29); D 0.80 (P=0.04); NH x D ns (P=0.69)							
	3	0-10	3.7	6.2	5.0	4.2	18.0	11.1	8.0
		10-30	2.3	2.4	2.3	2.4	5.1	3.7	3.0
		30-50	1.8	2.4	2.1	1.7	2.2	2.0	2.0
		50-80	1.4	1.8	1.6	1.6	1.4	1.5	1.5
		Mean N applied	2.3	3.2	2.8	2.5	6.7	4.6	
		LSD$^{0.05}$: NH ns (P=0.37); D 3.9 (P=0.02); NH x N ns (P=0.41); NH x D ns (P=0.31); NH x N x D ns (P=0.37)							
	6	0-10	4.1	3.6	3.8	3.9	5.5	4.7	4.3
		10-30	2.8	2.5	2.7	2.1	2.3	2.2	2.4
		30-50	1.9	2.1	2.0	2.3	2.6	2.5	2.2
		50-80	1.7	1.7	1.7	1.6	2.1	1.9	1.8
		Mean N applied	2.6	2.5	2.5	2.5	3.1	2.8	
		LSD$^{0.05}$: NH ns (P=0.49); D 0.7 (P<0.01); NH x N ns (P=0.29); NH x D ns (P=0.24); NH x N x D ns (P=0.44)							
	9	0-10	2.1	2.1	2.1	2.5	1.6	2.1	2.1
		10-30	1.5	1.4	1.4	1.7	1.4	1.5	1.5
		30-50	1.2	1.3	1.2	1.8	1.0	1.4	1.3
		50-80	1.4	1.5	1.4	1.1	1.0	1.0	1.2
		Mean N applied	1.5	1.5	1.5	1.8	1.2	1.5	
		LSD$^{0.05}$: NH ns (P=0.82); D ns (P=0.10); NH x N ns (P=0.13); NH x D ns (P=0.84); NH x N x D ns (P=0.91)							
	12	0-10	2.2	4.0	3.1	1.9	2.0	1.9	2.5
		10-30	1.1	1.3	1.2	2.6	3.1	2.8	2.0
		30-50	1.4	1.7	1.5	1.4	2.1	1.7	1.6
		50-80	1.1	1.4	1.3	0.8	2.1	1.5	1.4
		Mean N applied	1.4	2.1	1.8	1.7	2.3	2.0	
		LSD$^{0.05}$: NH ns (P=0.44); D ns (P=0.06); NH x N ns (P=0.93); NH x D 1.2 (P=0.03); NH x N x D ns (P=0.37)							

Table 6-26 Soil mineral-N concentrations (mg/kg) associated with the 4R crop, N application rates and N rate history to a depth of 80 cm in the trial at Mackay (Mky NxFS2)

Crop	Time	Soil depth (D) (cm)	N rate history (kg/ha)						Overall mean depth
			0			150			
			N applied (kg/ha)		Mean	N applied (kg/ha)		Mean	
			0	150	Depth	0	150	Depth	
4R	0	0-10	2.2	4.0	3.1	1.9	2.0	1.9	2.5
		10-30	1.1	1.3	1.2	2.6	3.1	2.8	2.0
		30-50	1.4	1.7	1.5	1.4	2.1	1.7	1.6
		50-80	1.1	1.4	1.3	0.8	2.1	1.5	1.4
		Mean N applied	1.4	2.1	1.8	1.7	2.3	2.0	
		$LSD^{0.05}$: NH ns (P=0.44); D ns (P=0.06); NH x N ns (P=0.93); NH x D 1.2 (P=0.03); NH x N x D ns (P=0.37)							
	12	0-10	2.3	3.0	2.6	1.9	2.5	2.2	2.4
		10-30	2.0	1.5	1.7	1.6	1.2	1.4	1.6
		30-50	1.3	1.3	1.3	1.4	1.2	1.3	1.3
		50-80	2.2	2.0	2.1	1.6	1.2	1.4	1.7
		Mean N applied	1.9	1.9	1.9	1.6	1.5	1.6	
		$LSD^{0.05}$: NH ns (P=0.09); D ns (P=0.41); NH x N ns (P=0.77); NH x D ns (P=0.97); NH x N x D ns (P=0.99)							

6.2.2.3. Third leaf N

Mky NxFS1:

Significant differences in third leaf N concentration among N rate treatments were present in all three crops (Table 6-27). In the second ratoon, the 0 kg N/ha treatment was lower than all others, the 95 and 150 kg N/ha treatments were similar and the 200 kg N/ha treatment was higher than all others. There was no difference between farming systems and no N rate by farming system interaction. In the third ratoon, the 0 and 75 kg N/ha treatments were lower than the 150 and 200 kg N/ha treatments. There was no difference between farming systems and no N rate by farming system interaction. In the 4R crop, the 0 Kg N/ha treatment was lower than the 75 kg N/ha treatment which was lower than both the 150 and 200 kg N/ha treatments. The GCTB farming system had higher third leaf N concentration than the Burnt system in the fourth ratoon crop, however the magnitude of this difference was small. Overall, the 150 kg N/ha treatment, which was the SIX EASY STEPS rate for this site, maintained third leaf N concentration above the critical value (1.8-1.9). The 95/75 kg N/ha treatment had third leaf N concentrations that were marginally below the critical value, particularly in the third and fourth ratoon crops. The 0 kg N/ha treatment had low third leaf N concentrations (1.5-1.6) and was clearly N deficient. Data from third leaf N analyses did not indicate any difference in N supply or N uptake between GCTB and Burnt farming systems.

Table 6-27 Third leaf N concentration (%DM) as influenced by N rates and farming systems for the 2R, 3R and 4R crops in the trial at Mackay (Mky NxFS1)

Crop	Farming system (FS)	Third leaf N values (%DM)				
		N applied (kg/ha)				Mean for FS
		0	95	150	200	
2R	Burnt	1.55	1.98	2.13	2.24	1.97[A]
	GCTB	1.49	1.90	1.99	2.19	1.89[A]
	Mean for N applied	1.52[C]	1.94[B]	2.06[B]	2.21[A]	
	LSD$^{(0.05)}$: FS ns (P=0.52); N 0.13 (P<0.01); FS x N ns (P=0.85)					
		0	75	150	200	
3R	Burnt	1.58	1.76	2.12	2.21	1.92[A]
	GCTB	1.66	1.70	1.98	2.08	1.85[A]
	Mean for N applied	1.62[B]	1.73[B]	2.05[A]	2.14[A]	
	LSD$^{(0.05)}$: FS ns (P=0.17); N 0.15 (P<0.01); FS x N ns (P=0.33)					
4R	Burnt	1.56	1.68	2.00	2.03	1.82[A]
	GCTB	1.54	1.77	1.88	2.01	1.80[B]
	Mean for N applied	1.55[C]	1.72[B]	1.94[A]	2.02[A]	
	LSD$^{(0.05)}$: FS 0.016 (P=0.04); N 0.11 (P<0.01); FS x N ns (P=0.27)					

[A,B,C] Mean values accompanied by the same letter in a group are “not significantly” different

Mky NxFS2:

In the second ratoon crop, sugarcane that received 150 kg N/ha had significantly higher third leaf N concentration than where 0 kg N/ha was applied (Table 6-28). There was no difference in third leaf N concentration between soybean and bare fallow farming systems and no significant interaction. Similarly, in the third and fourth ratoon crops, sugarcane that received 150 kg N/ha had higher third leaf N concentration than sugarcane that received 0 kg N/ha. There was no statistically significant difference due to N rate history and no interaction for both third and fourth ratoon crops. In the third ratoon, plots that received 0 kg N/ha with a history of 150 kg N/ha had higher mean third leaf N concentration (1.75) than plots with a history of 0 kg N/ha (1.68). Although not statistically significant, this may be an indication of the residual effect from N application history. This observation was not present in the fourth ratoon crop. Overall, the 150 kg N/ha treatment maintained third leaf N concentrations at or slightly above the critical value. Plots that received 0 kg N/ha were below the critical value and clearly N deficient.

Table 6-28 Third leaf N concentration (%DM) as influenced by N rates and farming systems for the 2R crop, and N rate and N rate history for the 3R and 4R crops in the trial at Mackay (Mky NxFS2)

Crop	Farming system (FS)	Third leaf N values (%DM)		
		N applied		
		0	150	Mean (FS)
2R	Bare	1.57	2.04	1.80[A]
	Soybean	1.62	2.05	1.83[A]
	Mean for N applied	1.59[B]	2.04[A]	
	LSD$^{(0.05)}$: FS ns (P=0.68); N 0.05 (P<0.01); FS x N ns (P=0.19)			

Crop	N rate history (NH)	Third leaf N values (%DM)		
		N applied		Mean for N history
		0	150	
3R	0	1.68	2.06	1.87[A]
	150	1.75	2.03	1.89[A]
	Mean for N applied	1.71[B]	2.04[A]	
	LSD$^{(0.05)}$: NH ns (P=0.54); N 0.09 (P<0.01); NH x N ns (P=0.22)			
4R	0	1.64	1.90	1.77[A]
	150	1.65	1.90	1.78[A]
	Mean for N applied	1.64[B]	1.90[A]	
	LSD$^{(0.05)}$: NH ns (P=0.57); N 0.04 (P<0.01); NH x N ns (P=0.57)			

[A,B,C] Mean values accompanied by the same letter in a group are "not significantly" different

6.2.2.4. Biomass and N uptake

Mky NxFS1

At the final harvest of the first ratoon crop (12 months), the 0 kg N/ha rate produced significantly lower dry biomass than all other N rates (Table 6-29). Significantly higher dry biomass was produced in the GCTB than the Burnt farming system. A similar result was present for crop N uptake (Table 6-30) with the 0 kg N/ha rate having lower crop N than all other N rates. However, there was no difference in terms of N uptake between farming systems.

In the second ratoon crop, significant differences in dry biomass were found due to N rate (Table 6-29), crop age and an interaction between N rate and crop age (Figure 6-10). Dry biomass increased with N rate up to the 150 kg N/ha rate. Dry biomass increased with crop age. The interaction was due to similar dry biomass among all N rates at 3 months, but thereafter the 0 kg N/ha rate was significantly lower than all others. The 95 kg N/ha rate was also lower than both the 150 and 200 kg N/ha rates at 9 months and the 200 kg N/ha rate at 12 months (Figure 6-10). There were no statistically significant effects associated with farming systems.

Crop N content in the second ratoon crop (Table 6-10) were also affected by N rate, crop age and the interaction of these two effects (Figure 6-10). Crop N content increased significantly with crop N rate. Crop N content increased up until 6 months after harvest, declined slightly between 6 and 9 months and then remained stable. The interaction between crop age and N rate was due to there being no difference between crop N contents for any N rate at 3 months, crop N content increased between 3 and 6 months for all N rates but this increase was lower for the 0 and 95 kg N/ha treatments, crop N content remained stable between 6 and 9 months in the 0 and 200 kg N/ha rates but declined in the 95 and 150 kg N/ha rates, between 9 and 12 months crop N content declined further in the 150 kg N/ha rate whereas others remained stable. It was also evident that crop N content in the 0 kg N/ha rate increased with crop age and did not peak at 6 months.

Similar effects were also present in the third ratoon crop for both dry biomass production and crop N content. Dry biomass increased with N rate up to the 75 kg N/ha rate but not thereafter (Table 6-29). Dry biomass increased with crop age and the largest dry biomass was achieved at 12 months (not shown). The interaction between crop age and N rate was highly significant. This was due to there being no difference in crop dry biomass due to crop N rate at 3 months, the 0 kg N/ha rate being lower than all others at 6 and 9 months, and the 0 kg N/ha rate being lower than the 75 kg N/ha rate which was significantly lower than the 150 and 200 kg N/ha rates at 12 months (Figure 6-10). Crop N content of the third ratoon crop was significantly higher in the GCTB than Burnt farming system (Table 6-30). Crop N content increased with N rate, although there was no statistically significant difference between the 75 and 150 kg N/ha rates. Crop N content increased with age up to 6 months after harvest, there was a significant decline between 9 and 12 months. A significant interaction between crop age and N rate on crop N content was due to no difference in crop N content among N rates at 3 months, whereas the 0 kg N/ha rate was lower than all others and the 75 kg N/ha rate was lower than the 200 kg N/ha rate at 6, 9 and 12 months. There was no statistically significant difference in crop N content between the 150 and 200 kg N/ha rates at any time.

Dry biomass of the fourth ratoon crop was affected by N rate, crop age, the interaction between N rate and farming system, N rate and crop age and N rate, crop age and farming system (Table 6-29). As indicated, the fourth ratoon crop was damaged by Cyclone Debbie, which introduced variability in the trial and potentially some unexpected results. Dry biomass generally increased with N rate, however the 150 kg N/ha rate was lower than both the 75 and 200 kg N/ha rates. As the crop was only sampled at 3 and 9 months, there was a large difference in dry biomass at these two times. The N rate by farming system interaction was primarily due to a greater difference in dry biomass between the 75 and 150 kg N/ha rates in the GCTB system than the Burnt system. The N rate by crop age interaction was due to similar biomass among N rates at 3 months and significant differences among all N rates at 9 months (Figure 6-10). The significant three way interaction was complex, but appeared to be primarily due to there being no difference between the 0 and 150 kg N/ha rates at 9 months in the GCTB system in comparison to the Burnt system where dry biomass for the 0 kg N/ha rate was significantly lower than the 150 kg N/ha rate at 9 months. Crop N content of the fourth ratoon crop was affected by N rate, crop age and their interaction. The 0 kg N/ha rate had lower N content than all other treatments, the 75 and 150 kg N/ha rates were similar and the 200 kg N/ha rate was significantly higher than all others. Crop N content was higher at 9 months than at 3 months after harvest. The significant interaction was due to a change at 9 months, in comparison to at 3 months, where the 150 kg N/ha rate had lower crop N content than both the 75 and 200 kg N/ha rates (Figure 6-10).

Table 6-29 Effect of N rates and farming systems on dry biomass production (t/ha) at 3, 6, 9 and 12 months after harvest of 1R, 2R, 3R and 4R crops at Mackay.

Crop	Farming system (FS)	Crop Age (A)	Dry biomass (t/ha)				
			N applied (kg/ha)				Mean (FS)
			0	95	150	200	
1R	Burnt	12	19.9	29.3	30.8	31.1	27.6
	GCTB	12	24.7	33.5	32.9	36.1	31.8
	Mean N applied		22.3	31.4	31.9	34.0	
	LSD 0.05 :FS 0.9 (P<0.01); N 2.9 (P<0.01); FS x N ns (P=0.70)						
2R	Burnt	3	1.0	0.9	1.2	1.3	1.1
		6	6.9	12.8	15.9	13.8	12.3
		9	10.2	17.3	21.6	20.9	17.5
		12	13.5	24.9	26.1	28.3	23.2
		Mean	7.9	14.0	16.2	16.1	13.5
	GCTB	3	0.8	1.2	1.1	1.3	1.1
		6	6.3	13.6	15.3	15.8	12.7
		9	10.8	19.3	22.7	23.6	19.1
		12	14.8	26.2	28.1	29.8	24.7
		Mean	8.2	15.1	16.8	17.6	14.4
	Mean N applied		8.0	14.5	16.5	16.9	
	LSD 0.05 :FS ns (P=0.62); N 1.6 (P<0.01); FS x N ns (P=0.76); A x FS ns (P=0.58); A x FS x N ns (P=0.99)						
			0	75	150	200	
3R	Burnt	3	0.8	0.5	0.7	0.6	0.7
		6	5.1	8.9	7.7	9.0	7.7
		9	11.2	13.0	13.3	14.0	12.9
		12	8.2	17.5	20.9	21.6	17.1
		Mean	6.4	10.0	10.7	11.3	9.6
	GCTB	3	1.1	1.5	1.5	1.7	1.4
		6	5.9	11.3	12.4	12.1	10.4
		9	12.3	16.7	19.7	19.5	17.1
		12	10.4	21.7	26.0	27.9	21.5
		Mean	7.4	12.8	14.9	15.3	12.6
	Mean N applied		6.9	11.4	12.8	13.3	11.1
	LSD 0.05 :FS ns (P=0.08); N 2.1 (P<0.01); FS x N ns (P=0.33); A x FS ns (P=0.18); A x FS x N ns (P=0.99)						
4R	Burnt	3	0.7	0.9	1.2	1.8	1.1
		9	6.7	19.5	16.8	23.1	16.5
		Mean	3.7	10.2	9.0	12.5	8.8
	GCTB	3	0.9	1.6	1.5	1.8	1.5
		9	12.6	23.1	15.2	21.0	18.0
		Mean	6.8	12.3	8.4	11.4	9.7
	Mean N applied		5.2	11.2	8.7	11.9	
	LSD 0.05 :FS ns (P=0.42); N 0.9 (P<0.01); FS x N 3.8 (P<0.01); A x FS ns (P=0.14); A x FS x N 2.8 (P=0.01)						

Table 6-30 Effect of N rates and farming systems on crop N uptake (kg N/ha) at 3, 6, 9 and 12 months after harvest of 1R, 2R, 3R and 4R crops at Mackay.

Crop	Farming system (FS)	Crop Age (A)	Crop N (kg/ha)				
			N applied (kg/ha)				
			0	95	150	200	Mean (FS)
1R	Burnt	12	38.5	51.3	64.2	76.1	56.3^{A}
	GCTB	12	46.1	72.3	68.5	65.4	63.1^{A}
	Mean N applied		42.3^{B}	61.8^{A}	66.3^{A}	70.0^{A}	
	$LSD^{0.05}$:FS ns (P=0.10); N 17.8 (P=0.01); FS x N ns (P=0.24)						
2R	Burnt	3	6.8	8.1	12.3	14.7	10.5
		6	24.7	52.1	88.6	71.4	59.2
		9	24.4	46.9	63.8	73.2	52.1
		12	27.9	49.0	52.8	68.1	49.5
		Mean	21.0	39.0	54.4	56.9	42.8
	GCTB	3	7.4	16.6	14.7	15.7	13.6
		6	18.2	55.9	63.9	78.9	54.2
		9	28.2	42.9	61.2	69.5	50.5
		12	32.1	51.2	53.6	67.2	51.0
		Mean	21.5	41.6	48.4	57.8	42.3
	Mean N applied		21.2	40.3	51.4	57.3	
	$LSD^{0.05}$:FS ns (P=0.88); N 3.6 (P<0.01); FS x N ns (P=0.10); A x FS ns (P=0.27); A x FS x N ns (P=0.16)						
			0	75	150	200	
3R	Burnt	3	6.8	7.7	10.9	10.0	8.8
		6	23.5	56.1	55.4	65.8	50.2
		9	34.1	40.0	49.5	59.0	45.6
		12	17.2	34.2	40.5	42.6	33.6
		Mean	20.4	34.5	39.1	44.4	34.6
	GCTB	3	8.2	24.2	24.4	28.6	21.4
		6	23.3	50.5	76.8	86.7	59.3
		9	40.7	48.5	59.9	69.4	54.6
		12	21.4	37.8	54.0	63.7	44.2
		Mean	23.4	40.3	53.8	62.1	44.9
	Mean N applied		21.9	37.4	46.4	53.2	
	$LSD^{0.05}$:FS 7.9 (P=0.04); N 10.1 (P<0.01); FS x N ns (P=0.32); A x FS ns (P=0.95); A x FS x N ns (P=0.88)						
4R	Burnt	3	8.0	13.7	19.4	30.2	17.8
		9	19.5	38.9	36.1	60.8	38.8
		Mean	13.7	26.3	27.8	45.5	28.3
	GCTB	3	10.5	23.0	24.2	25.3	20.8
		9	27.9	50.6	31.2	49.3	39.8
		Mean	19.2	36.8	27.7	37.3	30.3
	Mean N applied		16.5	31.6	27.7	41.4	
	$LSD^{0.05}$:FS ns (P=0.74); N 8.0 (P<0.01); FS x N ns (P=0.12); A x FS ns (P=0.58); A x FS x N ns (P=0.39)						

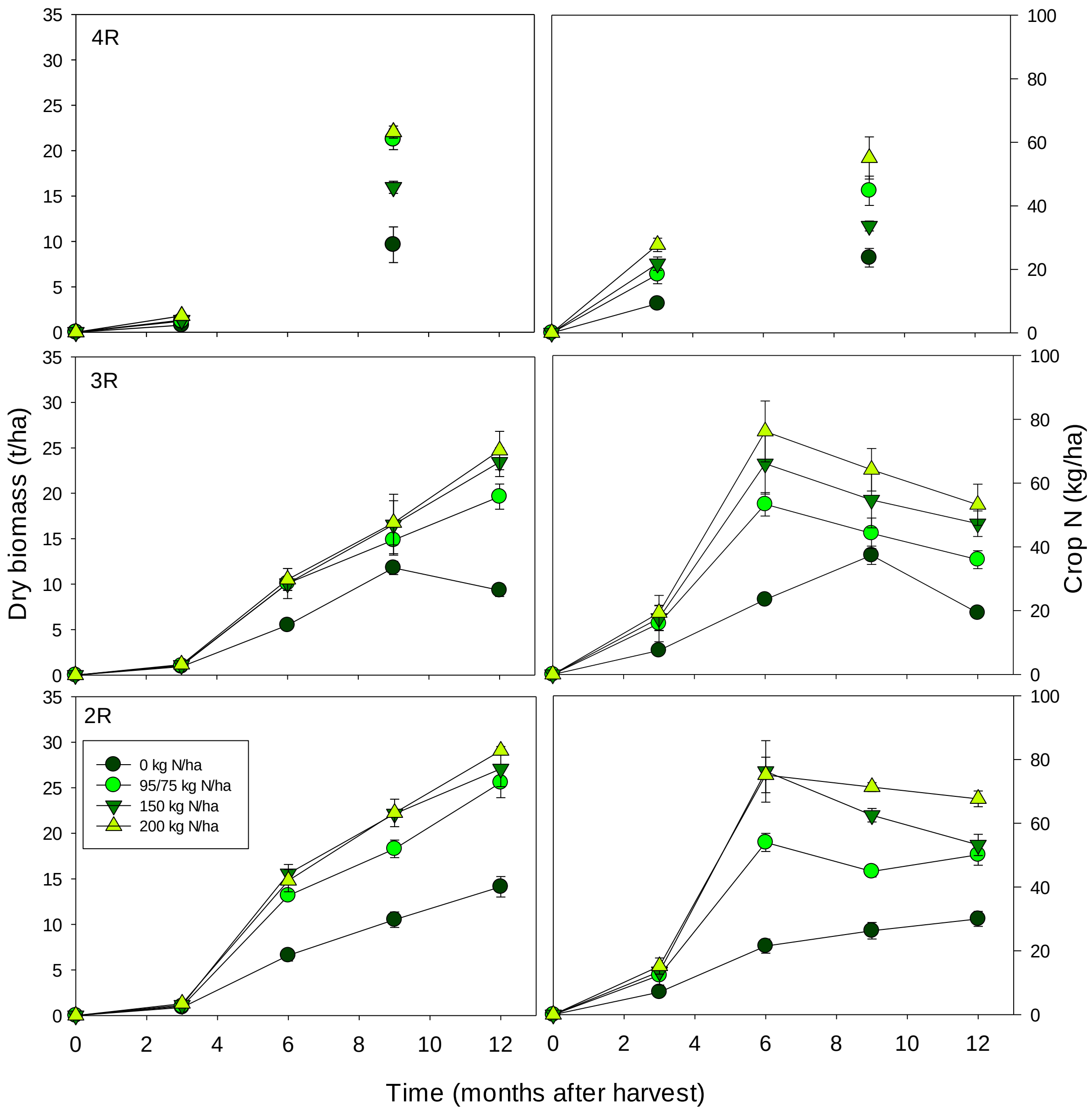


Figure 6-10 Crop dry biomass (t/ha) and N content (kg/ha) over time for a second, third and fourth ratoon crop that received 0, 95/75, 150 and 200 kg N/ha (Mky NxFS1)

Mky NxFS2

Dry biomass at final harvest of the first ratoon crop showed statistically significant differences due to crop N rate and the interaction between N rate and farming system (Table 6-31). Dry biomass was greater in the 150 kg N/ha than the 0 kg N/ha rate. At 0 kg N/ha, dry biomass was significantly lower in the soybean fallow than the bare fallow system. This difference was not present where 150 kg N/ha was applied. Crop N content of the first ratoon crop was higher where 150 kg N/ha was applied to the crop. There was no overall difference in N content between the soybean and bare fallow systems, however where 150 kg N/ha was applied to the crop, crop N content was higher following soybean than the bare fallow. As was the case in the first ratoon crop, dry biomass and crop N content in the second ratoon were significantly higher in the 150 kg N/ha rate than the 0 kg N/ha rate. This effect was also evident in the third and fourth ratoon crops for both traits (Table 6-31). Significant crop age by N rate interactions were found for both dry biomass and crop N content in the second ratoon (Figure 6-11). For dry biomass, this was due to there being no difference in dry biomass between N rates at 3 months but dry biomass was significantly higher in the 150 kg N/ha treatment thereafter. For crop N content, there was no difference between N rates at 3 months but crop N content was significantly higher in the 150 kg N/ha rate thereafter. There was no increase in crop N content in the 150 kg N/ha rate after 6 months (Figure 6-11). No significant effects due to farming system were evident in the second ratoon crop.

In the 3R crop treatments were changed to investigate the effect of N rate history. There was significantly higher dry biomass and crop N content where there was a history of 150 kg N/ha than a history of 0 kg N/ha (Table 6-31). This was an indication of the contribution past fertiliser practices have on the availability of nitrogen in a given season. A significant crop age by N rate interaction was found for both dry biomass and crop N content. Again this effect was due to there being no differences between N rate treatments at 3 months, and significant differences thereafter. Crop biomass peaked at 9 months whereas N content peaked at 6 months after harvest, particularly in the 150 kg N/ha treatment. There was a decline in crop N content between 9 and 12 months.

The effect of N rate history on dry biomass and crop N content was not significant in the fourth ratoon crop. The crop age by N rate interaction was significant for both traits and was again associated with small differences between N rate treatments when the crop was only 3 months old.

General

There were a number consistent results in terms of biomass development and crop N content across both Mky NxFS1 and Mky NxFS2. In both experiments, biomass development was slow in the first 3 months. Similarly, crop N content at 3 months was low and there were few differences due to N rates at this time. This suggests that the crop had low N demand and that background N in the soil pool was mostly able to support growth during this period. This result is consistent with recommendations that suggest a delay to fertiliser application after harvest by up to 6 weeks is unlikely to have any impact on yield. Chapman (1996) also showed low crop N content at 10 weeks after harvest and no difference between N rate treatments at this time. Biomass development and crop N uptake in the first three months may have been associated with below average rainfall and no irrigation application during spring in all growing seasons during the experiments. The extent to which irrigation management can manipulate N uptake during this early growth period is an important issue that needs to be investigated.

While biomass development tended to increase between 3 and 12 months, crop N content reached a maximum at 6 months after harvesting and in many cases declined between 9 and 12 months after harvesting. This may be associated with a loss of green leaves and canopy late in the season or translocation of N within the crop to below ground tissues or suckers. The N content of dead leaves, root systems and suckers were not assessed in the experiments. Crop N content did increase throughout the growing season in 0 kg N/ha treatments. This suggests that when a crop is nitrogen deficient, it will continue to take up any available N during the season.

Soil mineral N data showed evidence of fertiliser N at 3 and 6 months, but values at 9 months were low. Potentially, the lack of any further N uptake after 6 months may have been associated with a lack of N supply after this time. Chapman (1996) also showed that crop N uptake primarily occurred in the first 22 weeks (5.5 months) after harvesting, but again this coincided with a decline in soil mineral N in most treatments. Where mineral N was available in the soil profile (a treatment that received 300 kg N/ha), crop N uptake increased significantly after 22 weeks. This suggests that the decline in soil mineral N in the profile around 6 months, which is most likely linked to the onset of the wet season, could be the factor which causes crop N uptake to plateau.

In Mky NxFS1, there were generally consistent results for both third leaf N % and crop N content (kg/ha). In both cases, statistically significant differences were found due to N rates. While crop N content allows a number of NUE estimates to be performed, leaf sampling can still provide valuable information about the crops N status.

Table 6-31Effect of N rates and farming systems/N rate history on dry biomass (t/ha) production and crop N uptake (kg N/ha) at 3, 6, 9 and 12 months after harvest of 1R, 2R, 3R and 4R crops at Mackay.

Crop	Farming system (FS)	Age	Dry biomass (t/ha) N applied (kg/ha)			Crop N (kg/ha) N applied (kg/ha)		
			0	150	Mean FS	0	150	Mean FS
1R	Bare	12	21.7	33.6	27.7	37.0	61.1	49.0
	Soybean	12	18.6	35.4	27.0	32.1	78.8	55.5
	Mean N applied		20.2	34.5		34.5	69.9	
	LSD$^{0.05}$		FS ns (P=0.55); N 1.6 (P<0.01); FS x N 3.0 (P<0.01)			FS ns (P=0.06); N 10.4 (P<0.01); FS x N 14.8 (P=0.04)		
2R	Bare	3	0.9	1.2	1.1	6.5	12.7	9.6
		6	6.1	13.5	9.8	21.7	50.8	36.3
		9	10.1	22.3	16.2	27.3	59.0	43.2
		12	13.9	28.7	21.3	29.9	55.3	42.6
		Mean	7.7	16.4	12.1	21.3	44.5	32.9
	Soybean	3	0.9	1.2	1.0	6.0	13.5	9.8
		6	6.2	13.7	10.0	24.2	54.9	39.5
		9	10.9	20.2	15.6	27.8	51.0	39.4
		12	18.0	23.9	21.0	34.4	40.3	37.4
		Mean	9.0	14.8	11.9	23.1	39.9	31.5
	Mean N applied		8.4	15.6		22.2	42.2	
	LSD$^{0.05}$		FS ns (P=0.79); N 3.0 (P<0.01); FS x N ns (P=0.17); A x FS ns (P0.99); A x FS x N ns (P=0.57)			FS ns (P=0.56); N 1.3 (P<0.01); FS x N ns (P=0.13); A x FS ns (P=0.57); A x FS x N ns (P=0.36)		

Crop	N rate history (NH)	Age	Dry biomass (t/ha) N applied (kg/ha)			Crop N (kg/ha) N applied (kg/ha)		
			0	150	Mean NH	0	150	Mean NH
3R	0	3	1.2	1.8	1.5	9.3	27.6	18.5
		6	6.1	12.0	9.0	25.9	69.6	47.8
		9	14.9	20.2	17.5	48.3	64.3	56.3
		12	8.6	24.3	16.5	16.9	48.9	32.9
		Mean	7.7	14.6	11.1	25.1	52.6	38.9
	150	3	1.0	1.6	1.3	10.2	27.2	18.7
		6	8.3	13.8	11.1	35.5	84.5	60.0
		9	15.6	26.6	21.1	55.9	86.2	71.0
		12	11.2	24.3	17.7	23.0	47.2	35.1
		Mean	9.0	16.6	12.8	31.2	61.3	46.2
	Mean N applied		8.3	15.6		28.1	57.0	
	LSD$^{0.05}$		NH 1.1 (P=0.02); N 1.1 (P<0.01); NH x N ns (P=0.39); A x NH ns (P=0.30); A x NH x N ns (P=0.21)			NH 2.5 (P<0.01); N 2.5 (P<0.01); NH x N ns (P=0.19); A x NH ns (P=0.18); A x NH x N ns (P=0.50)		
4R	0	3	1.1	1.3	1.2	9.1	19.8	14.5
		9	11.0	24.8	17.9	23.8	52.8	38.3
		Mean	6.1	13.1	9.6	16.4	36.3	26.4
	150	3	1.3	2.1	1.7	12.3	33.6	22.9
		9	11.2	24.9	18.0	24.8	53.5	39.2
		Mean	6.2	13.5	9.8	18.6	43.5	31.0
	Mean N applied		6.1	13.3		17.5	39.9	
	LSD$^{0.05}$		NH ns (P=0.86); N 4.3 (P=0.02); NH x N ns (P=0.93); A x NH ns (P=0.89); A x NH x N ns (P=0.90)			NH ns (P=0.22); N 9.5 (P<0.01); NH x N ns (P=0.46); A x NH 9.0 (P0.03); A x NH x N ns (P=0.07)		

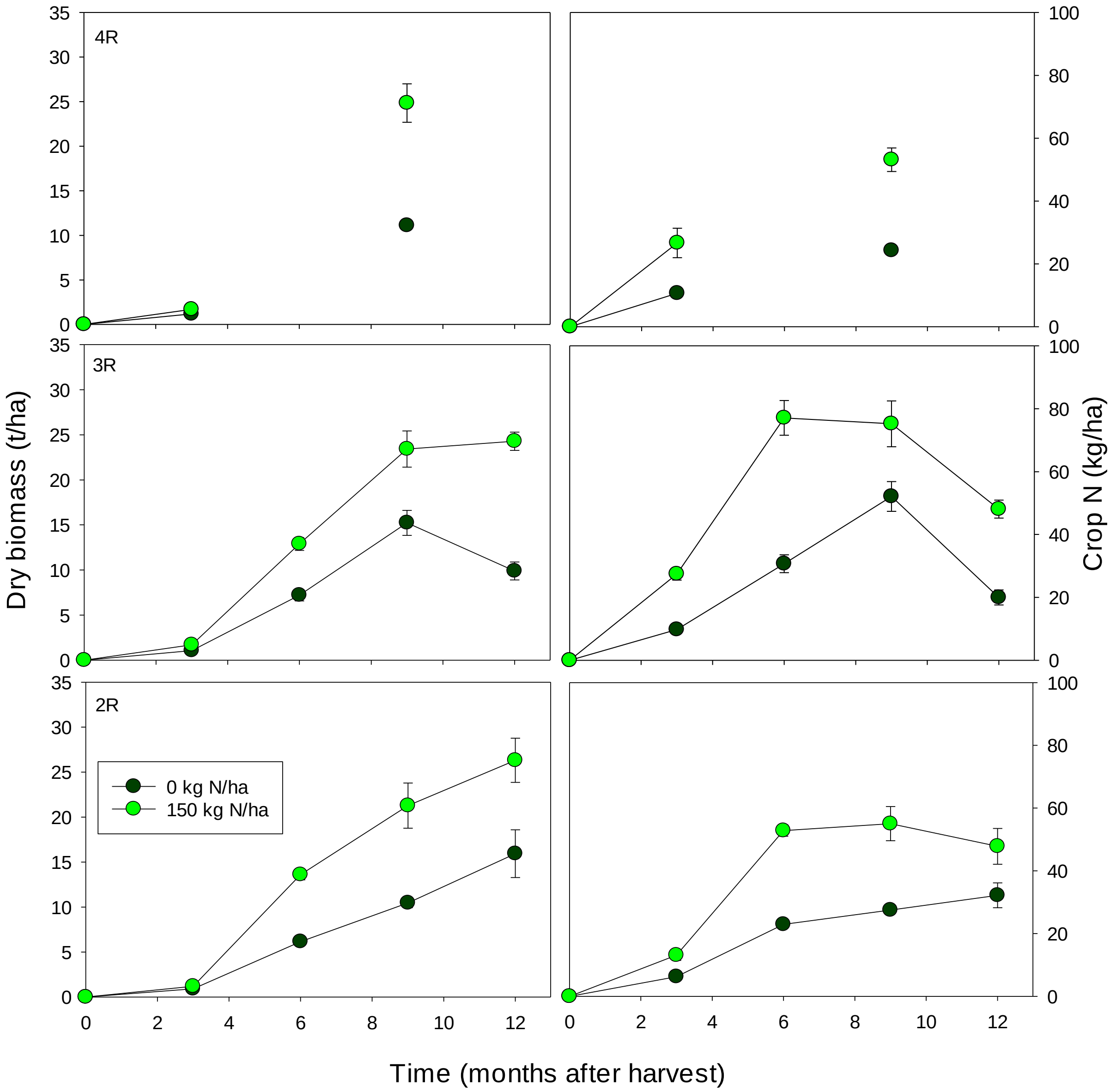


Figure 6-11 Crop dry biomass (t/ha) and N content (kg/ha) over time for a second, third and fourth ratoon crop that received 0 or 150 kg N/ha (Mky NxFS2)

6.2.2.5. Yield and CCS

Mky NxFS1

In the first ratoon crop, sugarcane yield increased significantly with N rate, however there was no difference between the 95 and 150 kg N/ha treatments. Yield was significantly higher in the GCTB farming system than Burnt but the interaction between N rate and farming system was not significant (Table 6-32). In the second ratoon crop, sugarcane yield increased significantly with N rate. The 0 kg N/ha rate was significantly lower than the 95 kg N/ha rate which was significantly lower than the 150 kg N/ha rate which was significantly lower than the 200 kg N/ha rate. A significant N rate by farming system interaction was due to yield increasing at the 200 kg N/ha rate in the GCTB system but not in the Burnt system. The GCTB farming system produced significantly greater yield than the Burnt system. In the third ration crop, sugarcane yield increased significantly with N rate. The 0 kg N/ha rate was significantly lower than the 75 kg N/ha rate which was significantly lower than the 150 kg N/ha and 200 kg N/ha rate. Yield was significantly higher in the GCTB farming system but the interaction between N rate and farming system was not significant. A similar result was present in the fourth ratoon crop, although in this case there was no difference between 75 and 150 kg N/ha rates. Yield at the site was relatively low, most likely due to a lack of irrigation.

CCS declined significantly with N rate in the first ratoon crop (Table 6-33). The 0 kg N/ha rate was higher than the 95 and 150 kg N/ha rates which were both higher than the 200 kg N/ha rate. There was no difference between farming systems and no interaction between N rate and farming system. In the second ratoon crop, CCS in the 0 kg N/ha rate was significantly lower than all others. There was no difference between farming systems and no interaction between N rate and farming system. CCS of the second ratoon was high, most likely reflecting dry growing conditions. In the third ratoon crop, there was no overall effect of N rate or farming system on CCS. However, a significant interaction effect was evident. This was associated with CCS increasing with N rate in the GCTB system but not in the Burnt system. CCS in the fourth ratoon crop was affected by N rate. In this case the 150 kg N/ha treatment was lower than the 200 kg N/ha treatment but not the 0 or 75 kg N/ha rates. This is an unusual result, and may be associated with variability present in the trial due to cyclone damage. There was no difference in CCS due to farming system in the fourth ratoon. The data suggests that under mild N deficiency CCS may be increased. However, under more severe deficiency, following multiple years of low application rates, CCS is either reduced or similar to sugarcane that has received recommended levels of N fertiliser.

The effect of N rates and farming systems on sugar yield (Table 6-34) were very similar to those reported for sugarcane yield. A key difference was that for sugar yield there was no statistically significant difference between 150 and 200 kg N/ha rates for any crop.

Table 6-32 Effect of N rates and farming systems on sugarcane yield (tc/ha) at Mackay (Mky NxFS1).

Crop	Farming system (FS)	Sugarcane yield				
		N applied (kg/ha)				Mean FS
		0	95	150	200	
1R	Burnt	52.2	79.6	82.0	84.4	74.5^{B}
	GCTB	64.9	90.9	90.7	98.7	86.3^{A}
	Mean N applied	58.6^{C}	85.2^{B}	86.4^{B}	91.5^{A}	
	$LSD^{0.05}$: FS 3.3 (P<0.01); N 6.7 (P<0.01); FS x N ns (P=0.84)					
2R	Burnt	26.8	61.4	68.3	67.2	55.9^{B}
	GCTB	28.8	66.3	71.4	80.6	61.8^{A}
	Mean N applied	27.8^{D}	63.9^{C}	69.9^{B}	73.9^{A}	
	$LSD^{0.05}$: FS 4.4 (P=0.02); N 4.0 (P<0.01); FS x N 5.7 (P=0.03)					
		0	75	150	200	
3R	Burnt	22.8	47.3	60.8	61.4	48.1^{B}
	GCTB	30.3	69.2	73.3	82.5	63.8^{A}
	Mean N applied	26.6^{C}	58.3^{B}	67.0^{A}	71.9^{A}	
	$LSD^{0.05}$: FS 2.5 (P<0.01); N 6.9 (P<0.01); FS x N ns (P=0.12)					
4R	Burnt	27.1	57.6	75.3	78.6	59.8^{B}
	GCTB	28.7	75.5	75.6	86.8	65.3^{A}
	Mean N applied	27.9^{C}	67.8^{B}	75.4^{AB}	82.1^{A}	
	$LSD^{0.05}$: FS 2.5 (P<0.01); N 9.5 (P<0.01); FS x N ns (P=0.32)					

^{A,B,C} Mean values accompanied by the same letter in a group are “not significantly” different

Table 6-33 Effect of N rates and farming systems on CCS at Mackay (Mky NxFS1).

Crop	Farming system (FS)	Commercial cane sugar (%)				
		N applied (kg/ha)				Mean FS
		0	95	150	200	
1R	Burnt	15.97	15.16	15.10	14.29	15.13^{A}
	GCTB	15.60	15.07	15.12	14.83	15.16^{A}
	Mean N applied	15.78^{A}	15.11^{B}	15.11^{B}	14.56^{C}	
	$LSD^{0.05}$: FS ns (P=0.89); N 0.50 (P<0.01); FS x N ns (P=0.32)					
2R	Burnt	18.27	18.54	18.77	18.19	18.44^{A}
	GCTB	17.57	18.58	18.58	18.47	18.30^{A}
	Mean N applied	17.92^{B}	18.56^{A}	18.68^{A}	18.33^{A}	
	$LSD^{0.05}$: FS ns (P=0.25); N 0.45 (P=0.01); FS x N ns (P=0.17)					
		0	75	150	200	
3R	Burnt	14.97	14.87	14.60	15.00	14.86^{A}
	GCTB	14.25	14.54	14.84	15.09	14.68^{A}
	Mean N applied	14.61^{A}	14.71^{A}	14.72^{A}	15.05^{A}	
	$LSD^{0.05}$: FS ns (P=0.15); N ns (P=0.06); FS x N 0.47 (P=0.03)					
4R	Burnt	16.83	16.65	16.28	17.05	16.70^{A}
	GCTB	16.75	16.78	16.87	17.03	16.86^{A}
	Mean N applied	16.79^{AB}	16.71^{AB}	16.57^{B}	17.04^{A}	
	$LSD^{0.05}$: FS ns (P=0.18); N 0.33 (P=0.05); FS x N ns (P=0.18)					

^{A,B,C} Mean values accompanied by the same letter in a group are “not significantly” different

Table 6-34 Effect of N rates and farming systems on sugar yield (ts/ha) at Mackay (Mky NxFS1).

Crop	Farming system (FS)	Sugar yield				
		N applied (kg/ha)				Mean FS
		0	95	150	200	
1R	Burnt	8.3	12.1	12.4	12.1	11.2^{B}
	GCTB	10.1	13.7	13.7	14.6	13.0^{A}
	Mean N applied	9.2^{B}	12.9^{A}	13.0^{A}	13.4^{A}	
	$LSD^{0.05}$: FS 0.95 (P<0.01); N 0.99 (P<0.01); FS x N ns (P=0.61)					
2R	Burnt	4.9	11.4	12.8	12.2	10.3^{B}
	GCTB	5.1	12.3	13.3	14.9	11.4^{A}
	Mean N applied	5.0^{C}	11.8^{B}	13.0^{A}	13.5^{A}	
	$LSD^{0.05}$: FS 0.8 (P=0.03); N 0.9 (P<0.01); FS x N 1.2 (P=0.03)					
		0	75	150	200	
3R	Burnt	3.4	7.0	8.9	9.2	7.1^{B}
	GCTB	4.3	10.1	10.9	12.5	9.4^{A}
	Mean N applied	3.9^{C}	8.5^{B}	9.9^{A}	10.8^{A}	
	$LSD^{0.05}$: FS 0.5 (P<0.01); N 1.0 (P<0.01); FS x N ns (P=0.10)					
4R	Burnt	4.5	9.5	12.3	13.4	10.0^{B}
	GCTB	4.8	12.6	12.8	14.7	11.0^{A}
	Mean N applied	4.7^{C}	11.3^{B}	12.5^{AB}	14.0^{A}	
	$LSD^{0.05}$: FS 0.6 (P<0.01); N 1.6 (P<0.01); FS x N ns (P=0.38)					

^{A,B,C} Mean values accompanied by the same letter in a group are “not significantly” different

Sugarcane and sugar yield data at the site showed yield was increased in a GCTB farming system and there was a significant response to N rate. Improved yield in a GCTB farming system has been identified previously (Chapman *et al.,* 2001). While differences in yield between the two systems may be attributed to a number of factors, the effect of trash on soil moisture is likely to be significant. The response to N was similar in both farming systems. The results showed that the 150 kg N/ha rate (SIX EASY STEPS N rate) was able to maintain sugar yields in both systems. No statistically significant difference was found between this rate and the 200 kg N/ha rate for any crop. This result is consistent with third leaf %N data that was above the critical value in both the 150 and 200 kg N/ha treatments. These treatments also had similar crop N contents. The 95 kg N/ha rate, which changed to 75 kg N/ha in the third ratoon crop produced significantly lower yields than the 150 kg N/ha rate in the second and third ratoon crops, and was significantly lower than the 200 kg N/ha rate in the second, third and fourth ratoon crops. Clearly, this rate was marginal in terms of optimising production. This result was also supported by third leaf %N data which was slightly below the critical value and crop N content that was lower than the 150 and 200 kg N/ha rates in the second and third ratoon crops. This rate was also shown to be marginal despite the relatively low yields at the site. After the first ratoon crop, yield in the 0 kg N/ha treatment stabilised at ~ 30 tc/ha. This would appear to be the level of production that could be supported by mineralisation in the absence of fertiliser N at this site (in the absence of irrigation).

Given that there were few significant farming system by N rate interactions for yield at the site, this would suggest that N availability was similar in both farming systems. Soil mineral N data and third leaf %N data also support this observation as they too showed few significant farming system effects. These result are also similar to those reported from the previous crop cycle (Salter et al., 2010). The farming system treatments had been in place at the site since 1993. Initial work suggested that N rates could potentially be reduced following long-term trash blanketing due to increased soil C and N supply (Robertson and Thorburn, 2007). However, the amount of N fertiliser that can be saved in these long-term system may only be modest (≤ 20 kg N/ha) (Meier and Thorburn, 2016). Recent analysis of soil carbon in the two systems also showed no difference in soil C (Page *et al*., 2013). Understanding why soil C has not improved under long-term GCTB at this site is important as soil C is seen as a key indicator of soil condition and function. Potentially, tillage operations between crop cycles may negate any soil C accumulation within the crop cycle.

Mky NxFS2

Sugarcane yield in the first ratoon crop was affected by the interaction of N rate and farming systems (Table 6-35). Where the crop received 0 kg N/ha, sugarcane yield was significantly higher in the bare fallow than the soybean fallow. No difference was found between farming system where 150 kg N/ha was applied. This result suggests that there was limited N contribution to the first ratoon crop from the soybean fallow. Only 18 kg N/ha was applied to the plant cane crop following the soybean fallow (cw. 138 following bare fallow). The results from the first ratoon crop suggest that this rate was low and could have resulted in lower residual N in the soil pool following soybean fallow than the bare fallow system going into the first ratoon crop. Sugar yield in the first ratoon crop showed that where 150 kg N/ha was applied, yield was higher following the soybean than the bare fallow. Given that the response was the opposite at the 0 kg N/ha N rate, this may suggest that this yield response may be due to factors other than nitrogen. In the second ratoon crop, sugarcane yield was significantly higher following 150 kg N/ha than 0 kg N/ha. No difference between farming systems or interaction between N rate and farming system was evident. This suggest that any difference in soil N pools present in the first ratoon were no longer present following two seasons where no nitrogen was applied. The results also indicates that a soybean fallow has no lasting N contribution through the crop cycle, especially if N rates in the plant cane crop are reduced as recommended in the SIX EASY STEPS.

Treatments were altered in the third ratoon crop to explore the effect of N rate history. A significant interaction between N rate history and N rate was evident in the third ratoon crop. Where 0 kg N/ha was applied to the crop, sugarcane and sugar yield were significantly higher where there was a history of applying N at 150 kg N/ha in comparison to a history of 0 kg N/ha. There was no difference between histories where 150 kg N /ha was applied to the crop. There was an additional 10.2 tc/ha that appeared to be supported by residual N in the soil pool due to fertiliser history. This effect was not present in the fourth ratoon crop, where the only significant difference was due to N applied in that season. This suggest that while past fertiliser history contributes to N uptake in following crops, one season with very low N application can eliminate this effect.

CCS was higher in the 0 kg N/ha treatment than the 150 kg N/ha treatment in the first ratoon crop, but lower than the 150 kg N/ha treatment in the second ratoon crop. This result is consistent with those reported for Mky NxFS1. There was no effect of farming system on CCS and no significant interaction between N rates and farming system in the first and second ratoon crops. In the third ratoon crop CCS was significantly lower in the 0 kg N/ha treatment than the 150 kg N/ha treatment. This effect was not present in the fourth ratoon crop. There was no effect of N rate history or interaction between N rate history and N rate in either the third or fourth ratoon crops.

Table 6-35 Effect of N rates and farming systems/N rate history on sugarcane yield (tc/ha), CCS and sugar yield (ts/ha) at Mackay (Mky NxFS2).

Crop	Farming system (FS)	Sugarcane yield (t/ha)			Commercial cane sugar (%)			Sugar yield (t/ha)		
		N applied (kg/ha) 0	N applied (kg/ha) 150	Mean FS	N applied (kg/ha) 0	N applied (kg/ha) 150	Mean FS	N applied (kg/ha) 0	N applied (kg/ha) 150	Mean FS
1R	Bare	59.7	92.6	76.1^{A}	15.51	15.16	15.34^{A}	9.3	14.0	11.6^{A}
	Soybean	50.7	98.1	74.4^{A}	15.86	15.33	15.59^{A}	8.0	15.0	11.5^{A}
	Mean N applied	55.2^{B}	95.3^{A}		15.69^{A}	15.25^{B}		8.7^{B}	14.5^{A}	
	LSD $^{0.05}$	*FS ns (P=0.49); N 3.4 (P<0.01) FS x N 6.7 (P<0.01)*			*FS ns (P=0.28); N 0.27 (P<0.01) FS x N ns (P=0.44)*			*FS ns (P=0.71); N 0.5 (P<0.01) FS x N 0.8 (P<0.01)*		
2R	Bare	28.4	67.5	47.9^{A}	17.51	18.80	18.15^{A}	5.0	12.7	8.8^{A}
	Soybean	31.5	69.4	50.5^{A}	17.92	18.69	18.30^{A}	5.6	13.0	9.3^{A}
	Mean N applied	29.9^{B}	68.5^{A}		17.72^{B}	18.74^{A}		5.3^{B}	12.8^{A}	
	LSD $^{0.05}$	*FS ns (P=0.10); N 4.1 (P<0.01) FS x N ns (P=0.74)*			*FS ns (P=0.50); N 0.18 (P<0.01) FS x N 0.60 (P=0.01)*			*FS ns (P=0.08); N 0.8 (P<0.01) FS x N ns (P=0.59)*		

Crop	N rate history (NH)	Sugarcane yield (t/ha)			Commercial cane sugar (%)			Sugar yield (t/ha)		
		N applied (kg/ha) 0	N applied (kg/ha) 150	Mean NH	N applied (kg/ha) 0	N applied (kg/ha) 150	Mean NH	N applied (kg/ha) 0	N applied (kg/ha) 150	Mean NH
3R	0	28.0	73.8	50.9^{B}	14.35	15.08	14.72^{A}	4.0	11.1	7.6^{B}
	150	38.2	73.2	55.7^{A}	14.22	14.98	14.60^{A}	5.4	11.0	8.2^{A}
	Mean N applied	33.1^{B}	73.5^{A}		14.29^{B}	15.03^{A}		4.7^{B}	11.0^{A}	
	LSD $^{0.05}$	*NH 3.7 (P=0.01); N 3.7 (P<0.01); NH x N 5.3 (P<0.01)*			*NH ns (P=0.50); N 0.33 (P<0.01); NH x N ns (P=0.93)*			*NH 0.6 (P=0.03); N 0.6 (P<0.01); NH x N 0.8 (P<0.01)*		
4R	0	27.9	82.8	55.4^{A}	16.71	16.91	16.81^{A}	4.7	14.0	9.3^{A}
	150	32.7	81.4	57.0^{A}	16.89	16.72	16.80^{A}	5.5	13.6	9.6^{A}
	Mean N applied	30.3^{B}	82.1^{A}		16.80^{A}	16.82^{A}		5.1^{B}	13.8^{A}	
	LSD $^{0.05}$	*NH ns (P=0.50); N 5.0 (P<0.01); NH x N ns (P=0.22)*			*NH ns (P=0.95); N ns (P=0.91); NH x N ns (P=0.17)*			*NH ns (P=0.61); N 0.9 (P<0.01); NH x N ns (P=0.15)*		

^{A,B,C} Mean values accompanied by the same letter in a group are "not significantly" different

6.2.2.6. NUE and economics

Mky NxFS1

Nitrogen use efficiency data are shown in Table 6-36. It includes estimates of NUE at the optimum N rate (Opt N) which was calculated from N response curves. In most cases, the more simple estimates of NUE (tc/kg N applied; kg N applied/tc) showed a decline in NUE with increasing N rate. However, this often occurred with increasing yield. This trend was not as clear for NUpEfert, where in many cases values for the 200 kg N/ha rate were equivalent or better than the 95/75 kg N/ha rate. The average OptN over all crops for the Burnt and GCTB systems was 129 and 128 kg N/ha, respectively.

Calculation of grower partial net return and industry net return are presented in Table 6-37. In the Burnt farming system, grower and industry returns were maximised at the Opt N rate (107 kg N/ha) in the first ratoon, at 150 kg N/ha in the second ratoon, and at 200 kg N/ha in the third and fourth ratoon crops. In the GCTB farming system, grower partial net return and industry net return were maximised at the 200 kg N/ha rate for all crops. This was primarily due to higher mean sugarcane yield at this N rate without any reduction in CCS. This high return would need to be balanced against the greater potential for N losses and associated environmental concerns. The Opt N rate was the next most profitable in the GCTB system.

Table 6-36 Effect of N rates and farming systems on NUE (Mky NxFS1)

Crop	Yield and efficiency factors	Burnt					GCTB				
		N applied (kg N/ha)				Opt N	N applied (kg N/ha)				Opt N
		0	95	150	200	= 107	0	95	150	200	= 135
1R	Mean yield (tc/ha)	52.2	79.6	82.0	84.4	79.7	64.9	90.9	90.7	98.7	94.0
	tc/kg N applied	-	0.8	0.5	0.4	0.7	-	1.0	0.6	0.5	0.7
	kg N applied/tc	-	1.2	1.8	2.4	1.3	-	1.0	1.7	2.0	1.4
	Agron Efffert (kg N/additional TCH)	-	3.5	5.0	6.2	3.9	-	3.7	5.8	5.9	4.6
	Crop N uptake (kg N/ha)[1]	38.5	51.3	64.2	76.1	54.1	46.1	72.3	68.5	65.4	69.5
	NUtE (TCH/kg crop N)	1.4	1.6	1.3	1.1	1.5	1.4	1.3	1.3	1.5	1.4
	Fertiliser N uptake (kg N/ha)	-	12.8	25.7	37.7	15.6	-	26.2	22.3	19.2	23.4
	NUpEfert (additional kg N uptake/kg fert applied) %	-	13.5	17.1	18.8	14.6	-	27.5	14.9	9.6	17.3
						121					152
2R	Mean yield (tc/ha)	26.8	61.4	68.3	67.2	66.2	28.8	66.3	71.4	80.6	74.5
	tc/kg N applied	-	0.6	0.5	0.3	0.5	-	0.7	0.5	0.4	0.5
	kg N applied/tc	-	1.5	2.2	3.0	1.8	-	1.4	2.1	2.5	2.0
	Agron Efffert (kg N/additional TCH)	-	2.7	3.6	5.0	3.1	-	2.5	3.5	3.9	3.3
	Crop N uptake (kg N/ha)[1]	24.4	46.9	63.8	73.2	54.9	28.2	42.9	61.2	69.5	61.6
	NUtE (TCH/kg crop N)	1.1	1.3	1.1	0.9	1.2	1.0	1.5	1.2	1.2	1.2
	Fertiliser N uptake (kg N/ha)	-	22.4	39.4	48.8	30.5	-	14.7	33.0	41.3	33.4
	NUpEfert (additional kg N uptake/kg fert applied) %	-	23.6	26.3	24.4	25.2	-	15.5	22.0	20.6	21.9
		0	75	150	200	136	0	75	150	200	122
3R	Mean yield (tc/ha)	22.8	47.3	60.8	61.4	59.1	30.3	69.2	73.3	82.5	75.1
	tc/kg N applied	-	0.6	0.4	0.3	0.4	-	0.9	0.5	0.4	0.6
	kg N applied/tc	-	1.6	2.5	3.3	2.3	-	1.1	2.0	2.4	1.6
	Agron Efffert (kg N/additional TCH)	-	3.1	4.0	5.2	3.8	-	1.9	3.5	3.8	2.7
	Crop N uptake (kg N/ha)[1]	34.1	40.0	49.5	59.0	47.7	40.7	48.5	59.9	69.4	55.7
	NUtE (TCH/kg crop N)	0.7	1.2	1.2	1.0	1.2	0.7	1.4	1.2	1.2	1.3
	Fertiliser N uptake (kg N/ha)	-	5.9	15.4	25.0	13.6	-	7.8	19.3	28.7	15.0
	NUpEfert (additional kg N uptake/kg fert applied) %	-	7.9	10.3	12.5	12.7	-	10.4	12.9	14.3	14.0
						152					103
4R	Mean yield (tc/ha)	27.1	57.6	75.3	78.6	75.9	28.7	75.5	75.6	86.8	78.5
	tc/kg N applied	-	0.8	0.5	0.4	0.5	-	1.0	0.5	0.4	0.8
	kg N applied/tc	-	1.3	2.0	2.5	2.0	-	1.0	2.0	2.3	1.3
	Agron Efffert (kg N/additional TCH)	-	2.5	3.1	3.9	3.1	-	1.6	3.2	3.4	2.1
	Crop N uptake (kg N/ha)[1]	19.5	38.9	36.1	60.8	37.1	27.9	50.6	31.2	49.3	43.4
	NUtE (TCH/kg crop N)	1.4	1.5	2.1	1.3	2.0	1.0	1.5	2.4	1.8	1.8
	Fertiliser N uptake (kg N/ha)	-	19.4	16.6	41.3	17.6	-	22.8	3.3	21.5	15.5
	NUpEfert (additional kg N uptake/kg fert applied) %	-	25.9	11.1	20.6	11.6	-	30.3	2.2	10.7	15.1

Opt N = N rate corresponding to 95% of the maximum yield calculated from a response curve.
Assumptions: Sugar price = $370/ts, harvesting and levies = $10/tc, cost of fertiliser = $1.30/kg N

Table 6-37 Effect of N rates and farming systems on mean input, yield and economics parameters (Mky NxFS1)

Crop	Inputs, yield and economic parameters	Burnt					GCTB				
		N applied (kg N/ha)				Opt N =	N applied (kg N/ha)				Opt N =
		0	95	150	200	107	0	95	150	200	135
1R	Cost of N fertiliser($/ha)	0.0	123.5	195.0	260.0	139.1	0.0	123.5	195.0	260.0	175.5
	Mean cane yield (tc/ha)	52.2	79.6	82.0	84.4	79.7	64.9	90.9	90.7	98.7	94.0
	ccs (%)	16.0	15.2	15.1	14.3	15.2	15.6	15.1	15.1	14.8	15.1
	Mean sugar yield (ts/ha)	8.3	12.1	12.4	12.1	12.2	10.1	13.7	13.7	14.6	14.0
	Grower partial net return[2] ($/ha)	$1,590	$2,084	$2,066	$1,837	$2,073	$1,897	$2,371	$2,312	$2,372	$2,404
	Industry net return[2] ($/ha)	$2,561	$3,545	$3,563	$3,362	$3,570	$3,090	$4,033	$3,969	$4,166	$4,076
2R						121					152
	Cost of N fertiliser($/ha)	0.0	123.5	195.0	260.0	157.3	0.0	123.5	195.0	260.0	197.6
	Mean cane yield (tc/ha)	26.8	61.4	68.3	67.2	66.2	28.8	66.3	71.4	80.6	74.5
	ccs (%)	18.3	18.5	18.8	18.2	18.6	17.6	18.6	18.6	18.5	18.6
	Mean sugar yield (ts/ha)	4.9	11.4	12.8	12.2	12.3	5.1	12.3	13.3	14.9	14.0
	Grower partial net return2 ($/ha)	$1,023	$2,271	$2,522	$2,283	$2,449	$1,032	$2,473	$2,602	$2,865	$2,730
	Industry net return2 ($/ha)	$1,540	$3,463	$3,861	$3,589	$3,716	$1,586	$3,778	$4,000	$4,437	$4,220
3R		0	75	150	200	136	0	75	150	200	122
	Cost of N fertiliser($/ha)	0.0	97.5	195.0	260.0	176.8	0.0	97.5	195.0	260.0	158.6
	Mean cane yield (tc/ha)	22.8	47.3	60.8	61.4	59.1	30.3	69.2	73.3	82.5	75.1
	ccs (%)	15.0	14.9	14.6	15.0	14.6	14.3	14.5	14.8	15.1	14.7
	Mean sugar yield (ts/ha)	3.4	7.0	8.9	9.2	8.7	4.3	10.1	10.9	12.5	11.1
	Grower partial net return2 ($/ha)	$619	$1,170	$1,379	$1,411	$1,353	$749	$1,682	$1,761	$2,012	$1,823
	Industry net return2 ($/ha)	$1,034	$2,027	$2,480	$2,534	$2,441	$1,293	$2,935	$3,091	$3,526	$3,212
4R						152					103
	Cost of N fertiliser($/ha)	0.0	97.5	195.0	260.0	197.6	0.0	97.5	195.0	260.0	133.9
	Mean cane yield (tc/ha)	27.1	57.6	75.3	78.6	75.9	28.7	75.5	75.6	86.8	78.5
	ccs (%)	16.8	16.7	16.3	17.0	16.3	16.8	16.8	16.9	17.0	16.7
	Mean sugar yield (ts/ha)	4.5	9.5	12.3	13.4	12.5	4.8	12.6	12.8	14.7	12.9
	Grower partial net return2 ($/ha)	$902	$1,789	$2,176	$2,415	$2,192	$948	$2,405	$2,333	$2,692	$2,452
	Industry net return2 ($/ha)	$1,413	$2,859	$3,593	$3,913	$3,654	$1,489	$3,824	$3,776	$4,328	$3,862

Opt N = N rate corresponding to 95% of the maximum yield calculated from a response curve.
Assumptions: Sugar price = $370/ts, harvesting and levies = $10/tc, cost of fertiliser = $1.30/kg N

Mky NxFS2

Estimates of NUE for Mky NxFS2 are shown in Table 6-38. As this experiment did not contain a full range of N rates, N Opt could not be determined and economic parameters were not calculated. In the first ratoon crop, higher N uptake in the soybean fallow system resulted in higher NUpEfert % (additional kg N uptake/kg fert applied). However, as yields were similar, NUtE (TCH/kg crop N) was lower in the soybean fallow system. NUE declined in the second ratoon crop due to a decrease in sugarcane yield, but improved in the fourth ratoon crop with an increase in sugarcane yield most likely due to increased December rainfall. Overall, NUpEfert was poor ranging from 10.6 – 31.1 % of applied fertiliser. However, as shown in this experiment, some of the fertiliser N not taken up by the crop is available to following crops.

Table 6-38 Effect of N rates and farming systems/N rate history on NUE (Mky NxFS2)

Crop	Yield and efficiency factors	Bare		Soybean	
		N applied (kg/ha)			
		0	150	0	150
1R	Mean yield (tc/ha)	59.7	92.6	50.7	98.1
	tc/kg N applied	-	0.6	-	0.7
	kg N applied/tc	-	1.6	-	1.5
	Agron Efffert (kg N/additional TCH)	-	4.6	-	3.9
	Crop N uptake (kg N/ha)[1]	37.0	61.1	32.1	78.8
	NUtE (TCH/kg crop N)	1.62	1.52	1.58	1.24
	Fertiliser N uptake (kg N/ha)	-	24.1	-	46.7
	NUpEfert (additional kg N uptake/kg fert applied) %	-	16.1	-	31.1
2R	Mean yield (tc/ha)	28.4	67.5	31.5	69.4
	tc/kg N applied	-	0.4	-	0.5
	kg N applied/tc	-	2.2	-	2.2
	Agron Efffert (kg N/additional TCH)	-	3.8	-	3.2
	Crop N uptake (kg N/ha)[1]	27.3	59.0	27.8	51.0
	NUtE (TCH/kg crop N)	1.0	1.1	1.1	1.4
	Fertiliser N uptake (kg N/ha)	-	31.8	-	23.3
	NUpEfert (additional kg N uptake/kg fert applied) %	-	21.2	-	15.5

Crop	Yield and efficiency factors	N rate history (kg/ha)			
		0		150	
		N applied (kg/ha)			
		0	150	0	150
3R	Mean yield (tc/ha)	28.0	73.8	38.2	73.2
	tc/kg N applied	-	0.5	-	0.5
	kg N applied/tc	-	2.0	-	2.0
	Agron Efffert (kg N/additional TCH)	-	3.3	-	4.3
	Crop N uptake (kg N/ha)[1]	48.3	64.3	55.9	86.2
	NUtE (TCH/kg crop N)	0.6	1.1	0.7	0.8
	Fertiliser N uptake (kg N/ha)	-	15.9	-	30.3
	NUpEfert (additional kg N uptake/kg fert applied) %	-	10.6	-	20.2
4R	Mean yield (tc/ha)	27.9	82.8	32.7	81.4
	tc/kg N applied		0.6		0.5
	kg N applied/tc		1.8		1.8
	Agron Efffert (kg N/additional TCH)		2.7		3.1
	Crop N uptake (kg N/ha)[1]	23.8	52.8	24.8	53.5
	NUtE (TCH/kg crop N)	1.2	1.6	1.3	1.5
	Fertiliser N uptake (kg N/ha)	-	29.1	-	28.7
	NUpEfert (additional kg N uptake/kg fert applied) %	-	19.4	-	19.1

[1]Crop N uptake based on data collected at 9 months

6.2.2.7. Conclusions: Mky NxFS

Mky NxFS1

- Long-term burnt and GCTB farming systems showed similar response to N.
- There was no indication of greater N availability in the long-term GCTB system despite the retention of trash blankets between crops for over two decades.
- Productivity was increased in the GCTB farming system, most likely due to soil moisture retention.
- While there was no statistically significant increase in sugar yield between 150 and 200 kg N/ha rates, sugarcane yield was higher where 200 kg N/ha was applied and this resulted in this treatment having the highest economic return, particularly in the GCTB system. This was also associated with the lowest NUE. The SIX EASY STEPS rate for this site (150 kg N/ha)

could be viewed as providing a balance between productivity, profitability and the environment.

- The average Opt N rate estimated for the site was 130 kg N/ha. While this was marginally lower than the SIX EASY STEPS rate, yields were relatively poor at the site and Opt N may have been more similar to the SIX EASY STEPS recommendation if better growing conditions were experienced.
- Crop N uptake and biomass development were slow in the first 3 months after harvesting and there were few differences due to N rates at this time. This suggests that the crop had low N demand and that background N in the soil pool was mostly able to support growth during this period.
- This result is consistent with recommendations that suggest a delay to fertiliser application after harvest by up to 6 weeks is unlikely to have any impact on yield. It should, however, be noted that this is not a practical management practice for crops harvested late in the season.

Mky NxFS2

- Ratoon crops following a soybean fallow did not acquire additional N in comparison to a bare fallow. There was evidence from the first ratoon crop that there may have been less N in the soil pool in the soybean fallow system due to lower sugarcane yield at the 0 kg N/ha rate. This was possibly due to the significantly reduced fertiliser N rate in the plant crop following the soybean fallow.
- Given the above result, recommendations to supply 'normal' N application on ratoon crops following a soybean fallow are justified, particularly if N applications are reduced in the plant crop to account for the legume N.
- The experiment to investigate the effect of fertiliser history showed that N from past fertiliser applications may become available to following crops.
- Significantly higher yields were achieved in plots that received no N where there was a history of 150 kg N/ha in comparison to a history of 0 kg N/ha. This effect appeared to be associated with greater N availability, but was only evident in the first season. This could indicate that the amount of N that becomes available due to past practices was small. However, the result also indicates that a portion of fertiliser N assumed as lost to the environment, is incorporated into soil pools, most likely biological.

6.2.3. Macknade N x Farming Systems trials

6.2.3.1. Rainfall

The monthly and annual rainfall data from the Macknade Mill weather station for the period Oct 2013 to Sep 2017 are presented in Figure 6-12. This period included the growing of the plant crop at the trial sites (Mkd NxFS1 and Mkd NxFS2) established in Jun 2013 (as part of a previous project), to the harvest of the 3R crop from Mkd NxFS1. Trial Mkd NxFS2 was terminated at the end of the 2R crop. The 2013/14 cropping season (Oct to Sep) at Macknade was close to the average in terms of the amount (1924 mm of recorded rainfall versus the mean annual rainfall of 2141 mm) and distribution (Figure 6-12). The 2014/15 cropping season was dry (recorded rainfall: 1107 mm) but the rainfall pattern reflected the usual periods of expected rainfall. In contrast, 1891 mm of rainfall was recorded during the period Oct 2015 to Sep 2016, which was similar to the overall amount recorded in 2013/14. However, the distribution pattern was dissimilar with an exceptionally dry summer and excessive rain (about 880 mm) in Mar 2016. The 2016/2017 cropping season had a dry spring followed by an 'average' summer and then a relatively dry autumn and winter. This resulted in below average rainfall (1640 mm) over the period Oct 2016 and Sep 2017.

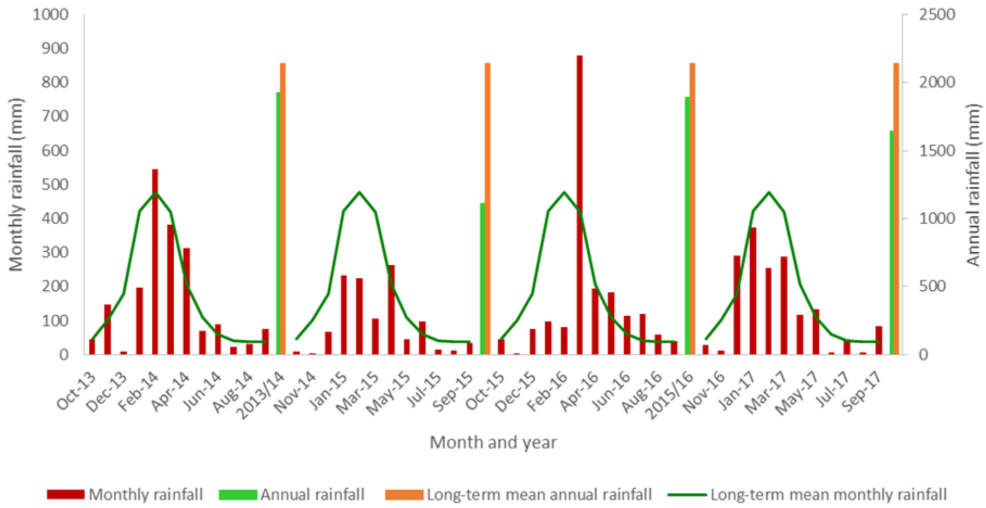


Figure 6-12 Monthly and annual recorded rainfall from the Macknade Mill weather station for the period Oct 2013 to Sep 2017.

6.2.3.2. Soil mineral

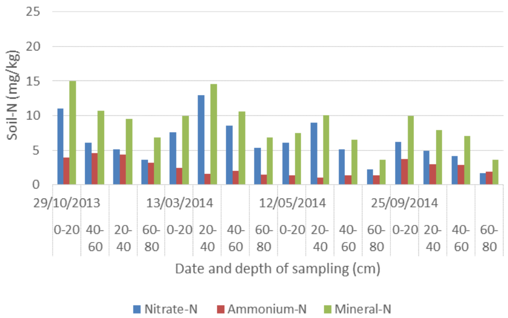
Soil NO_3^--N, NH_4^+-N and min-N concentrations (to a depth of 80 cm in 20 cm increments) associated with the different rates of N applied to the 1R crop of the "conventional tillage farming system" treatments of the Mkd NxFS1 trial are shown in Table 6-39. Although the values do not vary significantly with the amount of N applied, there does appear to be an upward trend in NH_4^+-N and min-N values (15 Dec 2014) following application of the fertiliser N treatment on 10 Nov 2014. However, NO_3^--N values did not generally reflect the rates of N applied. Most apparent was the statistically different N values (NO_3^--N, NH_4^+-N and min-N) down the soil profile with evidence of movement to the lower depths with time. As there was little indication of a 'farming systems' effect, data for the 'permanent bed' treatment are not included here. As similar patterns in the distribution of mineral N emerged in the Mkd NxFS2 trial, that data are also not reported here. Instead, soil NO_3^--N, NH_4^+-N and min-N concentrations to a depth of 80 cm (in 20 cm increments) in the uncropped/ unfertilised areas adjacent to the Mkd NxFS1 and Mkd NxFS2 trials from Oct 2013 to Nov 2017 due are shown in Figure 6-13. Most striking is the initially relatively high values in Oct 2013 at both sites. This was probably due to residual N fertiliser, and/or mineralisation of 'inherent' soil org C, trash from previous crop cycles and/or the remains of fallow crops grown previously at these sites. The sequences of bar-graphs from (a) 2013/2014 to (d) 2016/2017 relevant to Mkd NxFS1 and (e.) 2013/2014 to (h) 2016/2017 relevant to Mkd NxFS2 illustrate the decline of N in the soil with time. Although the N mineralisation cycles showing flushes of N are also evident, they are more apparent at the Mkd NxFS2 site.

Table 6-39 Soil nitrate-N, ammonium-N and total mineral N concentrations (to a depth of 80 cm) associated with the rates of N applied to the 1R sugarcane crop grown after conventional tillage prior to the plant crop of trial Mkd NxFS1.

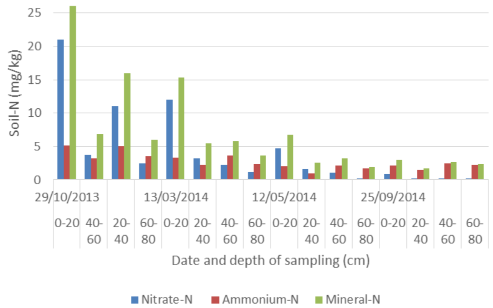
The samples were collected on four occasions during the 2014/15 cropping season.

Date	Depth	N applied (kg/ha) applied to cane grown																	
		0	40	80	120	160	M	0	40	80	120	160	M	0	40	80	120	160	M
		Soil N (mg/kg)																	
		Nitrate-N						Ammonium-N						Mineral-N					
22 Aug 2014	0 – 20	4.75	3.73	5.38	4.35	3.05	4.25^{A}	1.85	2.38	2.08	2.48	3.10	2.38^{A}	6.60	6.08	7.43	6.80	6.13	6.61^{A}
	20 – 40	0.78	1.45	1.58	1.80	2.05	1.53^{B}	1.43	1.50	1.85	1.85	1.03	1.53^{B}	2.18	2.93	3.43	3.58	3.10	3.04^{B}
	40 – 60	0.28	0.45	0.28	0.38	0.23	0.32^{C}	0.90	1.00	1.48	1.05	0.73	1.03^{B}	1.15	1.45	1.73	1.43	0.98	1.35^{C}
	60 – 80	0.30	0.30	0.55	0.28	0.25	0.34^{C}	0.53	0.73	1.03	0.83	0.78	0.78^{B}	0.83	1.00	1.58	1.10	1.08	1.12^{C}
	Mean	1.52 A	1.48 A	1.94 A	1.70 A	1.39 A		1.18 A	1.40 A	1.61 A	1.55 A	1.41 A		2.69 A	2.86 A	3.54 A	3.23 A	2.82 A	
	Tukey HSD$^{0.05}$	*N = ns (P=0.65) Depth = 0.94 (P<0.001) N x Depth = ns (P=0.53)*						*N = ns (P=0.19) Depth = 0.76 (P<0.001) N x Depth = ns (P=0.87)*						*N = ns (P=0.46) Depth = 0.95 (P<0.001) N x Depth = ns (P=0.99)*					
15 Dec 2014	0 – 20	0.15	0.40	0.73	1.05	0.78	0.62^{A}	2.18	4.60	9.20	15.1	14.5	9.11^{A}	2.33	5.03	9.93	16.1	15.3	9.73^{A}
	20 – 40	0.35	0.30	0.30	0.33	0.28	0.31^{B}	1.40	1.50	2.05	1.75	2.48	1.84^{B}	1.75	1.85	2.35	2.08	2.78	2.16^{B}
	40 – 60	0.35	0.35	0.33	0.35	0.35	0.35^{AB}	0.58	0.38	0.92	0.70	0.78	0.67^{B}	0.93	0.70	1.23	1.05	1.15	1.01^{B}
	60 – 80	0.38	0.38	0.30	0.33	0.40	0.36^{AB}	0.25	0.18	0.88	0.63	0.80	0.55^{B}	0.63	0.55	1.15	0.95	1.18	0.89
	Mean	0.31 A	0.36 A	0.41 A	0.51 A	0.45 A		1.10 A	1.66 A	3.26 A	4.54 A	4.63 A		1.41 A	2.03 A	3.66 A	5.04 A	5.09 A	
	Tukey HSD$^{0.05}$	*N = ns (P=043) Depth = 0.28 (P<0.05) N x Depth = ns (P=0.34)*						*N = ns (P=0.15) Depth = 3.79 (P<0.001) N x Depth = ns (P=0.94)*						*N = ns (P=0.11) Depth = 3.68 (P<0.001) N x Depth = ns (P=0.07)*					
13 Apr 2015	0 – 20	1.23	0.68	0.59	0.84	0.48	0.77^{A}	3.98	4.83	5.72	5.65	5.72	5.18^{A}	5.21	5.51	6.31	6.49	6.21	5.94^{A}
	20 – 40	0.18	0.24	0.17	0.40	0.25	0.25^{B}	2.52	2.52	3.38	2.58	3.74	2.95^{B}	2.70	2.75	3.55	2.98	3.98	3.19^{B}
	40 – 60	0.30	2.27	0.34	0.28	0.22	0.28^{B}	2.02	2.05	2.08	2.11	2.39	2.13^{B}	2.32	2.31	2.42	2.39	2.61	2.41^{B}
	60 – 80	0.32	0.29	0.23	0.26	0.28	0.28^{B}	1.57	2.05	1.70	1.50	2.22	1.80^{B}	1.89	2.32	1.93	1.76	2.51	2.08^{B}
	Mean	0.51 A	0.37 A	0.33 A	0.44 A	0.31 A		2.52 A	2.86 A	3.22 A	2.96 A	3.52 A		3.03 A	3.22 A	3.55 A	3.40 A	3.82 A	
	Tukey HSD$^{0.05}$	*N = ns (P=0.38) Depth = 0.29 (P<0.001) N x Depth = ns (P=0.68)*						*N = ns (P=027) Depth = 1.16 (P<0.001) N x Depth = ns (P=0.98)*						*N = ns (P=0.40) Depth = (P<0.001) N x Depth = ns (P=0.10)*					
28 May 2015	0 – 20	0.31	0.70	0.63	0.36	0.80	0.56^{A}	3.50	3.18	2.58	2.45	2.88	2.92^{A}	3.81	3.88	3.20	2.81	3.68	3.48^{A}
	20 – 40	0.25	0.25	0.25	0.39	0.41	0.31^{B}	2.85	2.53	1.83	1.88	2.83	2.38^{A}	3.10	2.78	2.08	2.26	3.24	2.69^{B}
	40 – 60	0.25	0.25	0.25	0.31	0.25	0.26^{B}	2.13	1.45	1.60	1.38	2.40	1.79^{B}	2.38	1.70	1.85	1.69	2.65	2.05^{C}
	60 – 80	0.25	0.25	0.25	0.25	0.25	0.25^{B}	1.95	1.80	1.53	1.88	1,63	1.76^{B}	2.20	2.05	1.78	2.13	1.88	2.01^{C}
	Mean	0.27 A	0.36 A	0.34 A	0.33 A	0.43 A		2.61 A	2.24 A	1.88 A	1.89 A	2.42 A		2.87 A	2.60 A	2.23 A	2.22 A	2.86 A	
	Tukey HSD$^{0.05}$	*N = ns (P=0.32) Depth = 0.29 (P<0.001) N x Depth = ns9 (P=0.27)*						*N = ns (P=0.239) Depth = 0.56 (P<0.001) N x Depth = ns (P=0.68)*						*N = ns (P=0.37) Depth = 0.62 (P<0.001) N x Depth = ns (P=0.77)*					

^{A,B,C} Mean values accompanied by the same letter in a group are “not significantly” different



(a)



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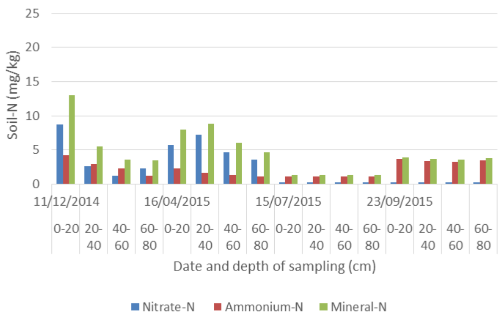

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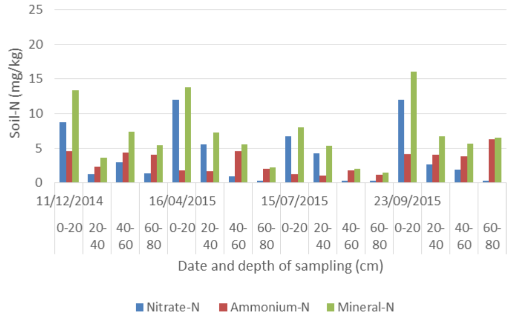

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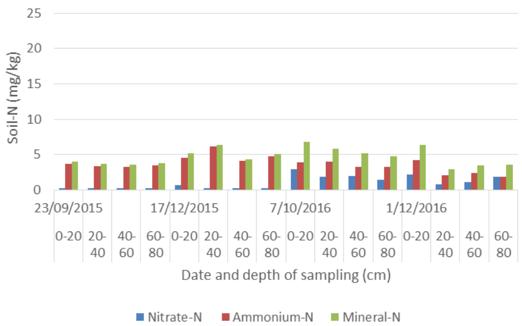

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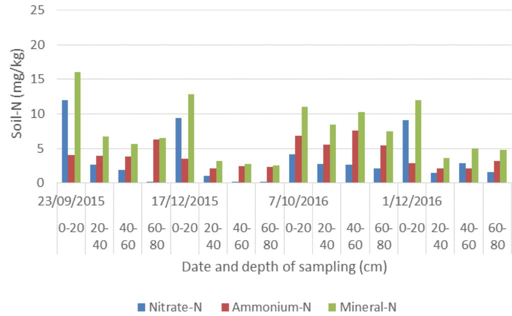
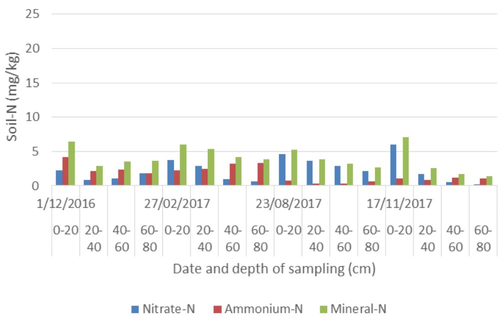
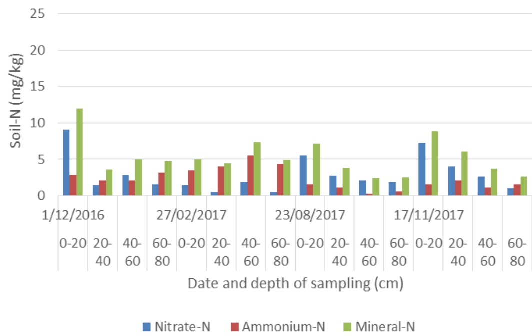


(g)



(d)



(h)

Figure 6-13 Soil nitrate-N, ammonium-N and mineral N concentrations (mg N/ha) to a depth of 80 cm (0 – 20, 20 – 40, 40 – 60 and 60 – 80 cm) in uncropped/unfertilised areas adjacent to the trial sites at Macknade. Mkd NxFS1: a) 2013/14 adjacent to PC; b) 2014/15 adjacent to 1R crop; c) 2015/16 adjacent to 2R crop; d) 2016/17 adjacent to 3R. **Mkd NxFS2**: e) 2013/14 adjacent to PC; f) 2014/15 adjacent to 1R; g) 2015/16 adjacent to 2R crop; h) 2016/17 adjacent to fallow.

6.2.3.3. Third leaf N

Third leaf N values (N%DM) as influenced by rate of N applied and the underlying farming systems (conventional tillage versus permanent beds) for the 1R and 2R crops in trials Mkd NxFS1 and Mkd NxFS2 are shown in Tables 6-40 and 6-41 respectively.

Third leaf N values in trial Mkd NxFS1 increased significantly with increased rates of N applied in both crops, but with no response to the underlying farming systems. In the 1R crop the mean values ranged from 1.58 %N (zero N applied) to 1.81%N (at 200 kg N/ha). In the 2R crop the values ranged from 1.40 %N (zero N applied) to 1.72 %N (at 200 kg N/ha). As the established critical value for third leaf N for samples collected in March is 1.7%N, the previously established SIX EASY STEPS N rate of 150 kg N/ha would appear to have been appropriate here. However, it may have been marginal in the 2R crop given that the mean third leaf N value at 150 kg N/ha was 1.65 %N (Table 6-40).

Due to apparent variability of the third leaf N values in samples collected from the 1R crop in trial Mkd NxFS2, differences were not significant (Table 4-41). In contrast, the third leaf N values in the 2R crop increased significantly with the rate of N applied, and ranged from 1.47 %N (zero N applied) to 1.69 %N (at 200 kg N/ha). The previously established SIX EASY STEPS N application rate of 130 - 140 kg N/ha for this site may have been considered marginal in this case, given the established critical value of 1.7 %N (March sampling). However, the excessive rainfall the occurred in March 2016 (Figure 6-12) may have affected the supply of N and/or the third leaf N values. As in the case of Mkd NxFS1, the farming systems treatments had no significant effect on the third leaf N values (Table 6-41).

Table 6-40 Third leaf N concentration (%DM) as influenced by the N and Farming Systems treatments in the 1R and 2R crops in trial Mkd NxFS1.

Crop	N application rate (kg N/ha)	Third leaf N values (%DM)		
		Farming System (FS)		Means for N applied
		Conventional	Permanent beds	
1R	0	1.60	1.57	1.58^{BC}
	50	1.60	1.61	1.60^{BC}
	100	1.70	1.73	1.72^{AB}
	150	1.69	1.75	1.72^{AB}
	200	1.78	1.85	1.81^{A}
	Means for the FS	1.67^{A}	1.70^{A}	
	Tukey $HSD^{0.05}$: N = 0.12 (P<0.001); FS = ns (P=0.82); N x FS = ns (P=0.63)			
2R	0	1.43	1.38	1.40^{D}
	50	1.46	1.45	1.45^{CD}
	100	1.52	1.56	1.54^{BC}
	150	1.65	1.65	1.65^{AB}
	200	1.75	1.69	1.72^{A}
	Means for the FS	1.56^{A}	1.54^{A}	
	Tukey $HSD^{0.05}$: N = 0.13 (P<0.001); FS = ns (P=0.57); N x FS = ns (P=0.67)			

^{A,B,C,D} Mean values accompanied by the same letter in a group are “not significantly” different

Table 6-41 Third leaf N concentration (%DM) as influenced by the N and Farming Systems treatments in the plant, 1R, 2R, 3R crops: trial Mkd NxFS2.

Crop	N application rate (kg N/ha)	Third leaf N values (%DM)		
		Farming System (FS)		Means for N applied
		Conventional	Permanent beds	
1R	0	1.66	1.58	1.62[A]
	50	1.60	1.64	1.62[A]
	100	1.66	1.61	1.63[A]
	150	1.79	1.78	1.78[A]
	200	1.92	1.76	1.84[A]
	Means for the FS	1.72[A]	1.67[A]	
	Tukey HSD$^{0.05}$: N = 0.25 (P<0.05); FS = ns (P=0.19); N x FS = ns (P=0.68)			
2R	0	1.48	1.47	1.47[C]
	50	1.50	1.46	1.48[C]
	100	1.50	1.61	1.55[BC]
	150	1.55	1.71	1.63[AB]
	200	1.66	1.73	1.69[A]
	Means for the FS	1.53[A]	1.59[A]	
	Tukey HSD$^{0.05}$: N = 0.13 (P<0.01); FS = ns (P=0.24); N x FS = ns (P=0.15)			

[A,B,C] Mean values accompanied by the same letter in a group are "not significantly" different

6.2.3.4. N uptake

N-uptake values associated with the different fertiliser N application rates and farming systems treatments for the 1R and 2R crops in trials Mkd NxFS1 and Mkd NxFS2 are shown in Table 6-42. These values were determined using the N content of the dry biomass samples (stalks, leaves and tops) collected in May of each year (9-months after harvest of the previous crops). Conventional tillage and minimum/zero tillage treatments in permanent beds had no significant effect on N uptake in either trial or in either season. N-uptake was generally higher in the 1R crops than in the 2R crops across both trials. This was in agreement with the third leaf values in Tables 6-40 and 6-41.

6.2.3.5. Yield

Cane yield response curves for the 1R and 2R crops harvested at the trial sites are shown in Figures 6-14 and 6-15 respectively. Although similar yields were produced on these two site with zero N applied, there was a greater response to applied N and larger crops were produced at the higher rates of N applied in Mkd NxFS2 (River Bank silty loam) than in Mkd NxFS2 (Clay Loam soil) in both seasons. Trial Mkd NxFS2 is in a lower position in the landscape than Mkd NxFS1. Although it was postulated that the use of permanent beds in Mkd NxFS2 would produce improved yields compared to the conventionally tilled system, this did not eventuate (in these crops or previously at this site). Based on the response curves, the optimum N rate (corresponding to 95% of the maximum yield) for Mkd NxFS2 was 120 kg N/ha in both seasons. In contrast, the optimum N rate for Mkd NxFS1 was 160 kg N /ha in the 1R crop (Figure 6-14), but 200 kg N/ha in the 2R crop (Figure 6-15). These differences may be due to the marked climatic differences between these two seasons.

Table 6-42 Effect of N and FS treatments on crop N uptake (kg N/ha) 9 months after harvest of the previous crop: Mkd NxFS1 and Mkd NxFS2.

Crop	N application rate (kg N/ha)	N uptake (kg N/ha)		
		Farming System (FS)		Means for N applied
		Conventional	Permanent beds	
Trial: Mkd NxFS1				
1R	0	51.8	52.6	52.2^{B}
	50	63.1	76.2	69.7^{AB}
	100	68.7	79.9	74.3^{AB}
	150	85.8	85.8	85.8^{A}
	200	87.2	108.8	98.0^{A}
	Means for the FS	71.3^{A}	80.7^{A}	
	Tukey $HSD^{0.05}$: N =31.4 (P<0.01); FS = ns (P=0.55); N x FS = ns (P=0.73)			
2R	0	43.6	37.7	40.7^{B}
	50	39.2	46.5	42.8^{B}
	100	58.9	52.0	55.4^{AB}
	150	77.8	66.4	72.1^{A}
	200	71.4	69.8	70.6^{A}
	Means for the FS	58.2^{A}	54.5A	
	Tukey $HSD^{0.05}$: N = ns (P=0.38); FS = ns (P=0.73); N x FS = ns (P=0.21)			
Trial: Mkd NxFS2				
1R	0	92.4	45.3	68.8^{B}
	50	74.7	69.4	72.1^{B}
	100	83.7	62.0	72.9^{B}
	150	81.0	84.5	82.8^{AB}
	200	124.1	94.4	109.5^{A}
	Means for the FS	91.2^{A}	71.2^{A}	
	Tukey $HSD^{0.05}$: N = 28.5 (P<0.01); FS = ns (P=0.08); N x FS = ns (P=0.09)			
2R	0	51.8	43.9	47.9^{B}
	50	59.8	54.3	56.9^{AB}
	100	68.2	70.5	69.3^{AB}
	150	65.0	78.7	76.8^{AB}
	200	103.5	71.8	87.6^{A}
	Means for the FS	71.6^{A}	63.8^{A}	
	Tukey $HSD^{0.05}$: N = 34.8 (P<0.05); FS = ns (P=0.33); N x FS = ns (P=0.46)			

^{A,B} Mean values accompanied by the same letter in a group are "not significantly" different

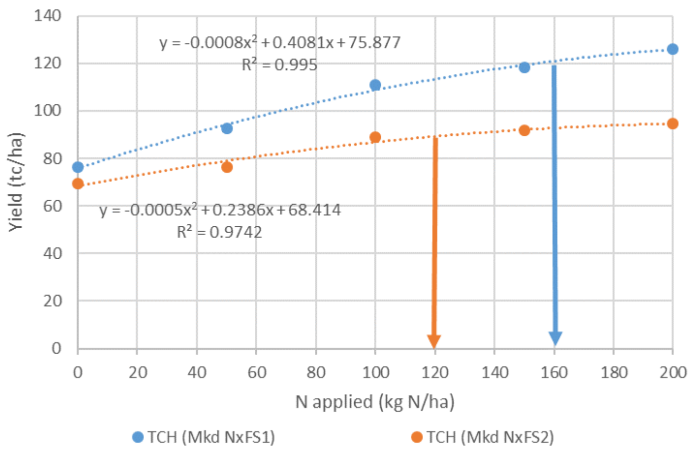


Figure 6-14 Yield response curves associated with the 1R crop from the N trials (Mkd NxFS1 and Mkd NxFS2) at Macknade.

The optimum N rates (at 95% of the maximum yield) are shown by the downward-pointing arrows

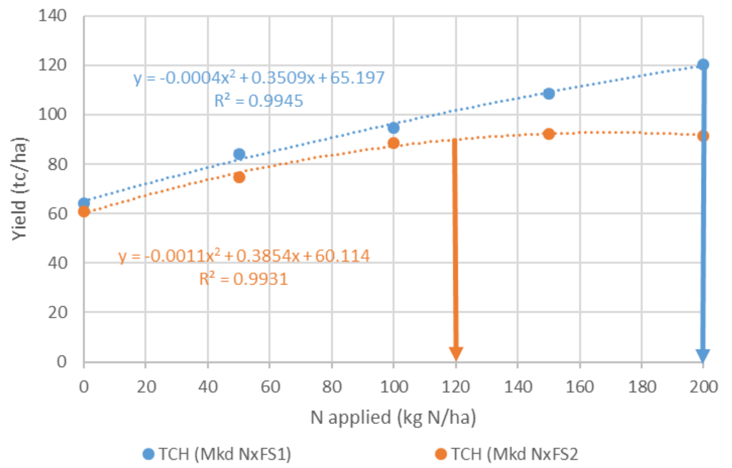


Figure 6-15 Yield response curves associated with the 2R crop from the N trials (Mkd NxFS1 and Mkd NxFS2) at Macknade.

The optimum N rates (at 95% of the maximum yield) are shown by the downward-pointing arrows

6.2.3.6. NUE indicators

Cane yields and NUE indicators for the 1R and 2R crops at both trial sites (Mkd NxFS1 and Mkd NxFS2) are shown in Tables 6-43 and 6-44 respectively. As expected, the commonly used and industry understood NUE expressed as tonnes cane/ha decreased as the N rates increased across the trials and seasons. Conversely, NUE expressed as kg N/t cane increased with the rate of N applied, as did the Agron Eff_{fert} that relates only to the additional sugarcane yield above the yield achieved when no N is applied. These values were therefore markedly higher than those expressed as kg N/t cane.

In the 1R crops, the cane grown at the Mkd NxFS1 site used N more efficiently than the cane grown at the Mkd NxFS2 due to the differences in overall yields. Optimum N rates determined from the response (Figures 6-14) were 160 kg N/ha and 120 kg N/ha respectively. The predetermined SIX EASY STEPS rates for these two sites [150 kg N/ha (Mkd NxFS1) and 140 kg N/ha (Mkd NxFS2) resulted in NUE indicators that were in the mid-range, but did not result in compromised yields.

Table 6-43 N application rates, yield data and calculated NUE factors for the 1R crop at Mkd NxFS1 and Mkd NxFS2.

Yield and efficiency factors	Treatments					Optimum N	SIX EASY STEPS
	(kg N applied/ha)						
	0	50	100	150	200	A	B
Mkd NxFS1							
Yield (tonnes cane/ha)	76.4	92.6	100.8	118.4	126.1	120	120
tonnes cane/N applied	-	1.85	1.11	0.79	0.63	0.75	0.80
kg N applied/tonne cane	-	0.54	0.90	1.27	1.59	1.33	1.27
Agron Eff_{Fert} (kg N/additional TCH)	-	3.1	2.9	3.6	4.9	3.6	3.4
Mkd NxFS2							
Yield (tonnes cane/ha)	69.3	76.5	89.1	91.7	94.5	90	90
tonnes cane/N applied	-	1.53	0.89	0.61	0.47	0.75	0.64
kg N applied/tonne cane	-	0.65	1.12	1.64	2.12	1.33	1.56
Agron Eff_{Fert} (kg N/additional TCH)	-	6.9	5.1	6.7	7.9	5.7	6.7

Mkd NxFS1: A = 160 kg N/ha and B = 150 kg N/ha; **Mkd NxFS2**: a = 120 kg N/ha and b = 140 kg N/ha

A larger suite of NUE indicators were calculated for the 2R crops at both trial sites (Table 6-44). The same trends that occurred in the 1R crops were also noted for the 2R crops, as shown in Table 6-43.

The crop N uptake in trial Mkd NxFs (River Bank soil) ranged from 40.7 kg N/ha (at zero N applied) to about 70 kg N/ha with increased N applied. This range was lower than that measured for the Clay Loam soil [47.9 kg N/ha (at zero N applied) to 87.6 kg N/ha (at 200 kg N/ha)]. On the River bank soil fertiliser N uptake ranged from about 2 kg N/ha (at 50 kg N/ha applied) to about 30 kg N/ha (at 200 kg N/ha applied). On the Clay Loam, fertiliser N uptake ranged from 9 kg N/ha (at 50 kg N/ha applied) to about 40 kg N/ha (at 200 kg N/ha applied). The N fertiliser uptake efficiency ($NUpEff_{fert}$) values were more variable in Mkd NxFS1 than in Mkd NxFS2 where it was approximately constant at 20% across N treatments.

Table 6-44 N application rates, yield data and calculated NUE factors for the 2R crop at Mkd NxFS1 and Mkd NxFS2.

Yield and efficiency factors	Treatments					Optimum N	SIX EASY STEPS
	(kg N applied/ha)						
	0	50	100	150	200	A	B
Mkd NxFS1							
Yield (tonnes cane/ha)	64.2	84.3	94.8	108.7	120.3	120	110
tonnes cane/N applied	-	1.69	0.95	0.72	0.60	0.60	0.73
kg N applied/tonne cane	-	0.59	1.05	1.38	1.66	1.67	1.36
Agron Eff_{Fert} (kg N/additional TCH)	-	2.5	3.3	3.4	3.6	3.6	3.3
NUtE (TCH/kg crop N)[1]	-	2.0	1.7	1.5	1.7	1.7	1.5
Crop N uptake (kg N/ha)[1]	40.7	42.8	55.4	72.1	70.6	70.6	72.1
Fertiliser N uptake (kg/ha)		2.1	14.7	31.4	29.9	29.9	31.4
NUpEfert(additional kg uptake/kg fert applied) %	-	4.2	14.7	20.9	15.0	14.9	20.9
Mkd NxFS2							
Yield (tonnes cane/ha)	60.7	74.9	88.7	92.1	91.6	90	90
tonnes cane/N applied	-	1.50	0.89	0.61	0.46	0.75	0.64
kg N applied/tonne cane	-	0.67	1.13	1.63	2.18	1.33	1.56
Agron Eff_{Fert} (kg N/additional TCH)	-	3.5	3.6	4.8	6.5	4.1	4.8
NUtE (TCH/kg crop N)[1]	-	1.3	1.3	1.2	1.0	1.3	1.2
Crop N uptake (kg N/ha)[1]	47.9	56.9	69.3	76.8	87.6	72	74
Fertiliser N uptake (kg/ha)	-	9.0	21.4	28.9	39.7	24.1	26.1
$NUpE_{fert}$(additional kg uptake/kg fert applied) %	-	18.0	21.4	19.3	19.9	20.1	18.6

Mkd NxFS1: A = 200 kg N/ha and B = 150 kg N/ha; **Mkd NxFS2**: a = 120 kg N/ha and b = 140 kg N/ha
[1]Calculated using final yields and N uptake at 9 months after the previous harvest

6.2.3.7. Conclusions: Mkd NxFS1 and Mkd NxFS2

- Soil sampling indicated that there was an upward trend in NH_4^+-N and min-N values following application of the fertiliser N treatment although differences were not statistically significant. In these trials, NO_3^--N values did not appear to reflect the rates of N applied.
- Statistically different N values (NO_3^--N, NH_4^+-N and min-N) were most apparent down the soil profile with evidence of movement to the lower depths with time.
- As there were no apparent difference in min-N values due to a ‘farming systems’ effect (conventional tillage versus permanent beds).

- Soil $NO3^{-}$-N, NH_4^{+}-N and min-N concentrations in the uncropped/ unfertilised areas adjacent to the Mkd NxFS1 and Mkd NxFS2 trials showed relatively high initial values probably due to residual N fertiliser, and/or mineralisation of 'inherent' soil Org C, trash from previous crop cycles and/or the remains of fallow crops grown previously at these sites. Theses declined with time although flushes of N were evident due to assumed mineralisation processes. As expected seasonal rainfall and particularly excessive events (e.g March 2016) appeared to have an effect on the distribution of min-N with depth.
- Third leaf N values provided a useful index of assessing N uptake.
- Conventional tillage and minimum/zero tillage treatments in permanent beds had no significant effect on N uptake in either trial or in either season.
- Although similar yields were produced on these two site with zero N applied, there was a greater response to applied N and larger crops were produced at the higher rates of N applied to the River Bank silty loam than to the Clay Loam (which is in a lower position in the landscape) in both seasons.
- Use of permanent beds in in the Clay loam did not appear to improve yields.
- There was strong evidence that optimum N rates were affected by positions in the landscape and the interaction with seasonal climatic conditions.
- As expected, the commonly used and industry understood NUE expressed as tonnes cane/ha decreased as the N rates increased across the trials and seasons. Conversely, NUE expressed as kg N/t cane increased with the rate of N applied, as did the Agron Eff_{fert}.
- The various NUE indicators were not particularly well-aligned with optimum N rates (as determined from response curves). This was particularly evident in the 1R crop in Mkd NxFS1 where the Opt N rate was 200 kg N/ha, but NUE indicators would have suggested that rates below 100 kg N/ha would have been more suitable.
- It would have been inappropriate to set NUE targets because of the range and variability in values, particularly due to seasonal climatic conditions.
- SIX EASY STEPS rates continue to strike a balance between ensuring appropriate productivity and environmental awareness.
- As the underlying 'farming systems treatments did not results in significant differences in soil min-N, crop N-uptake or yields, the existing SIX EASY STEPS guidelines are appropriate for both conventional and permanent bed/minimum tillage systems.

6.2.4. Tully N rates of N trials

6.2.4.1. Rainfall

Measured rainfall for the trial period [Bureau of Meteorology station located at Tully Sugar Limited (Station 32042)] was used to calculate annual rainfall for the 4R, 5R and 6R crops for the periods from October – September each year as this corresponded well with crop harvesting times (Figure 6-16). Annual rainfall for the 4R crop was well below average (4075 mm) at 2523 mm and below average for the 5R and 6R crops at 3673 mm and 3250 mm, respectively.

Previous research has reported total spring-summer rainfall has a strong influence on Tully cane yields (Skocaj & Everingham 2014; Skocaj 2015). Dry years can be defined as receiving less than or equal to 1492 mm of rainfall over spring-summer and wet years as receiving at least 2184 mm of rainfall (Skocaj 2015). Despite not being able to calculate total spring-summer rainfall, there is still value in looking at total rainfall for the period to October-February each year as this still give some indication of the climate season experienced. Based on the total rainfall for the period October-

February each year, the climate season for the 4R and 5R crops can be defined as dry and the 6R as normal. It is unfortunate Tully did not experience a wet climate season during the trial period.

During the 4R crop, October-December rainfall was below the long-term average but January to March rainfall exceeded the long-term monthly average. Despite total rainfall being below average for the 5R crop, autumn and winter rainfall greatly exceeded the long-term average. During the 6R crop, monthly rainfall exceeded the long-term average from January to July and a significant rainfall event in early January 2017 (544 mm within 72 hours) resulted in major flooding. Significant autumn rainfall events affected 6-month biomass, crop N and soil sampling activities during the 4R crop at site T1 and both the 4R and 5R crops at site T3.

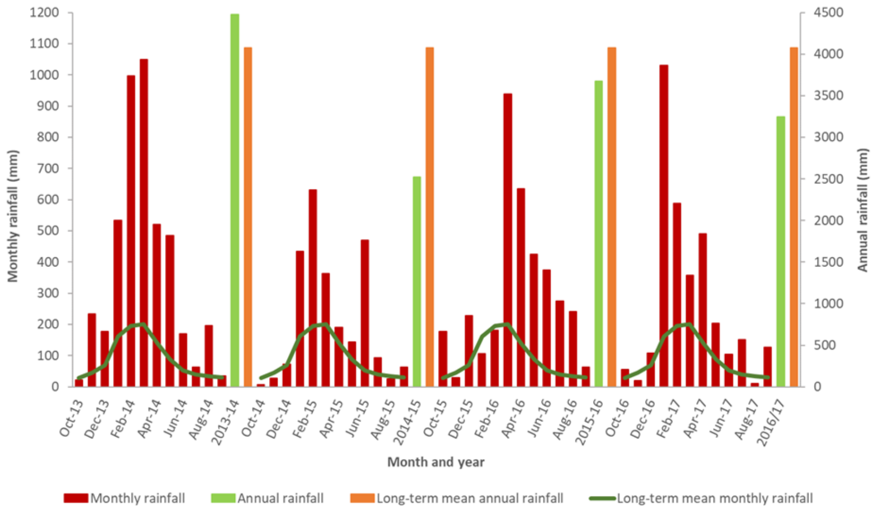


Figure 6-16 Monthly and annual recorded rainfall from the Tully Sugar Limited Bureau of Meteorology station relevant to the T1 and T3 trial sites (Oct 2013 to Sep 2017).

6.2.4.2. Soil mineral N

Analysis of soil mineral N during the 4R (Table 45) and 5R crop (Table 46) at site T1, and 4R (Table 47) and 5R (Table 48) at site T3 revealed sample depth had a statistically significant effect. Total soil mineral N levels decreased with soil depth at all sampling times. Total soil mineral N levels also tended to be highest 3 months after harvesting. The higher soil mineral N levels identified in the top 0-20 cm and at 3 months after harvest is most likely associated with fertiliser application. The amount of N applied did not have a statistically significant effect on total soil mineral N except for the 6-month sampling time in the 5R crop at site T1. The 0, 30, 60 and 75 kg N/ha treatments had significantly less total soil mineral N than the 180, 210 and 240 kg N/ha treatments. This response did not follow through to the 9- and 12-month sampling times for the 5R crop.

6.2.4.3. Third leaf N

The amount of N applied had a significant effect on third leaf N concentrations for the 4R and 5R crops at both sites T1 and T3 (Table 6-49). For the 4R and 5R crops at site T1 the lower N treatments resulted in significantly lower third leaf N concentrations than the higher N treatments. At site T3, the lower N treatments also resulted in significantly lower third leaf N concentrations. In the 6R crop at site T1, N treatment did not have a significant effect on third leaf N concentrations.

Third leaf N concentrations were below the critical value (1.8-1.9%) for all N treatments in the 4R crops at sites T1 and T3 and the 6R crop at site T1. Third leaf N concentrations in the 5R crop at site T1 were above the critical value for the higher N treatments (135, 180, 210 and 240 kg N/ha). In the 5R crop at site T3, N rates of 105 kg N/ha and higher maintained third leaf N concentrations above the critical value. Rainfall in January, February and March, immediately prior to leaf sampling the 4R and 6R crops was much higher than the 6R crop and well above the long-term Tully average.

Table 6-45 Total mineral N (mg/kg) associated with the 4R crop for twelve N application rates to a depth of 100 cm in increments of 20 cm at Site T1.
Samples were collected from all plots in replicates 1 and 3.

1/12/201	Depth	N applied (kg/ha) applied to cane grown												
		0	30	60	75	90	105	120	135	150	180	210	240	Mean
		Soil N (mg/kg)												
		Total Mineral-N												
4R 3 month	0 – 20	8.45	14.90	11.30	16.30	42.20	22.70	37.45	26.40	21.65	42.75	92.65	79.25	34.67^{A}
	20 – 40	3.00	4.35	2.55	4.20	4.30	5.35	5.45	3.50	6.65	4.40	13.30	6.70	5.31^{B}
	40 – 60	2.40	1.90	2.25	3.30	1.95	3.55	4.45	2.55	1.35	3.60	1.40	3.60	2.69^{B}
	60 – 80	0.85	3.60	2.15	5.45	1.75	4.45	0.85	3.00	1.95	3.30	1.30	4.40	2.75^{B}
	80 – 100	0.75	0.75	0.50	5.35	0.40	1.80	0.50	2.15	0.25	8.55	2.00	3.30	2.19^{B}
	Mean	3.09	5.10	3.75	6.92	10.12	7.57	9.74	7.52	6.37	12.52	22.13	19.45	
	$LSD^{0.05}$	*N = ns (P=0.52), Depth = 8.52 (P<0.001)*												
25/06/20	Depth	N applied (kg/ha) applied to cane grown												
		0	30	60	75	90	105	120	135	150	180	210	240	Mean
		Soil N (mg/kg)												
		Total Mineral-N												
4R 9 month	0 – 20	13.20	9.20	12.80	20.85	11.15	13.40	15.65	11.20	7.90	13.25	10.45	15.00	12.84^{A}
	20 – 40	7.50	5.80	8.25	7.20	10.85	8.85	8.45	5.95	4.85	6.10	7.35	9.50	7.55^{B}
	40 – 60	6.25	6.55	5.15	3.60	3.35	3.35	4.35	4.70	4.55	6.15	6.70	9.15	5.32^{C}
	60 – 80	3.10	3.60	3.70	3.75	3.00	2.85	3.10	5.40	4.00	5.00	11.90	8.35	4.81^{C}
	80 – 100	4.15	2.15	2.50	2.55	5.85	6.10	3.70	3.70	2.80	3.60	3.90	9.80	4.23^{C}
	Mean	6.84	5.46	6.48	7.59	6.84	6.91	7.05	6.19	4.82	6.82	8.06	10.36	
	$LSD^{0.05}$	*N = ns (P=0.54), Depth = 1.91 (P<0.001)*												
13/10/20	Depth	N applied (kg/ha) applied to cane grown												
		0	30	60	75	90	105	120	135	150	180	210	240	Mean
		Soil N (mg/kg)												
		Total Mineral-N												
4R 12 month	0 – 20	10.35	10.75	13.30	14.00	6.50	7.70	19.55	12.85	13.65	7.25	16.20	16.85	12.41^{A}
	20 – 40	7.20	12.95	8.75	14.95	10.30	5.05	14.20	12.50	11.65	5.35	16.00	16.85	11.31^{A}
	40 – 60	6.35	8.60	7.50	6.70	7.25	3.55	11.25	8.70	8.15	2.65	9.50	4.85	7.09^{B}
	60 – 80	10.45	1.90	4.25	6.55	7.35	3.40	8.75	4.90	6.70	4.10	5.45	5.20	5.75^{B}
	80 – 100	9.70	5.40	5.20	7.30	3.10	3.60	7.45	5.00	5.15	3.75	3.85	5.40	5.41^{B}
	Mean	8.81	7.92	7.80	9.90	6.90	4.66	12.24	8.79	9.06	4.62	10.2	9.83	
	$LSD^{0.05}$	*N = ns (P=0.09), Depth = 2.78 (P<0.001)*												

^{A,B,C} Mean values accompanied by the same letter in a group are "not significantly" different

Table 6-46 Total mineral N (mg/kg) associated with the 5R crop for twelve N application rates to a depth of 100 cm in increments of 20 cm at Site T1.
Samples were collected from all plots in replicates 1 and 3.

15/12/2015	Depth	N applied (kg/ha) applied to cane grown												
		0	30	60	75	90	105	120	135	150	180	210	240	Mean
		Soil N (mg/kg)												
		Total Mineral-N												
5R 3 month	0 – 20	10.65	18.25	9.90	8.25	16.15	11.15	10.80	15.50	7.85	14.70	15.35	10.40	12.41^{A}
	20 – 40	8.80	13.60	7.40	7.35	19.05	9.40	9.90	14.65	10.10	14.20	14.75	6.55	11.31^{A}
	40 – 60	4.35	9.25	6.05	3.70	11.75	6.05	6.35	4.40	7.65	8.00	10.80	6.70	7.09^{B}
	60 – 80	5.50	7.80	3.65	3.45	4.25	2.55	3.10	2.25	9.25	7.35	9.05	10.80	5.75^{B}
	80 – 100	5.85	6.70	3.30	4.25	7.05	2.65	2.20	4.45	3.70	7.30	7.50	9.95	5.41^{B}
	Mean	7.03	11.12	6.06	5.4	11.65	6.36	6.47	8.25	7.71	10.31	11.49	8.88	
	$LSD^{0.05}$	*N = ns (P=0.07), Depth = 2.77 (P<0.001)*												

3/03/201	Depth	N applied (kg/ha) applied to cane grown												
		0	30	60	75	90	105	120	135	150	180	210	240	Mean
		Soil N (mg/kg)												
		Total Mineral-N												
5R 6 month	0 – 20	14.85	13.60	15.70	18.65	16.85	25.05	19.25	51.35	32.30	51.00	43.50	61.70	30.32^{A}
	20 – 40	8.20	9.95	10.10	12.05	12.35	13.70	11.25	17.60	21.80	23.80	34.00	41.70	18.04^{A}
	40 – 60	3.60	3.70	7.25	4.10	6.55	5.00	5.30	8.40	8.65	12.35	20.35	25.50	9.23^{C}
	60 – 80	2.80	3.30	4.50	2.90	4.00	4.40	3.65	7.25	4.40	7.65	10.95	15.80	5.97^{C}
	80 – 100	2.45	2.20	2.95	2.85	3.35	3.50	3.70	4.50	3.95	5.60	7.30	16.95	4.92^{C}
	Mean	6.38 D	6.55 D	8.10 D	8.11 D	8.62 CD	10.33 CD	8.63 CD	17.82 BCD	14.22 BCD	20.08 BC	23.22 AB	32.33 A	
	$LSD^{0.05}$	*N = 11.79 (P<0.001), Depth = 6.63 (P<0.001)*												

10/06/20	Depth	N applied (kg/ha) applied to cane grown												
		0	30	60	75	90	105	120	135	150	180	210	240	Mean
		Soil N (mg/kg)												
		Total Mineral-N												
5R 9 month	0 – 20	16.60	14.85	14.65	17.60	20.90	15.75	14.70	15.45	12.65	13.70	14.95	13.80	15.47^{A}
	20 – 40	8.80	7.75	8.40	9.80	8.80	9.45	10.05	8.45	6.50	8.45	7.95	10.30	8.73^{B}
	40 – 60	5.70	3.85	5.90	5.25	6.55	5.15	4.80	5.45	5.65	6.55	7.85	8.45	5.93^{C}
	60 – 80	4.65	2.55	4.50	4.60	5.70	2.30	4.15	5.10	4.60	5.80	8.15	8.45	5.05^{CD}
	80 – 100	5.05	2.25	4.05	3.20	4.75	1.50	4.05	3.45	3.00	3.95	3.00	7.90	3.85^{C}
	Mean	8.16	6.25	7.50	8.09	9.34	6.83	7.55	7.58	6.48	7.69	8.38	9.78	
	$LSD^{0.05}$	*N = ns (P=0.92), Depth = 1.27 (P<0.001)*												

14/10/20	Depth	N applied (kg/ha) applied to cane grown												
		0	30	60	75	90	105	120	135	150	180	210	240	Mean
		Soil N (mg/kg)												
		Total Mineral-N												
5R 12 month	0 – 20	10.90	14.95	9.10	15.15	11.75	11.55	10.85	11.20	11.30	11.25	11.55	9.80	11.61^{A}
	20 – 40	7.80	5.85	6.05	6.10	4.45	5.45	5.60	5.40	5.50	5.35	6.30	5.45	5.78^{B}
	40 – 60	5.55	3.65	4.30	4.45	3.30	3.50	3.80	4.10	3.30	3.60	4.45	5.45	4.12^{C}
	60 – 80	3.95	4.10	3.15	3.25	3.25	2.80	3.75	3.05	3.50	3.30	3.25	7.60	3.75^{C}
	80 – 100	4.25	4.45	3.00	2.50	4.40	2.05	3.80	3.05	3.50	2.40	3.70	7.75	3.74^{C}
	Mean	6.49	6.60	5.12	6.29	5.43	5.07	5.56	5.36	5.42	5.18	5.85	7.21	
	$LSD^{0.05}$	*N = ns (P=0.96), Depth = 0.96 (P<0.001)*												

^{A,B,C} Mean values accompanied by the same letter in a group are "not significantly" different

Table 6-47 Total mineral N (mg/kg) associated with the 4R crop for twelve N application rates to a depth of 100 cm in increments of 20 cm at Site T3.
Samples were collected from all plots in replicates 1 and 3.

2/12/210	Depth	N applied (kg/ha) applied to cane grown												
		0	30	60	75	90	105	120	135	150	180	210	240	Mean
		Soil N (mg/kg)												
		Total Mineral-N												
4R 3 month	0 – 20	7.60	39.90	26.05	42.10	39.30	60.50	53.55	82.67	41.35	56.45	46.60	26.30	49.13^{A}
	20 – 40	9.35	10.00	7.60	8.70	14.70	12.30	14.00	12.77	12.10	12.05	12.40	12.70	16.25^{B}
	40 – 60	3.60	4.15	4.65	3.60	7.60	8.40	5.65	5.30	6.80	4.15	4.90	5.80	9.93^{BC}
	60 – 80	2.70	3.00	4.20	2.60	6.85	3.50	4.05	3.53	2.20	4.90	5.15	2.90	8.47^{C}
	80 – 100	4.55	4.30	2.70	1.65	5.80	4.60	3.10	2.60	2.80	3.30	4.20	2.90	8.13^{C}
	Mean	9.43	16.14	12.91	15.60	18.72	21.24	19.94	21.37	16.92	20.04	18.52	13.99	
	$LSD^{0.05}$	*N = ns (P=0.99), Depth = 7.35 (P<0.001)*												
26/06/20	Depth	N applied (kg/ha) applied to cane grown												
		0	30	60	75	90	105	120	135	150	180	210	240	Mean
		Soil N (mg/kg)												
		Total Mineral-N												
4R 9 month	0 – 20	11.25	13.55	11.15	13.55	13.75	10.40	12.25	11.53	12.85	14.40	14.95	11.35	12.24^{A}
	20 – 40	5.55	8.80	5.45	5.00	9.30	6.00	5.60	6.93	7.00	7.35	5.95	7.40	6.35^{B}
	40 – 60	2.65	4.20	2.60	1.75	4.95	3.50	3.05	3.40	3.30	2.55	3.80	8.75	3.32^{C}
	60 – 80	2.45	3.10	2.05	1.50	2.55	3.80	2.20	2.73	2.40	1.95	3.70	6.95	2.52^{CD}
	80 – 100	1.65	4.10	1.80	1.15	3.45	3.30	2.00	2.47	2.40	1.75	3.20	4.30	2.21^{D}
	Mean	4.24	6.28	4.14	4.12	6.33	4.54	4.55	5.41	5.12	5.13	5.85	7.28	
	$LSD^{0.05}$	*N = ns (P=0.86), Depth = 0.98 (P<0.001)*												
15/10/20	Depth	N applied (kg/ha) applied to cane grown												
		0	30	60	75	90	105	120	135	150	180	210	240	Mean
		Soil N (mg/kg)												
		Total Mineral-N												
4R 12 month	0 – 20	9.15	9.35	10.00	9.90	10.95	7.80	10.85	12.50	12.35	10.60	10.45	11.80	10.71^{A}
	20 – 40	7.25	7.85	3.60	7.00	4.90	4.50	7.05	6.43	6.80	5.85	7.00	9.05	6.56^{B}
	40 – 60	1.95	3.95	1.75	3.20	4.30	3.00	4.35	3.70	5.00	3.05	5.95	5.60	3.89^{C}
	60 – 80	3.85	2.30	2.95	4.25	3.60	2.40	2.90	4.53	2.15	2.70	5.25	3.65	3.51^{C}
	80 – 100	2.70	1.50	1.95	2.80	4.05	2.60	1.95	3.00	2.65	2.10	3.30	3.70	2.75^{C}
	Mean	4.75	4.76	3.82	5.20	5.33	3.69	5.19	6.03	5.56	4.63	6.16	6.53	
	$LSD^{0.05}$	*N = ns (P=0.91), Depth = 1.19 (P<0.001)*												

^{A,B,C} Mean values accompanied by the same letter in a group are "not significantly" different

Table 6-48 Total mineral N (mg/kg) associated with the 5R crop for twelve N application rates to a depth of 100 cm in increments of 20 cm at Site T3.
Samples were collected from all plots in replicates 1 and 3.

	Depth	N applied (kg/ha) applied to cane grown												
16/12/20		0	30	60	75	90	105	120	135	150	180	210	240	Mean
		Soil N (mg/kg)												
		Total Mineral-N												
5R 3 month	0 – 20	24.90	28.10	20.20	23.95	36.50	36.00	45.50	58.37	29.15	46.00	28.85	54.50	38.92^{A}
	20 – 40	25.20	35.90	12.65	11.70	25.20	10.50	20.70	16.70	17.55	23.90	26.60	16.20	21.75^{B}
	40 – 60	31.80	25.00	8.55	7.65	17.50	4.30	13.20	10.70	7.95	14.50	18.00	11.00	15.15^{C}
	60 – 80	21.90	23.55	4.65	5.55	14.25	3.80	10.40	8.97	8.20	13.40	9.55	8.80	12.30^{C}
	80 – 100	26.80	20.90	5.85	5.65	14.05	2.50	12.80	9.23	7.15	6.10	10.65	6.55	11.74^{C}
	Mean	24.06	28.30	11.99	12.51	23.11	9.36	22.13	20.79	15.61	22.39	20.34	21.02	
	$LSD^{0.05}$	*N = ns (P=0.29), Depth = 6.51 (P<0.001)*												
8/06/201	Depth	N applied (kg/ha) applied to cane grown												
		0	30	60	75	90	105	120	135	150	180	210	240	Mean
		Soil N (mg/kg)												
		Total Mineral-N												
5R 9 month	0 – 20	8.90	12.60	17.45	15.75	20.00	23.00	17.55	14.13	14.40	17.85	13.80	12.15	14.64^{A}
	20 – 40	6.55	9.30	8.30	8.10	10.30	10.60	11.90	8.50	11.45	11.80	10.50	11.35	9.18^{B}
	40 – 60	2.75	12.20	8.40	6.25	8.35	9.50	9.80	4.57	8.75	5.75	6.70	6.05	6.59^{C}
	60 – 80	4.90	11.20	5.45	5.90	8.55	4.90	5.55	5.53	6.20	5.65	5.20	6.40	5.69^{C}
	80 – 100	4.65	4.70	4.90	3.00	5.90	13.80	3.50	6.67	7.00	4.95	6.75	3.50	4.85^{C}
	Mean	5.00	9.45	8.35	7.25	10.07	11.75	9.11	7.88	9.01	8.65	8.04	7.34	
	$LSD^{0.05}$	*N = ns (P=0.55), Depth = 2.00 (P<0.001)*												
13/10/20	Depth	N applied (kg/ha) applied to cane grown												
		0	30	60	75	90	105	120	135	150	180	210	240	Mean
		Soil N (mg/kg)												
		Total Mineral-N												
5R 12 month	0 – 20	10.10	19.35	19.05	21.25	18.80	21.10	18.65	17.23	19.00	22.50	20.35	15.20	17.94^{A}
	20 – 40	9.30	10.55	7.65	9.80	7.15	8.80	9.35	9.47	8.95	9.25	10.10	7.95	8.61^{B}
	40 – 60	2.40	8.65	4.85	4.10	4.00	5.80	4.85	4.97	5.10	3.15	6.10	5.05	4.43^{C}
	60 – 80	1.90	4.55	3.15	2.90	4.75	3.70	4.45	5.43	4.25	2.85	7.10	4.50	3.76^{C}
	80 – 100	1.55	4.25	2.60	3.10	5.30	3.90	4.90	4.07	4.60	2.70	6.40	4.00	3.51^{C}
	Mean	4.26	8.68	6.67	7.44	7.21	7.61	7.65	8.23	7.59	7.30	9.22	6.55	
	$LSD^{0.05}$	*N = ns (P=0.96), Depth = 1.43 (P<0.001)*												

A,B,C Mean values accompanied by the same letter in a group are "not significantly" different

Table 6-49 Third leaf N concentration (%DM) as influenced by N application rate for the 4R, 5R and 6R crops at site T1 and the 4R and 5R crops at site T3.

Site	Crop	Third leaf N values (%DM)												
		N applied (kg/ha)												
		0	30	60	75	90	105	120	135	150	180	210	240	Mean
T1	4R	1.35^{F}	1.42^{EF}	1.49^{DE}	1.53^{BCD}	1.51^{CDE}	1.53^{BCD}	1.51^{CDE}	1.58^{ABCD}	1.59^{ABC}	1.58^{ABCD}	1.64^{A}	1.63^{AB}	1.53
	5R	1.48^{C}	1.56^{BC}	1.70^{AB}	1.68^{ABC}	1.71^{AB}	1.77^{AB}	1.76^{AB}	1.85^{A}	1.77^{A}	1.82^{A}	1.89^{A}	1.88^{A}	1.74
	6R	1.65	1.70	1.51	1.63	1.63	1.52	1.68	1.57	1.63	1.55	1.78	1.55	1.62
	$LSD^{0.05}$: 4R = 0.10 (P=0.001); 5R = 0.21 (P<0.001); 6R = ns (P=0.08)													
T3	4R	1.30^{H}	1.45^{G}	1.47^{FG}	1.49^{EFG}	1.52^{DEFG}	1.54^{CDEF}	1.55^{BCDEF}	1.57^{BCDE}	1.61^{ABC}	1.61^{ABCD}	1.67^{A}	1.63^{AB}	1.54
	5R	1.50^{F}	1.60^{EF}	1.70^{CDE}	1.67^{DEF}	1.77^{BCDE}	1.83^{ABCD}	1.90^{AB}	1.87^{ABC}	1.78^{BCDE}	1.80^{BCD}	1.93^{AB}	2.00^{A}	1.78
	$LSD^{0.05}$: 4R = 0.09 (P<0.001); 5R = 0.18 (P<0.001)													

A,B,C,D,E,F, Mean values accompanied by the same letter in the same season are "not significantly" different

6.2.4.4. Biomass and N uptake

Analysis of dry biomass and crop N uptake at 9 months after harvest (Tables 6-50 and 6-51 respectively) revealed N treatment had a statistically significant effect in all crops at both sites. Dry biomass and crop N uptake increased with increasing N rate. At site T1, 180 kg N/ha produced the highest dry biomass whereas at site T3 dry biomass was maximised at 210 kg N/ha. However, these N rates did not produce significantly higher dry biomass than the corresponding SIX EASY STEPS N rate for the site except for the 6R crop at site T1. At site T1 there was a significant difference in crop N uptake between the SIX EASY STEPS N rate and rates equal to and above 180 kg N/ha in the 4R and 5R crops and 150 kg N/ha in the 6R crop. In the 4R crop at site T3, N rates above SIX EASY STEPS did not result in significantly higher crop N uptake but in the 5R crop, N rates equal to and greater than 180 kg N/ha resulted in significantly higher crop N uptake.

The effect of N rate on dry biomass was less pronounced 12 months after harvest. At the T1 site, dry biomass increased significantly at higher N rates with the maximum dry biomass realised at 180 kg N/ha in both the 4R and 5R crops. At site T3 the 0 kg N/ha treatment produced significantly less dry biomass than all other N rates and 210 kg N/ha significantly more than 30, 60, 120 and 150 kg N/ha. In the 5R crop, N rate did not have a statistically significant effect on dry biomass. Crop N uptake at 12 months was lower than 9 months for all crops at both sites. The amount of N applied had a statistically significant effect on crop N uptake in all crops. The lower N rates had significantly less crop N uptake than the higher N rates.

Table 6-50 Effect of N application rate on dry biomass production (t/ha) 9 months after harvest for the 4R, 5R and 6R crops at site T1, and the 4R and 5R crops at site T3.

Site	Date	Crop	Dry biomass (t/ha)												
			N applied (kg/ha)												
			0	30	60	75	90	105	120	135	150	180	210	240	Mean
T1	24/06/14	4R	22.0^{D}	29.6^{C}	34.4^{BC}	34.0^{BC}	35.7^{BC}	32.8^{BC}	35.3^{BC}	32.1^{BC}	37.4^{AB}	43.2^{A}	37.4^{AB}	38.8^{AB}	34.4
	31/05/15	5R	18.1^{F}	22.8^{EF}	23.4^{CDEF}	23.3^{DEF}	25.5^{BCDE}	29.0^{ABCD}	28.4^{ABCDE}	28.8^{ABCD}	30.0^{AB}	33.4^{A}	31.0^{AB}	29.4^{ABC}	26.9
	8/06/16	6R	14.4^{E}	23.6^{CD}	23.1^{CD}	22.4^{D}	22.8^{D}	28.8^{BC}	25.4^{BCD}	27.4^{BCD}	30.9^{AB}	35.4^{A}	30.5^{AB}	30.2^{AB}	26.2
		LSD$^{0.05}$: 4R = 7.03 (P=<0.00); 5R = 6.0 (P=<0.00); 6R = (P=<0.00)													
T3	23/06/14	4R	18.9^{E}	31.9^{CD}	35.3^{ABCD}	32.3^{BCD}	40.4^{ABC}	38.5^{ABCD}	35.8^{ABCD}	42.2^{AB}	30.3^{D}	37.0^{ABCD}	43.9^{A}	36.5^{ABCD}	35.5
	6/06/15	5R	17.6^{C}	22.5^{BC}	27.3^{AB}	25.3^{AB}	26.9^{AB}	28.6^{A}	25.5^{AB}	25.6^{AB}	25.4^{AB}	27.2^{AB}	29.4^{A}	27.4^{AB}	25.7
		LSD$^{0.05}$: 4R = 9.9 to 12.2 (P=0.01); 5R = 5.8 (P=0.03)													

^{A,B,C,D,E,F} Mean values accompanied by the same letter in the same season are "not significantly" different

Table 6-51 Effect of N application rate on N uptake (kg N/ha) 9 months after harvest for the 4R, 5R and 6R crops at site T1 and the 4R and 5R crops at site T3.

Site	Date	Crop	Crop N uptake (kg N/ha)												
			N applied (kg/ha)												
			0	30	60	75	90	105	120	135	150	180	210	240	Mean
T1	24/06/14	4R	61.5^{E}	83.0^{DE}	101.7^{CD}	99.2^{CD}	107.1^{CD}	104.2^{CD}	112.4^{C}	100.9^{CD}	116.7^{BC}	152.7^{A}	141.2^{AB}	145.3^{A}	110.5
	31/05/15	5R	47.8^{H}	56.9^{GH}	64.0^{FGH}	68.9^{EFG}	76.6^{DEF}	87.4^{CDE}	79.1^{CDEF}	88.9^{CD}	96.3^{BC}	110.2^{AB}	117.6^{A}	108.9^{AB}	83.6
	8/06/16	6R	33.8^{F}	55.7^{DE}	57.6^{DE}	53.4^{E}	60.1^{DE}	68.7^{DE}	65.7^{DE}	71.1^{CD}	95.7^{AB}	108.4^{A}	86.3^{BC}	87.5^{B}	70.3
		LSD$^{0.05}$: 4R =26.1 (P=<0.00); 5R = 18.7 (P=<0.00); 6R = (P=<0.00)													
T3	23/06/14	4R	47.4^{E}	90.4^{CD}	98.9^{BCD}	85.3^{D}	122.9^{ABC}	110.9^{ABCD}	115.6^{ABCD}	129.8^{AB}	102.9^{BCD}	120.1^{ABC}	144.8^{A}	119.1^{ABCD}	107.3
	6/06/15	5R	43.3^{E}	57.9^{DE}	60.8^{DE}	58.7^{DE}	91.3^{B}	91.7^{B}	85.8^{BC}	64.9^{CDE}	81.7^{BCD}	98.9^{AB}	93.2^{B}	117.5^{A}	78.8
		LSD$^{0.05}$: 4R = 33.9 to 41.5 (P=<0.00); 5R = 24.2 (P=<0.00)													

^{A,B,C,D,E,F,G,H} Mean values accompanied by the same letter in the same season are "not significantly" different

6.2.4.5. Yield and CCS

The rainfall experienced during the trial period tended to be lower earlier in the growing season (e.g. post fertilizer application) but above average from late summer through to winter with the 6R crop experiencing a flood in January 2017. This resulted in mean sugarcane yields (Table 6-52) being higher in the 4R and 5R crops (above 90 tc/ha) and lower in the 6R crop (78.7 tc/ha). The mean sugarcane yields of the 4R, 5R and 6R crops were comparable to the Tully mill average of 101, 101 and 84 tc/ha in 2015, 2016 and 2017, respectively.

Sugarcane yields increased significantly with N rate for all crops at both sites (Table 6-52). The nil N rate produced significantly lower sugarcane yields than all other N rates for all ratoon crops at both sites. Applying N rates greater than the SIX EASY STEPS guidelines for sites T1 (120 kg N/ha) and T3 (closest is 135 kg N/ha) did not result in significantly higher sugarcane yields. Maximum sugarcane yields were often reached at 180 kg N/ha but in all crops except 6R, these yields were not significantly higher than the corresponding SIX EASY STEPS N rate for the site. The statistical analysis also revealed N rates below the SIX EASY STEPS guidelines at these sites did not significantly reduce sugarcane yields.

There was no statistically significant effect of N rate on CCS at either site T1 or T3 for any of the ratoon crops (Table 6-53).

The effect of N rate on sugar yields was similar to those reported for sugarcane yields. Sugar yields increased significantly with N rate for all crops at both sites (Table 6-54). However, there was less statistical separation between N rates for sugar yields.

Table 6-52 Effect of N application rates on sugarcane yield (tc/ha) for the 4R, 5R and 6R crops at site T1 and the 4R and 5R crops at site T3.

Site	Date	Crop	Sugarcane Yield (tc/ha)												
			N applied (kg/ha)												
			0	30	60	75	90	105	120	135	150	180	210	240	Mean
T1	17/09/15	4R	53.3^{G}	75.1^{F}	91.1^{DE}	80.9^{EF}	91.9^{CDE}	95.2^{BCD}	96.2^{ABCD}	100.5^{ABCD}	106.5^{AB}	108.4^{A}	103.6^{ABCD}	104.1^{ABC}	92.2
	21/09/16	5R	55.2^{E}	80.7^{D}	100.4^{ABC}	79.7^{D}	84.7^{CD}	108.9^{AB}	97.5^{BCD}	103.1^{AB}	109.3^{AB}	106.4^{AB}	117.0^{A}	106.8^{AB}	95.8
	8/09/17	6R	43.8^{E}	63.4^{D}	88.0^{AB}	66.2^{CD}	77.2^{BCD}	81.7^{ABC}	77.2^{BCD}	89.5^{AB}	91.6^{AB}	94.7^{A}	86.3^{AB}	85.2^{AB}	78.7
		LSD$^{0.05}$: 4R = 12.8 (P<0.001); 5R = 18.0(P<0.00); 6R = 15.5 (P<0.00)													
T3	18/09/15	4R	47.5^{E}	84.6^{D}	90.3^{CD}	89.2^{CD}	99.2^{ABC}	100.4^{ABC}	96.2^{BCD}	104.0^{AB}	97.4^{ABCD}	110.0^{A}	108.6^{AB}	100.1^{ABC}	93.9
	22/09/16	5R	50.5^{C}	85.8^{B}	86.1^{B}	90.9^{AB}	98.9^{AB}	98.2^{AB}	91.7^{AB}	94.0^{AB}	94.3^{AB}	104.2^{A}	100.8^{AB}	89.7^{AB}	90.4
		LSD$^{0.05}$: 4R = 13.4 (P<0.00); 5R = 15.8 (P<0.00)													

^{A,B,C,D,E,F} Mean values accompanied by the same letter in the same season are “not significantly” different

Table 6-53 Effect of N application rates on CCS (%) for the 4R, 5R and 6R crops at site T1 and the 4R and 5R crops at site T3.

Site	Date	Crop	Commercial Cane Sugar (%)												
			N applied (kg/ha)												
			0	30	60	75	90	105	120	135	150	180	210	240	Mean
T1	17/09/2015	4R	16.0	15.9	16.4	16.7	16.3	15.9	16.2	16.0	16.1	16.2	15.4	15.7	16.1
	21/09/2016	5R	15.8	15.9	15.9	15.7	15.8	15.2	15.4	15.1	15.6	15.6	15.4	15.7	15.6
	8/09/2017	6R	18.0	17.7	17.8	17.2	17.6	18.2	17.7	18.0	18.0	17.4	17.3	17.8	17.7
		LSD$^{0.05}$: 4R = ns (P=0.09); 5R = ns (P=0.46); 6R = ns (P=0.67)													
T3	18/09/2015	4R	15.4	16.2	16.3	16.6	16.3	16.2	16.7	15.8	16.6	15.9	16.6	16.3	16.2
	22/09/2016	5R	16.4	16.7	16.6	16.8	17.1	16.8	16.9	16.1	16.5	16.1	16.7	16.3	16.6
		LSD$^{0.05}$: 4R = ns (P=0.32); 5R = ns (P=0.09)													

Table 6-54 Effect of N application rates on sugar yield (ts/ha) for the 4R, 5R and 6R crops at site T1 and the 4R and 5R crops at site T3.

Site	Date	Crop	Sugar Yield (ts/ha)												
			N applied (kg/ha)												
			0	30	60	75	90	105	120	135	150	180	210	240	Mean
T1	17/09/15	4R	8.5^{E}	11.9^{D}	15.0^{BC}	13.6^{CD}	15.0^{BC}	15.2^{BC}	15.6^{ABC}	16.1^{AB}	17.2A^{B}	17.6^{A}	15.9^{ABC}	16.4^{AB}	14.8
	21/09/16	5R	8.7^{F}	12.8^{DE}	16.0^{ABC}	12.5^{E}	13.4^{CDE}	16.6^{AB}	15.0^{BCDE}	15.5^{ABCD}	17.1^{AB}	16.6^{AB}	18.0^{A}	16.8^{AB}	14.9
	8/09/17	6R	7.8^{D}	11.2^{C}	15.6^{AB}	11.4^{C}	13.6^{BC}	14.9^{AB}	13.7^{BC}	16.1^{AB}	16.4^{A}	16.6^{A}	14.9^{AB}	15.2^{AB}	13.9
			$LSD^{0.05}$: 4R = 2.4 (P<0.00); 5R = 2.8 (P<0.001); 6R =2.7 (P<0.001)												
T3	18/09/15	4R	7.3^{D}	13.7^{C}	14.7^{BC}	14.8^{BC}	16.1^{AB}	16.3^{AB}	16.0^{ABC}	16.3^{AB}	16.2^{AB}	17.5^{A}	17.9^{A}	16.3^{AB}	15.3
	22/09/16	5R	8.3^{B}	14.3^{A}	14.3^{A}	15.3^{A}	16.9^{A}	16.5^{A}	15.5^{A}	15.1^{A}	15.6^{A}	16.8^{A}	16.9^{A}	14.6^{A}	15.0
			$LSD^{0.05}$: 4R = 2.3 to 2.6 (P<0.001); 5R = 2.8 (P<0.001)												

^{A,B,C,D,E,F} Mean values accompanied by the same letter in the same season are "not significantly" different

6.2.4.6. NUE and economics

Nitrogen use efficiency data for the different N application rates along with estimates of NUE at the SIX EASY STEPS and optimum N (OptN) rates as calculated from N response curves, is shown in Table 6-55 for site T1 and Table 6-56 for site T3. The OptN for the 4R, 5R and 6R crops at site T1 was 135, 135 and 125 kg N/ha, respectively. This was slightly higher than the ratoon crop SIX EASY STEPS N rate for the site of 120 kg N/ha. At site T3, the OptN for the 4R and 5R crops was 120 and 105 kg N/ha respectively. This was lower than the ratoon crop SIX EASY STEPS N rate for the site of 130 kg N/ha.

Both the more common and simpler to calculate NUE measures (tc/kg N applied and kg N applied/tc) and those requiring references to nil N plots (AgronEfffert and NUtE) declined with increasing N rate for all crops at both sites. This is despite N rate having a significant effect on final cane yield and crop N uptake (at 9 months post-harvest). The trend was similar but less consistent for NUpEfert.

Total crop N uptake increased with increasing N rate and was largely due to increases in fertiliser N uptake.

Grower partial net return and industry net return data for the different N application rates, including SIX EASY STEPS and OptN for sites T1 and T3 are reported in Tables 6-57 and 6-58, respectively. The highest grower and industry economic returns were not always associated with the N rate producing the highest cane or sugar yields. In addition, the N rates at which grower and industry economic returns were maximised were either much higher or lower than SIX EASY STEPS and OptN rates. Grower partial net returns were maximised at N rates higher than SIX EASY STEPS and Opt N in the 4R crops at both sites T1 (150 kg N/ha) and T3 (210 kg N/ha). However, in the 5R and 6R crops, N rates less than SIX EASY STEPS and OptN produced the highest grower partial net returns. Industry net returns were maximised at N rates higher than SIX EASY STEPS and OptN in the 4R (150 kg N/ha) and 5R (210 kg N/ha) crops at site T1 and 4R (210 kg N/ha) crop at site T3. This was reversed in the 6R crop at site T1 and 5R crop at site T3. In these crops, N rates lower than SIX EASY STEPS and OptN produced the highest industry partial net returns.

Table 6-55 Effect of N application rates on NUE for the 4R, 5R and 6R crops at site T1.

Crop	Yield and efficiency factors	N applied (kg N/ha)												Opt N[2]
		0	30	60	75	90	105	120[3]	135	150	180	210	240	135
4R	Mean yield (tc/ha)	53.3	75.1	91.1	80.9	91.9	95.2	96.2	100.5	106.5	108.4	103.6	104.1	100.5
	tc/kg N applied	-	2.50	1.52	1.08	1.02	0.91	0.80	0.74	0.71	0.60	0.49	0.43	0.74
	kg N applied/tc	-	0.40	0.66	0.93	0.98	1.10	1.25	1.34	1.41	1.66	2.03	2.31	1.34
	Agron Eff$_{fert}$ (kg N/additional TCH)	-	1.38	1.59	2.72	2.33	2.51	2.80	2.86	2.82	3.27	4.17	4.72	2.86
	Crop N uptake (kg N/ha)[1]	61.5	83	101.7	99.2	107.1	104.2	112.4	100.9	116.7	152.7	141.2	145.3	100.9
	NUtE (TCH/kg crop N)[1]	0.87	0.90	0.90	0.82	0.86	0.91	0.86	1.00	0.91	0.71	0.73	0.72	1.00
	Fertiliser N uptake (kg N/ha)	-	21.5	40.2	37.7	45.6	42.7	50.9	39.4	55.2	91.2	79.7	83.8	39.4
	NUpEfert (additional kg N uptake/kg fert applied) %	-	71.7	67.0	50.3	50.7	40.7	42.4	29.2	36.8	50.7	38.0	34.9	29.2
5R														135
	Mean yield (tc/ha)	55.2	80.7	100.4	79.7	84.7	108.9	97.5	103.1	109.3	106.4	117.0	106.8	103.1
	tc/kg N applied	-	2.69	1.67	1.06	0.94	1.04	0.81	0.76	0.73	0.59	0.56	0.45	0.76
	kg N applied/tc	-	0.37	0.60	0.94	1.06	0.96	1.23	1.31	1.37	1.69	1.79	2.25	1.31
	Agron Eff$_{fert}$ (kg N/additional TCH)	-	1.18	1.33	3.06	3.05	1.96	2.84	2.82	2.77	3.52	3.40	4.65	2.82
	Crop N uptake (kg N/ha)[1]	47.8	56.9	64	68.9	76.6	87.4	79.1	88.9	96.3	110.2	117.6	108.9	88.9
	NUtE (TCH/kg crop N)[1]	1.15	1.42	1.57	1.16	1.11	1.25	1.23	1.16	1.13	0.97	0.99	0.98	1.03
	Fertiliser N uptake (kg N/ha)	-	9.1	16.2	21.1	28.8	39.6	31.3	41.1	48.5	62.4	69.8	61.1	41.1
	NUpEfert (additional kg N uptake/kg fert applied) %	-	30.3	27.0	28.1	32.0	37.7	26.1	30.4	32.3	34.7	33.2	25.5	30.4
6R														125
	Mean yield (tc/ha)	43.8	63.4	88.0	66.2	77.2	81.7	77.2	89.5	91.6	94.7	86.3	85.2	86.7
	tc/kg N applied	-	2.11	1.47	0.88	0.86	0.78	0.64	0.66	0.61	0.53	0.41	0.36	0.69
	kg N applied/tc	-	0.47	0.68	1.13	1.17	1.29	1.55	1.51	1.64	1.90	2.43	2.82	1.44
	Agron Eff$_{fert}$ (kg N/additional TCH)	-	1.53	1.36	3.35	2.69	2.77	3.59	2.95	3.14	3.54	4.94	5.80	2.91
	Crop N uptake (kg N/ha)[1]	33.8	55.7	57.6	53.4	60.1	68.7	65.7	71.1	95.7	108.4	86.3	87.5	67.5
	NUtE (TCH/kg crop N)[1]	1.30	1.14	1.53	1.24	1.28	1.19	1.18	1.26	0.96	0.87	1.00	0.97	1.28
	Fertiliser N uptake (kg N/ha)	-	21.9	23.8	19.6	26.3	34.9	31.9	37.3	61.9	74.6	52.5	53.7	33.7
	NUpEfert (additional kg N uptake/kg fert applied) %	-	73.0	39.7	26.1	29.2	33.2	26.6	27.6	41.3	41.4	25.0	22.4	27.0

[1]Calculated on final yield and N uptake at 9 months after previous harvest. [2]Optimum N = N rate corresponding to 95% of the maximum yield calculated from a response curve. [3]The SIX EASY STEPS N rate for this site based on the mean soil organic carbon (%) is 120 kg N/ha for ratoon crops. The NUE parameters were calculated from the mean yield and crop N uptake data.

Table 6-56 Effect of N application rates on NUE for the 4R and 5R crops at site T3.

Crop	Yield and efficiency factors	N applied (kg N/ha)												Opt N[2]	6ES[3]
		0	30	60	75	90	105	120	135	150	180	210	240	120	130
4R	Mean yield (tc/ha)	47.5	84.6	90.3	89.2	99.2	100.4	96.2	104.0	97.4	110.0	108.6	100.1	96.2	104.7
	tc/kg N applied	-	2.82	1.51	1.19	1.10	0.96	0.80	0.77	0.65	0.61	0.52	0.42	0.83	0.81
	kg N applied/tc	-	0.35	0.66	0.84	0.91	1.05	1.25	1.30	1.54	1.64	1.93	2.40	1.27	1.24
	Agron Eff_{fert} (kg N/additional TCH)	-	0.81	1.40	1.80	1.74	1.98	2.46	2.39	3.01	2.88	3.44	4.56	2.47	2.27
	Crop N uptake (kg N/ha)[1]	47.4	90.4	98.9	85.3	122.9	110.9	115.6	129.8	102.9	120.1	144.8	119.1	115.6	125.1
	NUtE (TCH/kg crop N)[1]	1.00	0.94	0.91	1.05	0.81	0.91	0.83	0.80	0.95	0.92	0.75	0.84	0.83	0.84
	Fertiliser N uptake (kg N/ha)	-	43	51.5	37.9	75.5	63.5	68.2	82.4	55.5	72.7	97.4	71.7	68.2	77.7
	NUpEfert (additional kg N uptake/kg fert applied) %	-	143.3	85.8	50.5	83.9	60.5	56.8	61.0	37.0	40.4	46.4	29.9	56.8	59.8
5R														105	130
	Mean yield (tc/ha)	50.5	85.8	86.1	90.9	98.9	98.2	91.7	94.0	94.3	104.2	100.8	89.7	98.2	100.0
	tc/kg N applied	-	2.86	1.44	1.21	1.10	0.94	0.76	0.70	0.63	0.58	0.48	0.37	0.93	0.77
	kg N applied/tc	-	0.35	0.70	0.83	0.91	1.07	1.31	1.44	1.59	1.73	2.08	2.68	1.10	1.32
	Agron Eff_{fert} (kg N/additional TCH)	-	0.85	1.69	1.86	1.86	2.20	2.91	3.10	3.42	3.35	4.17	6.12	2.30	2.63
	Crop N uptake (kg N/ha)[1]	43.3	57.9	60.8	58.7	91.3	91.7	85.8	64.9	81.7	98.9	93.2	117.5	91.7	71.9
	NUtE (TCH/kg crop N)[1]	1.17	1.48	1.42	1.55	1.08	1.07	1.07	1.45	1.15	1.05	1.08	0.76	1.07	1.39
	Fertiliser N uptake (kg N/ha)	-	14.6	17.5	15.4	48	48.4	39.5	21.6	38.4	55.6	49.9	74.2	48.4	28.6
	NUpEfert (additional kg N uptake/kg fert applied) %	-	48.7	29.2	20.5	53.3	46.1	32.9	16.0	25.6	30.9	23.8	30.9	46.1	22.0

[1]Calculated on final yield and N uptake at 9 months after previous harvest. [2]Optimum N = N rate corresponding to 95% of the maximum yield calculated from a response curve. [3]The SIX EASY STEPS N rate for this site based on the mean soil organic carbon (%) is 130 kg N/ha for ratoon crops. The NUE parameters were calculated from the mean yield and crop N uptake data.

Table 6-57 Effect of N application rates on mean input, yield and economics parameters for the 4R, 5R and 6R crops at site T1.

Crop	Yield and efficiency factors	N applied (kg N/ha)												Opt N[1]
		0	30	60	75	90	105	120[3]	135	150	180	210	240	135
4R	Cost of N fertiliser($/ha)	0	39	78	98	117	137	156	176	195	234	273	312	176
	Mean cane yield (tc/ha)	53.3	75.1	91.1	80.9	91.9	95.2	96.2	100.5	106.5	108.4	103.6	104.1	100.5
	ccs (%)	16.0	15.9	16.4	16.7	16.3	15.9	16.2	16.0	16.1	16.2	15.4	15.7	16.0
	Mean sugar yield (ts/ha)	8.5	11.9	15.0	13.6	15.0	15.2	15.6	16.1	17.2	17.6	15.9	16.4	16.1
	Grower partial net return[2] ($/ha)	1736	2281	2766	2623	2781	2825	2724	2747	3009	3003	2676	2917	2747
	Industry net return[2] ($/ha)	2849	3775	4561	4273	4613	4724	4542	4599	5043	5017	4638	4988	4599
5R														135
	Cost of N fertiliser($/ha)	0	39	78	98	117	137	156	176	195	234	273	312	176
	Mean cane yield (tc/ha)	55.2	80.7	100.4	79.7	84.7	108.9	97.5	103.1	109.3	106.4	117.0	106.8	103.1
	ccs (%)	15.8	15.9	15.9	15.7	15.8	15.2	15.4	15.1	15.6	15.6	15.4	15.7	15.1
	Mean sugar yield (ts/ha)	8.7	12.8	16.0	12.5	13.4	16.6	15.0	15.5	17.1	16.6	18.0	16.8	15.5
	Grower partial net return[2] ($/ha)	1787	2482	2855	2415	2650	2859	2634	2291	2845	2833	2825	2821	2291
	Industry net return[2] ($/ha)	2979	4134	4757	4053	4456	4930	4503	4009	4883	4878	4951	4871	4009
6R														125
	Cost of N fertiliser($/ha)	0	39	78	98	117	137	156	176	195	234	273	312	163
	Mean cane yield (tc/ha)	43.8	63.4	88.0	66.2	77.2	81.7	77.2	89.5	91.6	94.7	86.3	85.2	86.7
	ccs (%)	18.0	17.7	17.8	17.2	17.6	18.2	17.7	18.0	18.0	17.4	17.3	17.8	17.7
	Mean sugar yield (ts/ha)	7.8	11.2	15.6	11.4	13.6	14.9	13.7	16.1	16.4	16.6	14.9	15.2	15.3
	Grower partial net return[2] ($/ha)	1878	2321	3192	2448	2828	2957	2665	2913	3064	2954	2864	2946	2923
	Industry net return[2] ($/ha)	2907	3649	4982	3891	4463	4645	4231	4598	4838	4747	4651	4749	4649

[1]Optimum N = N rate corresponding to 95% of the maximum yield calculated from a response curve. [2]Assumptions: Sugar price = $370/ts, harvesting and levies = $10/tc, cost of fertiliser = $1.30/kg N. [3]The SIX EASY STEPS N rate for this site based on the mean soil organic carbon (%) is 120 kg N/ha for ratoon crops. The grower partial net return and industry net return values reported for the twelve N rates are from the statistical analysis completed on the plot data rather than the mean yield data.

Table 6-58 Effect of N application rates on mean input, yield and economics parameters for the 4R and 5R crops at site T3.

Crop	Yield and efficiency factors	N applied (kg N/ha)												Opt N[1]	6ES[3]
		0	30	60	75	90	105	120	135	150	180	210	240	120	130
4R	Cost of N fertiliser($/ha)	0	39	78	98	117	137	156	176	195	234	273	312	156	169
	Mean cane yield (tc/ha)	47.5	84.6	90.3	89.2	99.2	100.4	96.2	104.0	97.4	110.0	108.6	100.1	96.2	104.7
	ccs (%)	15.4	16.2	16.3	16.6	16.3	16.2	16.7	15.8	16.6	15.9	16.6	16.3	16.7	15.8
	Mean sugar yield (ts/ha)	7.3	13.7	14.7	14.8	16.1	16.3	16.0	16.3	16.2	17.5	17.9	16.3	16.0	16.5
	Grower partial net return[2] ($/ha)	1145	2530	2641	2621	2914	2851	3069	2895	2979	3095	3256	2808	3069	2898
	Industry net return[2] ($/ha)	2040	4165	4388	4357	4833	4790	4943	4884	4874	5207	5365	4745	4943	4905
5R														105	130
	Cost of N fertiliser($/ha)	0	39	78	98	117	137	156	176	195	234	273	312	137	169
	Mean cane yield (tc/ha)	50.5	85.8	86.1	90.9	98.9	98.2	91.7	94.0	94.3	104.2	100.8	89.7	98.2	100.0
	ccs (%)	16.4	16.7	16.6	16.8	17.1	16.8	16.9	16.1	16.5	16.1	16.7	16.3	16.8	16.6
	Mean sugar yield (ts/ha)	8.3	14.3	14.3	15.3	16.9	16.5	15.5	15.1	15.6	16.8	16.9	14.6	16.5	16.6
	Grower partial net return[2] ($/ha)	1401	2705	2591	2750	3173	2988	3009	2715	2861	2990	3084	2476	2988	3027
	Industry net return[2] ($/ha)	2380	4379	4266	4527	5114	4909	4806	4524	4694	4998	5052	4211	4909	4873

[1]Optimum N = N rate corresponding to 95% of the maximum yield calculated from a response curve. [2]Assumptions: Sugar price = $370/ts, harvesting and levies = $10/tc, cost of fertiliser = $1.30/kg N. [3]The SIX EASY STEPS N rate for this site based on the mean soil organic carbon (%) is 130 kg N/ha for ratoon crops. The grower partial net return and industry net return values reported for the twelve N rates are from the statistical analysis completed on the plot data rather than the mean yield data.

6.2.4.7. Conclusions/key points: T1 and T3

- The amount of N applied had a statistically significant effect on dry biomass, crop N uptake and yields (cane and sugar yield) for most crops at both sites.
- There was no statistically significant effect of N rate measured for CCS in any crop.
- In general, the lower N rates had significantly less dry biomass, crop N uptake and yields than the higher N rates. It was more difficult to distinguish significant effects for N rates between 60 and 150 kg N/ha. At site T1 the OptN calculated from N response curves (135 kg N/ha for 4R and 5R and 125 kg N/ha for 6R) was slightly higher than the SIX EASY STEPS N rate (120 kg N/ha) for ratoon crops. However, at site T3, the OptN (120 kg N/ha for 4R and 105 kg N/ha for 5R) was slightly lower than the SIX EASY STEPS N rate (130 kg N/ha) for ratoon crops.
- The data provides no clear indication if less N is required in older ratoon crops. Despite the 4R and 5R crops considered as older ratoons, mean sugarcane yields were comparable to the Tully mill average in the respective seasons.
- Sugarcane yields declined in the 6R crop but climatic conditions, especially the timing and extent of rainfall appeared to have a more significant influence on N response than crop age.
- Grower and industry economic returns were maximised at N rates either much higher or lower than SIX EASY STEPS and OptN but these rates did not always reflect the N rate producing the highest cane or sugar yields.
- The SIX EASY STEPS and OptN rates do not focus on maximising production but rather maintaining sugarcane yields, improving profitability and environmental sustainability. However, the highest grower and industry economic returns were not always associated with the N rate producing the highest cane or sugar yields.
- These trials consisted of more N treatments (12 different N rates applied) than any other N response experiment reported in the literature, the differences between N rates was much smaller (often as little as 15 kg N/ha) and the increments between N treatments was not always equal (ranged from 15 to 30 kg N/ha). This made it more difficult to identify the response to applied N for biomass, crop N uptake and yields for N treatments between 60 and 150 kg N/ha as the results tended to be up-and-down and more variable than expected. As other field trials have tended to have much larger differences between N treatments this effect is not commonly observed. It is difficult to ascertain if this variability is due to the amount of N applied, metering accuracy (fertiliser box was always calibrated) or within field variations (the trial was designed to minimise variability within replicates but even slight differences in soil type and soil mineral N could influence the results). However, omitting some of the N treatments and redoing the statistical analyses for a smaller series of N treatments with equal differences between N rates (e.g. 30 or 60 kg N/ha increments) may make it easier to identify the effect of N fertiliser rates on biomass, crop N uptake and yields in older ratoons.

6.2.5. Bundaberg temporal N trial

6.2.5.1. Rainfall

Due to the proximity of this trial to Bdb NxK (as described previously), the rainfall data (Figure 6-8) and information provided in section 6.2.1.1. are also applicable here.

6.2.5.2. Soil mineral N

Mean soil mineral N (NO_3^--N, NH_4^+-N and min-N) values (as on 12 Dec 2015) following application of the initial di-ammonium phosphate (DAP) fertiliser on 9 Sep 2015 and the first side-dressing of the different fertiliser formulations (urea, DMPP-coated urea and poly-coated urea) on 25 Nov 2015 are shown in Table 6-59. Fertiliser formulations did not have a significant effect on these values. However, significant differences in the values were noted with soil depth, but again, these were not affected by the different N fertiliser formulations.

Mean soil NO_3^--N, NH_4^+-N and min-N values (as on 24 Feb 2016), following application of the second and third side-dressings of urea on 30 Dec 2015 and 28 Jan 2016, respectively, are shown in Table 6-60. Although the values had generally decreased since the previous sampling (12 Dec 2015), significant differences continued to be evident with depth across the different N treatments. In particular, there was evidence of movement of NO_3^--N to depth. Mean soil NH_4^+-N values associated with some of the urea treatments applied at split applications ([e.g. urea (2), urea (11)] were higher than the mean NH_4^+-N values associated with the other treatments. The treatments mentioned above also gave rises to some higher NO_3^--N and Min-N values in the topsoil (0 -20 cm) but not significantly different from the others.

Mean soil NO_3^--N, NH_4^+-N and min-N values as on 5 May 2016 (Figure 6-61) showed significant differences with soil depth but no treatment or interactive effects. Given the uniformity of soil mineral N values, only the min-N values for the subsequent samplings (14 Jun 2016 and 28 Sep 2016) are provide in table 6-62 together with a summary of the min-N values from Tables 6-59, 6-60 and 6-61). Min-N decreased significantly over the period 17 Dec 2015 to 28 Sep 2016 but no significant effects were apparent due to the different N treatments.

Mean soil NO_3^--N, NH_4^+-N and min-N values associated with the period during which the split fertiliser treatments were applied to the 1R crop are presented in Tables 6-63 (22 Nov 2016), 6-64 (20 Jan 2017) and 6-65 (19 Apr 2017). As with the plant crop, the soil N values differed significantly with depth but were unaffected by N treatments. Interactive effects between N treatment and depth were apparent by 19 April 2017 in the lowest soil depth (60 – 80 cm). The overall mean min-N values for the three sampling times are summarised in Table 6-66. As expected, the mean min-N values increased initially and then decreased as the season progressed.

6.2.5.3. Third leaf N

Third leaf N concentrations (N%DM) associated with the different N treatments for the plant and 1R crops are shown in Tables 6-67 and 6-68 respectively. No significant differences were observed in either crop. However, the values were generally lower across all treatments in the 1R crop (mean of 1.81 %N) compared to the plant crop (2.06 %N) across all N treatments.

Table 6-59 Effect of N fertiliser formulations or split rates of soil NO_3^--N, NH_4^+-N, and min N content of soil to depth in plant crop: Trial Bdb TN (12 Dec 2015).

Depth (cm)	Soil N	Application method	Treatment												Mean
			12	2	1	6	8	10	4	3	11	7	5	9	
			Control	Urea	Urea	Urea	DMPP-urea	PC-urea	Urea	Urea	Urea	Urea	DMPP-urea	PC-urea	
			Application (kg/ha)												
		Initial as DAP	40	40	40	40	40	40	40	40	40	40	40	40	
		1st side-dress	0	40	40	80	80	80	80	80	40	120	120	120	
		2nd side-dress	0	20	40	0	0	0	40	20	40	0	0	0	
		3rd side-dress	0	20	0	0	0	0	0	20	40	0	0	0	
0–20	NO_3^--N	(mg/kg)	6.3	10.0	8.6	10.3	9.7	7.9	8.2	6.9	7.9	10.3	9.3	9.2	8.7^{B}
	NH_4^--N		1.1	2.0	1.4	2.1	2.1	1.5	1.6	1.6	3.3	1.3	2.9	1.9	1.9^{G}
	Min-N		7.4	12.0	10.0	12.4	11.8	9.3	9.8	8.5	11.2	11.6	12.2	11.1	10.6^{S}
20-40	NO_3^--N		3.5	8.1	10.5	12.5	8.8	5.2	13.3	5.0	7.8	15.0	9.6	8.0	8.9^{B}
	NH_4^--N		0.9	1.6	1.5	2.5	1.4	1.7	1.1	1.9	2.0	1.3	2.6	1.7	1.7^{G}
	Min-N		4.4	9.7	12.0	15.0	10.2	6.9	14.4	6.9	9.8	16.3	12.2	9.7	10.6^{S}
40–60	NO_3^--N		11.5	11.5	12.5	10.8	11.0	15.5	10.3	12.2	10.2	10.7	10.2	10.9	11.4^{A}
	NH_4^--N		2.5	5.0	2.7	4.9	3.9	3.9	3.7	3.8	3.7	3.7	3.4	3.5	3.7_{F}
	Min-N		14.0	16.5	15.2	15.7	14.9	19.4	13.9	16.0	13.9	14.4	13.5	14.4	15.1^{R}
60–80	NO_3^--N		8.9	11.0	13.5	11.5	12.0	13.5	11.0	12.0	7.0	9.7	11.1	10.2	$10.9A^{AB}$
	NH_4^--N		1.9	3.9	2.3	6.1	3.8	2.9	2.7	2.8	2.0	2.7	2.1	3.1	3.0^{F}
	Min-N		10.8	14.9	15.8	17.6	15.8	16.4	13.7	14.8	9.0	12.4	13.2	13.3	14.0^{R}
Mean	NO_3^--N		7.5^{A}	10.1^{A}	11.2^{A}	11.3^{A}	10.4^{A}	10.5^{A}	10.7^{A}	9.0^{A}	8.2^{A}	11.4^{A}	10.0^{A}	9.5^{A}	
	NH_4^--N		1.6^{F}	3.1^{F}	2.0^{F}	3.9^{F}	2.8^{F}	2.5^{F}	2.3^{F}	2.5^{F}	2.8^{F}	2.4^{F}	2.7^{F}	2.6^{F}	
	Min-N		9.1^{R}	13.2^{R}	13.1^{R}	15.1^{R}	13.2^{R}	13.0^{R}	12.9^{R}	11.5^{R}	11.0^{R}	13.7^{R}	12.8^{R}	12.1^{R}	
Tukey $HSD^{0.05}$	NO_3^--N		Trt = ns (P=0.32); Depth = 2.3 (P<0.01); Trt x Depth = ns (P=0.43)												
	NH_4^--N		Trt = ns (P=0.32); Depth = 0.9(P<0.001); Trt x Depth = ns (P=0.92)												
	Min-N		Trt = ns (P=0.29); Depth = 2.4 (P<0.001); Trt x Depth = ns (P=0.52)												

[1]DMPP-coated urea; [2]Poly-coated urea; [3]N fertiliser uptake <0% were shown as blank.

[A,B,C] Mean NO_3^--N values accompanied by the same letter in a group are "not significantly" different

[F,G,H] Mean NH_4^+-N values accompanied by the same letter in a group are "not significantly" different

[R,S,T] Mean Min-N values accompanied by the same letter in a group are "not significantly" different

Table 6-60– Effect of N fertiliser formulations or split rates of soil NO_3^--N, NH_4^+-N, and min N content of soil to depth in plant crop: Trial Bdb TN (24 Feb 2016).

Depth (cm)	Soil N	Application method	Treatment												Mean
			12	2	1	6	8	10	4	3	11	7	5	9	
			Control	Urea	Urea	Urea	DMPP-urea	PC-urea	Urea	Urea	Urea	Urea	DMPP-urea	PC-urea	
			Applications (kg/ha)												
		Initial as DAP	40	40	40	40	40	40	40	40	40	40	40	40	
		1st side-dress	0	40	40	80	80	80	80	80	40	120	120	120	
		2nd side-dress	0	20	40	0	0	0	40	20	40	0	0	0	
		3rd side-dress	0	20	0	0	0	0	0	20	40	0	0	0	
0–20	NO_3^--N	(mg/kg)	3.5	7.1	2.2	2.8	3.2	3.1	2.4	5.4	12.2	4.7	2.6	5.2	4.5^{B}
	NH_4^--N		2.9	5.1	2.3	2.7	3.2	2.7	2.8	3.6	4.6	2.7	3.2	4.3	3.3^{F}
	Min-N		6.3	12.2	4.5	5.5	6.4	5.8	5.1	9.0	16.7	7.3	5.8	9.5	7.8^{S}
20-40	NO_3^--N		2.0	0.9	1.7	1.4	0.7	2.2	1.6	1.6	3.0	3.0	1.4	2.5	1.8^{B}
	NH_4^--N		2.4	2.1	2.0	2.4	2.5	2.0	2.2	2.5	2.9	2.3	2.4	2.1	2.3^{G}
	Min-N		4.4	3.0	3.7	3.7	3.2	4.2	3.8	4.1	5.9	5.2	3.8	4.6	4.1^{T}
40–60	NO_3^--N		2.8	4.0	7.0	1.2	1.0	1.8	4.0	4.9	4.1	4.7	5.9	6.0	3.9^{B}
	NH_4^--N		1.7	1.6	1.4	1.2	1.6	1.3	1.3	1.1	1.6	1.3	1.5	1.4	1.4^{H}
	Min-N		4.4	5.5	8.4	2.4	2.6	3.0	5.3	5.9	5.7	6.0	7.4	7.4	5.3^{ST}
60–80	NO_3^--N		11.6	10.1	23.0	7.3	6.8	5.9	12.2	9.9	8.7	17.0	17.2	15.1	12.0^{A}
	NH_4^--N		1.1	1.5	1.4	1.2	1.3	1.0	1.3	1.3	1.2	1.0	1.4	1.3	1.2^{H}
	Min-N		12.7	11.6	24.4	8.5	8.1	6.9	13.5	11.2	9.8	18.0	18.6	16.4	13.3^{R}
Mean	NO_3^--N		5.0^{A}	5.5^{A}	8.5^{A}	3.2^{A}	2.9^{A}	3.2^{A}	5.0^{A}	5.4^{A}	7.0^{A}	7.3^{A}	6.8^{A}	7.2^{A}	
	NH_4^--N		2.0^{FG}	2.6^{F}	1.8^{G}	1.9^{G}	2.1^{FG}	1.7^{G}	1.9^{G}	2.1^{FG}	2.5^{F}	1.8^{G}	2.1^{FG}	2.3^{FG}	
	Min-N		7.0^{R}	8.1^{R}	10.2^{R}	5.0^{R}	5.0^{R}	5.0^{R}	6.9^{R}	7.5^{R}	9.5^{R}	9.1^{R}	8.9^{R}	9.5^{R}	
Tukey $HSD^{0.05}$	NO_3^--N		Trt = ns (P=0.52); Depth = 3.0 (P<0.001); Trt x Depth = ns (P=0.36)												
	NH_4^--N		Trt = 0.4 (P<0.01); Depth = 0.6 (P<0.001); Trt x Depth = ns (P=0.16)												
	Min-N		Trt = ns (P=0.52); Depth = 3.0 (P<0.001); Trt x Depth = ns (P=0.19)												

[1]DMPP-coated urea; [2]Poly-coated urea; [3]N fertiliser uptake <0% were shown as blank.

[A,B,C] Mean NO_3^--N values accompanied by the same letter in a group are "not significantly" different

[F,G,H] Mean NH_4^+-N values accompanied by the same letter in a group are "not significantly" different

[R,S,T] Mean Min-N values accompanied by the same letter in a group are "not significantly" different

Table 6-61 Effect of N fertiliser formulations or split rates of soil NO_3^--N, NH_4^+-N, and min N content of soil to depth in plant crop: Trial Bdb TN (5 May 2016).

Depth (cm)	Soil N	Application method	Treatment												Mean
			12	2	1	6	8	10	4	3	11	7	5	9	
			Control	Urea	Urea	Urea	DMPP-urea	PC-urea	Urea	Urea	Urea	Urea	DMPP-urea	PC-urea	
			Applications (kg/ha)												
		Initial as DAP	40	40	40	40	40	40	40	40	40	40	40	40	
		1st side-dress	0	40	40	80	80	80	80	80	40	120	120	120	
		2nd side-dress	0	20	40	0	0	0	40	20	40	0	0	0	
		3rd side-dress	0	20	0	0	0	0	0	20	40	0	0	0	
0–20	NO_3^--N	(mg/kg)	3.3	3.6	2.7	2.6	2.4	2.0	3.0	2.3	8.6	3.8	2.2	3.2	3.3^{B}
	NH_4^--N		2.3	3.9	2.0	2.9	2.1	2.7	2.3	2.5	2.3	1.7	2.3	1.9	2.4^{F}
	Min-N		5.6	7.5	4.7	5.5	4.5	4.6	5.2	4.7	10.9	5.4	4.5	5.1	5.7^{S}
20-40	NO_3^--N		1.6	1.8	1.5	1.2	1.0	1.6	2.2	1.0	2.5	2.5	1.8	2.8	1.8^{B}
	NH_4^--N		1.9	1.5	1.3	1.7	1.3	2.0	1.7	1.4	2.0	1.0	2.0	2.2	1.6^{G}
	Min-N		3.4	3.2	2.8	2.8	2.2	3.6	3.9	2.4	4.4	3.5	3.8	5.0	3.4^{ST}
40–60	NO_3^--N		1.2	5.4	4.9	2.1	1.3	2.1	4.0	2.1	3.0	8.1	5.3	5.1	3.7^{B}
	NH_4^--N		1.2	1.8	1.0	1.1	0.9	1.8	1.0	1.1	0.8	0.9	1.2	1.3	1.1^{H}
	Min-N		2.4	7.1	5.9	3.1	2	3.8	5.0	3.2	3.8	9.0	6.5	6.4	4.8^{R}
60–80	NO_3^--N		5.5	10.1	12.0	4.8	5.26	3.1	11.0	5.7	7.0	15.2	8.7	11.2	8.3^{A}
	NH_4^--N		1.0	0.8	0.9	1.1	0.9	1.3	1.2	1.1	0.6	1.0	1.2	1.7	1.0^{H}
	Min-N		6.5	10.9	12.9	5.8	6.5	4.3	12.2	6.8	7.5	16.2	9.8	12.9	9.3^{T}
Mean	NO_3^--N		2.9^{A}	5.2^{A}	5.2^{A}	2.6^{A}	2.6^{A}	2.2^{A}	5.0^{A}	2.8^{A}	5.2^{A}	7.4^{A}	4.5^{A}	5.6^{A}	
	NH_4^--N		1.6^{F}	2.0^{F}	1.3^{F}	1.7^{F}	1.3^{F}	1.9^{F}	1.5^{F}	1.5^{F}	1.4^{F}	1.1^{F}	1.7^{F}	1.7^{F}	
	Min-N		4.5^{R}	7.2^{R}	6.5^{R}	4.3^{R}	3.8^{R}	4.1^{R}	6.6^{R}	4.2^{R}	6.6^{R}	8.5^{R}	6.1^{R}	7.3^{R}	
Tukey $HSD^{0.05}$	NO_3^--N		Trt = ns (P=0.66); Depth = 2.2 (P<0.001); Trt x Depth = ns (P=0.64)												
	NH_4^--N		Trt = ns (P=0.27); Depth = 0.3 (P<0.001); Trt x Depth = ns (P=0.18)												
	Min-N		Trt = ns (P=0.75); Depth = 2.2 (P<0.001); Trt x Depth = ns (P=0.47)												

[1]DMPP-coated urea; [2]Poly-coated urea; [3]N fertiliser uptake <0% were shown as blank.

^{A,B,C} Mean NO_3^--N values accompanied by the same letter in a group are “not significantly” different

^{F,G,H} Mean NH_4^+-N values accompanied by the same letter in a group are “not significantly” different

^{R,S,T} Mean Min-N values accompanied by the same letter in a group are “not significantly” different

Table 6-62 Effect of N fertiliser formulations or split rates of mineral-N content of soil with date of sampling: plant crop in Trial Bdb TN.

		Treatment												
Application method		12	2	1	6	8	10	4	3	11	7	5	9	Mean
		Control	Urea	Urea	Urea	[1]DMPP-urea	[2]PC-urea	Urea	Urea	Urea	Urea	[1]DMPP-urea	[2]PC-urea	
		Applications (kg/ha)												
Initial as DAP		40	40	40	40	40	40	40	40	40	40	40	40	
1st side-dress		0	40	40	80	80	80	80	80	40	120	120	120	
2nd side-dress		0	20	40	0	0	0	40	20	40	0	0	0	
3rd side-dress		0	20	0	0	0	0	0	20	40	0	0	0	
		Mineral N (mg/kg)												
Sampling Date	17 Dec 2015	9.1	13.2	13.1	15.1	13.2	13.0	12.9	11.5	11.0	13.7	12.8	12.1	12.6^{A}
	24 Feb 2016	7.0	8.1	10.2	5.0	5.0	5.0	6.9	7.5	9.5	9.1	8.9	9.5	7.6^{B}
	5 May 2016	4.5	7.2	6.5	4.3	3.8	4.1	6.6	4.2	6.6	8.5	6.1	7.3	5.8^{C}
	14 Jun 2016	3.8	4.9	5.0	4.7	4.7	4.1	8.4	5.0	4.6	10.9	5.5	8.1	5.8^{C}
	28 Sep 2016	4.0	5.1	6.7	3.3	3.2	4.3	5.4	4.1	3.7	6.5	5.0	5.7	4.7^{C}
	Mean	5.7^{A}	7.7^{A}	8.3^{A}	6.5^{A}	6.0^{A}	6.1^{A}	8.0^{A}	6.5^{A}	7.1^{A}	9.7^{A}	7.6^{A}	8.5^{A}	
Tukey $HSD^{0.05}$		Treatment = ns (P=0.56); Date = (P<0.001); Treatment x Date = ns (P=0.10)												

Table 6-63 Effect of N fertiliser formulations or split rates of soil NO_3^--N, NH_4^+-N, and min N content of soil to depth in the 1R crop: Trial Bdb TN (22 Nov 2016).

Depth (cm)	Soil N	Application method	Treatment												Mean
			12	2	1	6	8	10	4	3	11	7	5	9	
			Control	Urea	Urea	Urea	DMPP-urea	PC-urea	Urea	Urea	Urea	Urea	DMPP-urea	PC-urea	
			Application (kg/ha)												
		1st side-dress	0	40	40	40	40	40	40	40	40	40	40	40	
		2nd side-dress	0	40	40	80	80	80	80	80	40	120	120	120	
		3rd side-dress	0	20	40	0	0	0	40	20	40	0	0	0	
		4th side-dress	0	20	0	0	0	0	0	20	40	0	0	0	
0–20	NO_3^--N	(mg/kg)	5.0	5.0	5.1	3.9	4.5	4.8	4.9	4.0	5.2	5.1	4.9	5.1	4.8^{A}
	NH_4^--N		3.4	2.8	2.6	2.7	2.8	2.7	4.4	4.1	3.0	4.3	4.5	3.5	3.4^{F}
	Min-N		8.3	7.8	7.7	6.6	7.3	7.4	9.2	8.1	8.2	9.4	9.4	8.5	8.1^{R}
20-40	NO_3^--N		2.6	2.7	3.9	1.7	2.3	1.9	3.0	1.4	2.3	2.9	3.2	2.5	2.5^{B}
	NH_4^--N		1.7	1.5	3.0	1.5	1.3	1.2	2.1	0.9	1.8	2.0	2.0	1.5	1.7^{G}
	Min-N		4.2	4.2	6.9	3.2	3.6	3.1	5.1	2.3	4.1	4.9	5.2	4.0	4.2^{T}
40–60	NO_3^--N		1.6	1.9	2.7	1.3	1.2	1.9	3.3	1.3	2.4	3.5	4.5	2.3	2.3^{B}
	NH_4^--N		1.4	1.6	1.5	1.5	1.5	1.5	1.7	1.2	1.2	1.5	1.4	2.5	1.5^{G}
	Min-N		3.0	3.5	4.2	2.7	2.7	3.3	5.0	2.5	3.6	5.0	5.9	4.8	3.8^{T}
60–80	NO_3^--N		1.2	5.1	7.2	2.6	2.7	3.3	7.0	1.9	5.8	9.8	8.7	5.0	5.0^{A}
	NH_4^--N		1.2	1.3	1.5	1.5	1.5	1.6	1.5	1.6	1.5	1.4	1.3	1.3	1.4^{G}
	Min-N		2.4	6.3	8.6	4.1	4.1	4.9	8.5	3.5	7.3	11.2	10.0	6.3	6.4^{S}
Mean	NO_3^--N		2.6^{A}	3.7^{A}	4.7^{A}	2.4^{A}	2.6^{A}	2.9^{A}	4.5^{A}	2.1^{A}	3.9^{A}	5.3^{A}	5.3^{A}	3.7^{A}	
	NH_4^-—N		1.9^{F}	1.8^{F}	2.1^{F}	1.8^{F}	1.8^{F}	1.7^{F}	2.4^{F}	1.9^{F}	1.9^{F}	2.3^{F}	2.3^{F}	2.2^{F}	
	Min-N		4.5^{R}	5.4^{R}	6.8^{R}	4.1^{R}	4.4^{R}	4.7^{R}	6.9^{R}	4.1^{R}	5.8^{R}	7.6^{R}	7.6^{R}	5.9^{R}	
Tukey $HSD^{0.05}$	NO_3^--N		Treatment = ns (P=O.275); Depth = 1.5 (P<0.001); Trt x Depth = ns (P=0.825)												
	NH_4^--N		Treatment = ns (P=0.298); Depth = 0.5 (P<0.001); Trt x Depth = ns (P= 0.159)												
	Min-N		Treatment = ns (P=0.125); Depth = 1.7 (P<0.001); Trt x Depth = ns (P=0.957)												

[1]DMPP-coated urea; [2]Poly-coated urea; [3]N fertiliser uptake <0% were shown as blank.

[A,B,C] Mean NO_3^--N values accompanied by the same letter in a group are "not significantly" different

[F,G,H] Mean NH_4^+-N values accompanied by the same letter in a group are "not significantly" different

[R,S,T] Mean Min-N values accompanied by the same letter in a group are "not significantly" different

Table 6-64 Effect of N fertiliser formulations or split rates of soil NO_3^--N, NH_4^+-N, and min N content of soil to depth in the 1R crop: Trial Bdb TN (20 Jan 2017).

Depth (cm)	Soil N	Application method	Treatment												Mean
			12	2	1	6	8	10	4	3	11	7	5	9	
			Control	Urea	Urea	Urea	DMPP-urea	PC-urea	Urea	Urea	Urea	Urea	DMPP-urea	PC-urea	
			Application (kg/ha)												
		1st side-dress	0	40	40	40	40	40	40	40	40	40	40	40	
		2nd side-dress	0	40	40	80	80	80	80	80	40	120	120	120	
		3rd side-dress	0	20	40	0	0	0	40	20	40	0	0	0	
		4th side-dress	0	20	0	0	0	0	0	20	40	0	0	0	
0–20	NO_3^--N	(mg/kg)	3.0	10.5	6.7	9.6	7.3	3.8	10.5	10.5	8.0	9.4	7.1	3.9	7.5[A]
	NH_4^-N		2.8	2.3	3.2	3.6	2.3	3.0	3.5	3.3	3.2	2.5	2.5	2.2	2.8[F]
	Min-N		5.7	12.8	9.9	13.2	9.6	6.8	14.0	13.7	11.2	11.9	9.5	6.1	10.3[R]
20-40	NO_3^-N		3.4	4.6	5.2	9.6	5.0	4.0	5.6	7.7	8.0	7.0	9.0	3.3	6.0[AB]
	NH_4^-N		2.6	1.8	2.6	2.1	1.4	1.9	2.5	2.7	3.5	1.5	2.4	1.4	2.2[G]
	Min-N		5.9	6.4	7.8	11.7	6.4	5.9	8.1	10.4	11.5	8.4	11.4	4.7	8.2[S]
40–60	NO_3^-N		2.3	2.9	4.7	9.0	4.1	3.5	4.4	5.2	3.5	5.2	5.0	3.4	4.4[B]
	NH_4^-N		1.3	1.5	1.6	1.3	0.8	0.9	1.7	1.8	1.5	0.9	1.4	1.3	1.3[H]
	Min-N		3.5	4.4	6.3	10.2	4.9	4.4	6.0	6.9	5.0	6.1	6.3	4.7	5.7[T]
60–80	NO_3^-N		1.9	10.3	6.5	4.5	3.6	4.4	5.6	5.1	4.6	7.1	6.9	10.0	5.8[AB]
	NH_4^-N		1.2	1.2	0.9	1.1	0.9	1.0	1.2	1.5	1.1	0.7	1.2	0.8	1.0[H]
	Min-N		3.1	11.5	7.4	5.6	4.4	5.3	6.8	6.6	5.7	7.8	8.0	10.8	6.9[ST]
Mean	NO_3^-N		2.6	7.1	5.8	8.2	5.0	3.9	6.5	7.1	6.0	7.1	7.0	5.1	
	NH_4^-N		1.9	1.7	2.1	2.0	1.3	1.7	2.2	2.3	2.3	1.4	1.8	1.4	
	Min-N		4.5	8.7	7.8	10.1	6.3	5.6	8.7	9.4	8.3	8.5	8.8	6.6	
Tukey $HSD^{0.05}$	NO_3^--N		Treatment = ns (P=0.687); Depth = 1.8 (P<0.001); Trt x Depth = ns (P=0.193)												
	NH_4^--N		Treatment = ns (P=0.647); Depth = 0.4 (P<0.001); Trt x Depth = ns (P=0.861)												
	Min-N		Treatment = ns (P=0.692); Depth = 1.9 (P<0.001); Trt x Depth = ns (P=0.149)												

[1]DMPP-coated urea; [2]Poly-coated urea; [3]N fertiliser uptake <0% were shown as blank.

[A,B,C] Mean NO_3^--N values accompanied by the same letter in a group are "not significantly" different

[F,G,H] Mean NH_4^+-N values accompanied by the same letter in a group are "not significantly" different

[R,S,T] Mean Min-N values accompanied by the same letter in a group are "not significantly" different

Table 6-65 Effect of N fertiliser formulations or split rates of soil NO_3^--N, NH_4^+-N, and min N content of soil to depth in the 1R crop: Trial Bdb TN (19 Apr 2017).

Depth (cm)	Soil N	Application method	Treatment												Mean
			12	2	1	6	8	10	4	3	11	7	5	9	
			Control	Urea	Urea	Urea	DMPP-urea	PC-urea	Urea	Urea	Urea	Urea	DMPP-urea	PC-urea	
			Application (kg/ha)												
		1st side-dress	0	40	40	40	40	40	40	40	40	40	40	40	
		2nd side-dress	0	40	40	80	80	80	80	80	40	120	120	120	
		3rd side-dress	0	20	40	0	0	0	40	20	40	0	0	0	
		4th side-dress	0	20	0	0	0	0	0	20	40	0	0	0	
0–20	NO_3^--N	(mg/kg)	4.5	4.7	4.2	3.1	2.9	5.7	4.0	3.8	3.4	4.3	4.1	4.9	4.1^{A}
	NH_4^-N		4.1	2.1	2.2	4.0	2.3	3.0	3.0	2.7	3.0	2.6	2.5	3.1	2.9^{F}
	Min-N		8.6	6.8	6.4	7.1	5.2	8.7	6.9	6.5	6.4	6.9	6.6	8.0	7.0^{R}
20-40	NO_3^-N		2.2	2.9	4.6	1.2	1.6	2.8	3.5	2.1	1.7	2.5	1.7	2.8	2.4^{B}
	NH_4^-N		1.5	1.2	1.8	2.0	2.0	1.9	1.6	1.7	1.3	1.7	2.1	2.0	1.7^{G}
	Min-N		3.6	4.0	6.4	3.2	3.6	4.7	5.0	3.7	3.0	4.2	3.8	4.8	4.1^{S}
40–60	NO_3^-N		1.0	5.5	10.4	0.9	1.1	1.7	2.7	1.1	1.3	3.9	2.1	2.2	2.8^{B}
	NH_4^-N		1.1	1.2	1.3	1.5	1.2	1.3	1.1	1.2	0.9	1.5	1.0	1.1	1.2^{H}
	Min-N		2.0	6.6	11.7	2.3	2.3	3.0	3.8	2.3	2.1	5.4	3.0	3.3	4.0^{S}
60–80	NO_3^-N		0.8	6.5	12.2	2.0	2.7	2.2	2.9	2.6	1.6	8.8	5.2	3.1	4.2^{A}
	NH_4^-N		0.9	0.9	1.1	1.2	1.1	1.0	0.9	0.8	0.8	1.1	0.9	1.0	1.0^{H}
	Min-N		1.7	7.4	13.3	3.2	3.8	3.2	3.7	3.4	2.4	9.9	6.1	4.1	5.2^{S}
Mean	NO_3^-N		2.1^{A}	4.9^{A}	7.9^{A}	1.8^{A}	2.1^{A}	3.1^{A}	3.2^{A}	2.4^{A}	2.0^{A}	4.9^{A}	3.3^{A}	3.2^{A}	
	NH_4^-N		1.9^{F}	1.3^{F}	1.6^{F}	2.2^{F}	1.6^{F}	1.8^{F}	1.6^{F}	1.6^{F}	1.5^{F}	1.7^{F}	1.6^{F}	1.8^{F}	
	Min-N		4.0^{R}	6.2^{R}	9.4^{R}	3.9^{R}	3.7^{R}	4.9^{R}	4.8^{R}	4.0^{R}	3.5^{R}	6.6^{R}	4.8^{R}	5.0^{R}	
Tukey $HSD^{0.05}$	NO_3^--N		Treatment = ns (P=0.302); Depth = 1.3 (P<0.001); Trt x Depth = 7.4 same level of Treatment; = 12.6 different levels of Treatment (P<0.05)												
	NH_4^--N		Treatment = ns (P=0.805); Depth = 0.3 (P<0.001); Trt x Depth = ns (P=0.09)												
	Min-N		Treatment = ns (P=0.425); Depth = 1.4 (P<0.001); Trt x Depth = 7.6 same level of Treatment (P<0.01)												

[1]DMPP-coated urea; [2]Poly-coated urea; [3]N fertiliser uptake <0% were shown as blank.

[A,B,C] Mean NO_3^--N values accompanied by the same letter in a group are "not significantly" different

[F,G,H] Mean NH_4^+-N values accompanied by the same letter in a group are "not significantly" different

[R,S,T] Mean Min-N values accompanied by the same letter in a group are "not significantly" different

Table 6-66 – Effect of N fertiliser formulations or split rates of mineral-N content of soil with date of sampling: 1R crop in Trial Bdb TN.

Application method		Treatment												
		12	2	1	6	8	10	4	3	11	7	5	9	Mean
		Control	Urea	Urea	Urea	[1]DMPP-urea	[2]PC-urea	Urea	Urea	Urea	Urea	[1]DMPP-urea	[2]PC-urea	
		Applications (kg/ha)												
1st side-dress		0	40	40	40	40	40	40	40	40	40	40	40	
2nd side-dress		0	40	40	80	80	80	80	80	40	120	120	120	
3rd side-dress		0	20	40	0	0	0	40	20	40	0	0	0	
4th side-dress		0	20	0	0	0	0	0	20	40	0	0	0	
		Mineral N (mg/kg)												
Sampling Date	22 Nov 2016	4.5	5.4	6.8	4.1	4.4	4.7	6.9	4.1	5.8	7.6	7.6	5.9	5.6A
	20 Jan 2017	4.5	8.7	7.8	10.1	6.3	5.6	8.7	9.4	8.3	8.5	8.8	6.6	7.8^{B}
	19 Apr 2017	4.0	6.2	9.4	3.9	3.7	4.9	4.8	4.0	3.5	6.6	4.8	5.0	5.1^{A}
	Mean	4.3	6.8	8.0	6.1	4.8	5.0	6.8	5.8	5.8	7.6	7.1	5.8	
Tukey HSD$^{0.05}$		Treatment = ns (P=0.56); Date = (P<0.001); Treatment x Date = ns (P=0.10)												

[1]DMPP-coated urea; [2]Poly-coated urea; [3]N fertiliser uptake <0% were shown as blank.

^{A,B} Mean NO_3^--N values accompanied by the same letter in a group are "not significantly" different

Table 6-67 Effect of N fertiliser formulations or split rates of urea on sugarcane third leaf N (%DM) values: Plant crop Bdb TN

Treatment	Fertiliser formulation	N applications (kg N/ha)				Total N applied (kg N/ha)	Third leaf N (%DM)
		Initial as DAP	Side-dressings				
			1st	2nd	3rd		
12	Control	40	0	0	0	40	2.02^{A}
2	Urea	40	40	20	20	120	2.10^{A}
1	Urea	40	40	40	0	120	2.08^{A}
6	Urea	40	80	0	0	120	1.96^{A}
8	DMPP-urea[1]	40	80	0	0	120	2.03^{A}
10	PC-urea[2]	40	80	0	0	120	2.11^{A}
4	Urea	40	80	40	0	160	2.10^{A}
3	Urea	40	80	20	20	160	2.02^{A}
11	Urea	40	40	40	40	160	2.00^{A}
7	Urea	40	120	0	0	160	2.03^{A}
5	DMPP- urea[1]	40	120	0	0	160	2.15^{A}
9	PC-urea[2]	40	120	0	0	160	2.11^{A}
Mean							2.06
SE							0.05
P							0.412
Tukey's HSD$^{0.05}$							Ns

[1]DMPP-coated urea; [2]Poly-coated urea

^{A,B,C} Mean values accompanied by the same letter in a group are "not significantly" different

Table 6-68 Effect of N fertiliser formulations or split rates of urea on sugarcane third leaf N (%DM) values: First ratoon Bdb TN

Treatment	Fertiliser formulation	Side-dressing N applications (kg N/ha)				Total N applied (kg N/ha)	Third leaf N (%DM)
		1st	2nd	3rd	4th		
12	Control	40	0	0	0	40	1.75A
2	Urea	40	40	20	20	120	1.81A
1	Urea	40	40	40	0	120	1.84A
6	Urea	40	80	0	0	120	1.80A
8	DMPP-urea[1]	40	80	0	0	120	1.83A
10	PC-urea[2]	40	80	0	0	120	1.74A
4	Urea	40	80	40	0	160	1.87A
3	Urea	40	80	20	20	160	1.81A
11	Urea	40	40	40	40	160	1.86A
7	Urea	40	120	0	0	160	1.79A
5	DMPP- urea[1]	40	120	0	0	160	1.83A
9	PC-urea[2]	40	120	0	0	160	1.86A
Mean							1.81
SE							0.04
P							0.380
Tukey's HSD$^{0.05}$							ns

[1]DMPP-coated urea; [2]Poly-coated urea

A,B,C Mean values accompanied by the same letter in a group are "not significantly" different

6.2.5.4. Biomass, N uptake, yield and NUE indicators

Dry biomass at harvest (t/ha), total N uptake (kg N/ha) based on the N content of the dry biomass, yield (tc/ha) and NUE indicators [NUE (tc/kg N applied), NUtE (tc/kg crop N) and NUpEfert (additional kg N uptake/kg N fertiliser applied expressed on a percentage basis)] for the plant and 1R crops are shown in Tables 6-69 and 6-70 respectively.

In the plant crop, N treatments did not result in significant differences in dry biomass (t/ha) nor sugarcane yield (tc/ha) (Table 6-69). Although the N uptake associated with most of the N treatments was not significantly different from the control (40 kg N applied within the initial DAP applied) nor from each other, there were some exceptions. The N uptake associated with Treatment 1 (urea applied in 3 equal splits of 40 kg N/ha) was significantly lower than Treatment 9 (initial 40 kg N/ha in DAP and 120 kg N/ha applied as PC-urea).

In the 1R crop, there were also no differences in dry biomass (t/ha) nor sugarcane yields resulting from the different N treatments (Table 6-70). In contrast to the plant crop, differences in total N uptake (kg N/ha) were more apparent. In particular, N uptake associated with 120 kg N/ha applied as DMPP-urea (Treatment 8), urea applied as 40, 80, 40 kg N /ha split applications (Treatment 4), urea applied as 40, 40, 40, 40 kg N/ha split applications (Treatment 11), 160 kg N/ha applied as DMPP-urea (Treatment 5), and 160 kg N/ha applied as PC-coated urea (Treatment 9) were significantly higher than that of the control (Treatment 12). However, these treatments were not significantly different from each other or the rest of the N treatments. The NUtE value associated with the control (Treatment 12) was the highest (0.88 tc/kg crop N) of all the values and significantly better than that of Treatment 8 (120 kg N applied as DMPP-coated urea), urea applied as 40, 80, 40 kg N/ha split applications (Treatment 4), urea applied as 40, 40, 40, 40 kg N/ha split applications (Treatment 11), 160 kg N /ha as DMPP-coated urea (Treatment 5), and 160 kg N/ha as PC-coated urea (Treatment 9). This trend was also reflected in the $NUpEff_{fert}$ with values > 30 % in these treatments compared to values < 30% in the other treatments.

6.2.5.5. Yield, CCS and economic indicators

There were no significant differences in sugarcane yields (tc/ha), CCS values or sugar yields (ts/ha) in either the plant crop (Table 6-71) or the 1R crop (Table 6-72) due to the N treatments. The values, were however, were somewhat lower in the plant crop compared with the 1R crop.

Mean yields and mean CCS values were used to calculate partial net returns ($/ha) for the different N treatments for the plant and 1R crops in Tables 6-73 and 6-74 respectively. This was due to the absence of significant differences in these values in both the plant and 1R crops (Tables 6-69 and 6-70 respectively). The assumptions used in calculating the partial net returns are provided below each table. General NUE values (tc/kg N applied were calculated from the mean sugarcane yields and N input rates.

In both crops, the NUE values were lower for the 120 kg N/ha applications [0.66 tc/kg N applied for the plant crop and 0.69 tc/kg N applied (Table 6-73)] than for the 160 kg N/ha applications [0.5 tc/kg N applied for the plant crop and 0.52 tc/kg N applied for the 1R crop (table 6-74)]. For each crop, the partial net returns were ranked from best to worst (Tables 6-73 and 6-74). The highest partial net returns ($2,249/ha and $3,135/ha) corresponded to the control treatment (Treatment 12) in the plant and 1R crops respectively. Urea applied as a single side dressing (80 kg N/ha after the initial 40 kg N/ha as DAP) resulted in the next best partial net return ($2,145/ha) in the plant crop. In the 1R crop, urea applied in a single top-dressing of 120 kg N/ha resulted in the next best net partial return ($2,979/ha). DMPP-coated urea applied at 80 kg N/ha after the initial 40 kg N/ha applied at DAP in the plant crop was ranked 3rd in both the plant and 1R crops ($2,117 and $2,937 respectively). Urea applied at higher rates or split applications resulted in lower partial net returns than the top three treatments in both crops. The lowest partial net returns in both crops were associated with the 160 kg N/ha applied at PC-coated urea (Treatment 9).

Table 6-69 Effect of N fertiliser formulations or split rates of urea on sugarcane plant crop biomass (t/ha), total N uptake and NUE indicators: Trial Bdb TN

Treatment	Fertiliser formulation	N applied (kg N/ha)				Total N applied (kg N/ha)	At harvest					
		Initial as DAP	Side-dressings									
			1st	2nd	3rd		Dry biomass (t/ha)	Total N uptake (kg N/ha)	NUE (tc/kg N applied)	Yield (tc/ha)	NUtE (tc/kg crop N)	N fert uptake[3] (%)
12	Control	40	0	0	0	40	30.5^{A}	82.4^{AB}	2.02^{A}	75.7^{A}	0.98^{A}	Na
2	Urea	40	40	20	20	120	27.7^{A}	84.5^{AB}	0.66^{B}	74.4^{A}	0.94^{A}	-
1	Urea	40	40	40	0	120	27.8^{A}	74.8^{B}	0.63^{B}	86.5^{A}	1.02^{A}	-
6	Urea	40	80	0	0	120	28.7^{A}	82.0^{AB}	0.66^{B}	82.2^{A}	0.98^{A}	-
8	DMPP-urea[1]	40	80	0	0	120	29.0^{A}	84.1^{AB}	0.67^{B}	82.1^{A}	0.97^{A}	1.2
10	PC-urea[2]	40	80	0	0	120	28.9^{A}	93.2^{AB}	0.63^{B}	86.2^{A}	0.82^{A}	10.7
4	Urea	40	80	40	0	160	28.8^{A}	84.4^{AB}	0.48^{B}	87.1^{A}	0.92^{A}	0.7
3	Urea	40	80	20	20	160	29.0^{A}	89.0^{AB}	0.48^{B}	86.7^{A}	0.87^{A}	7.4
11	Urea	40	40	40	40	160	31.2^{A}	103.0^{AB}	0.53^{B}	82.6^{A}	0.83^{A}	19.8
7	Urea	40	120	0	0	160	28.4^{A}	85.8^{AB}	0.48^{B}	80.3^{A}	0.91^{A}	2.1
5	DMPP- urea[1]	40	120	0	0	160	31.2^{A}	97.7^{AB}	0.51^{B}	84.2^{A}	0.83^{A}	14.9
9	PC-urea[2]	40	120	0	0	160	33.1^{A}	109.4^{A}	0.57^{B}	85.6^{A}	0.83^{A}	23.3
Mean							29.5	89.2	0.69	82.8	0.91	5.8
SE							1.9	6.3	0.06	4.7	0.31	7.0
P							0.68	0.02	0.00	0.64	0.06	
Tukey's HSD$^{0.05}$							Ns	31.4	0.31	Ns	Ns	

[1]DMPP-coated urea; [2]Poly-coated urea; [3]N fertiliser uptake <0% were shown as blank.

^{A,B,C} Mean values accompanied by the same letter in a group are "not significantly" different

Table 6-70 – Effect of N fertiliser formulations or split rates of urea on sugarcane 1R crop biomass, total N uptake and NUE indicators: Trial Bdb TN

Treatment	Fertiliser formulation	Side-dressing N applications (kg N/ha)				Total N applied (kg N/ha)	At harvest					
		1st	2nd	3rd	4th		Dry biomass (t/ha)	Total N uptake (kg N/ha)	NUE (tc/kg N applied)	Yield (tc/ha)	NUtE (tc/kg crop N)	N fert uptake (%)
12	Control	0	0	0	0	0	31.3^{A}	87.9^{B}	Na	75.7^{A}	0.88^{A}	na
2	Urea	40	40	20	20	120	29.8^{A}	111.1^{AB}	0.62^{ABC}	74.4^{A}	0.68^{AB}	19.3
1	Urea	40	40	40	0	120	34.6^{A}	115.9^{AB}	0.72^{A}	86.5^{A}	0.75^{AB}	23.1
6	Urea	40	80	0	0	120	33.4^{A}	112.6^{AB}	0.68^{AB}	82.2^{A}	0.73^{AB}	21.4
8	DMPP-urea[1]	40	80	0	0	120	33.5^{A}	131.3^{A}	0.69^{AB}	82.1^{A}	0.63^{B}	32.3
10	PC-urea[2]	40	80	0	0	120	34.7^{A}	123.3^{AB}	0.72^{A}	86.2^{A}	0.71^{AB}	28.3
4	Urea	40	80	40	0	160	34.9^{A}	133.7^{A}	0.54^{BC}	87.1^{A}	0.66^{B}	33.2
3	Urea	40	80	20	20	160	34.6^{A}	120.3^{AB}	0.54^{BC}	86.7^{A}	0.73^{AB}	25.3
11	Urea	40	40	40	40	160	32.8^{A}	127.4^{A}	0.52^{C}	82.6^{A}	0.65^{B}	30.9
7	Urea	40	120	0	0	160	32.3^{A}	117.5^{AB}	0.50^{C}	80.3^{A}	0.68^{AB}	24.0
5	DMPP- urea[1]	40	120	0	0	160	34.5^{A}	134.6^{A}	0.53^{C}	84.2^{A}	0.64^{B}	31.7
9	PC-urea[2]	40	120	0	0	160	33.4^{A}	130.9^{A}	0.54^{BC}	85.6^{A}	0.66^{B}	32.2
Mean							33.3	120.5	0.71	82.8	0.70	27.4
SE							1.7	7.5	0.05	4.72	0.04	4.4
P							0.613	0.006	0.0001	0.638	0.009	
Tukey's HSD$^{0.05}$							Ns	37.3	0.16	Ns	0.20	

[1]DMPP-coated urea; [2]Poly-coated urea

^{A,B,C} Mean values accompanied by the same letter in a group are "not significantly" different

Table 6-71 Effect of N fertiliser formulations or split rates of urea on sugarcane plant crop yields (tc/ha): Bdb TN

Treatment	Fertiliser formulation	N applications (kg N/ha)				Total N applied (kg N/ha)	Yield		
		Initial as DAP	Side-dressings						
			1st	2nd	3rd		tc/ha	CCS	ts/ha
12	Control	40	0	0	0	40	80.6A	15.7A	12.6A
2	Urea	40	40	20	20	120	79.7A	15.6A	12.5A
1	Urea	40	40	40	0	120	75.7A	15.3A	11.6A
6	Urea	40	80	0	0	120	78.9A	15.5A	12.3A
8	DMPP-urea[1]	120	0	0	0	120	80.1A	15.2A	12.2A
10	PC-urea[2]	120	0	0	0	120	75.7A	15.4A	11.7A
4	Urea	40	80	40	0	160	77.5A	15.1A	11.7A
3	Urea	40	80	20	20	160	77.3A	15.5A	12.0A
11	Urea	40	40	40	40	160	84.4A	15.9A	13.4A
7	Urea	160	0	0	0	160	77.2A	15.4A	11.9A
5	DMPP- urea[1]	160	0	0	0	160	80.8A	15.7A	12.7A
9	PC-urea[2]	160	0	0	0	160	90.5A	15.5A	14.0A
Mean							79.9	15.5	12.4
SE							5.5	0.2	0.9
P							0.79	0.31	0.74
Tukey's HSD$^{0.05}$							ns	ns	Ns

[1]DMPP-coated urea; [2]Poly-coated urea
A,B,C Mean values accompanied by the same letter in a group are "not significantly" different

Table 6-72 Effect of N fertiliser formulations or split rates of urea on sugarcane first ratoon yields (tc/ha): Bdb TN

Treatment	Fertiliser formulation	Side-dressing N applications (kg N/ha)				Total N applied (kg N/ha)	Yield		
		1st	2nd	3rd	4th		tc/ha	CCS	ts/ha
12	Control	0	0	0	0	40	75.7A	18.2A	13.8A
2	Urea	40	40	20	20	120	74.4A	18.2A	13.5A
1	Urea	40	40	40	0	120	86.5A	18.5A	16.0A
6	Urea	40	80	0	0	120	82.2A	18.3A	15.0A
8	DMPP-urea[1]	120	0	0	0	120	82.1A	18.2A	14.9A
10	PC-urea[2]	120	0	0	0	120	86.2A	18.3A	15.8A
4	Urea	40	80	40	0	160	87.1A	17.8A	15.5A
3	Urea	40	80	20	20	160	86.7A	17.9A	15.6A
11	Urea	40	40	40	40	160	82.6A	18.2A	15.0A
7	Urea	160	0	0	0	160	80.3A	18.5A	14.8A
5	DMPP- urea[1]	160	0	0	0	160	84.2A	18.2A	15.3A
9	PC-urea[2]	160	0	0	0	160	85.6A	18.0A	15.4A
Mean							82.8	18.2	15.1
SE							4.7	0.2	0.9
P							0.64	0.17	0.66
Tukey's HSD$^{0.05}$							ns	ns	ns

[1]DMPP-coated urea; [2]Poly-coated urea
A,B,C Mean values accompanied by the same letter in a group are "not significantly" different

Table 6-73 Mean yields, NUE and partial net returns for the sugarcane plant crop: Bdb TN

Treatment	Side-dressing fertiliser formulation	N applications (kg N/ha)			Fertiliser cost ($/kg N)		Mean yield [no significant difference (Table 6.71)]		NUE (tc/kg N applied)	Partial net return	
		Initial	Side-dressings	Total N applied	Initial	Split formulation	tc/ha	CCS		(s/ha)	Ranking
12	Control	40	0	40	1.30	1.30	79.7	15.5	2.0	2249	1
2	Urea	40	40	120	1.30	1.30	79.7	15.5	0.66	2065	6
1	Urea	40	40	120	1.30	1.30	79.7	15.5	0.66	2105	4
6	Urea	40	80	120	1.30	1.30	79.7	15.5	0.66	2145	2
8	DMPP-urea[1]	40	80	120	1.30	1.65	79.7	15.5	0.66	2117	3
10	PC-urea[2]	40	80	120	1.30	4.15	79.7	15.5	0.66	1917	11
4	Urea	40	80	160	1.30	1.30	79.7	15.5	0.50	2053	7
3	Urea	40	80	160	1.30	1.30	79.7	15.5	0.50	2013	9,10
11	Urea	40	40	160	1.30	1.30	79.7	15.5	0.50	2013	9,10
7	Urea	40	120	160	1.30	1.30	79.7	15.5	0.50	2093	5
5	DMPP- urea[1]	40	120	160	1.30	1.65	79.7	15.5	0.50	2051	8
9	PC-urea[2]	40	120	160	1.30	4.15	79.7	15.5	0.50	1715	12

Assumptions: Sugar price = $370/ts; harvesting and levies = $10/tc; fertiliser costs: urea = $1.30/kg N, DMPP-urea = $1.65/kg N and PC-urea = $4.15/kg N; additional cost of applying each split application = $40/ha.

Table 6-74 Mean yields, NUE and partial net returns for the 1R crop: Bdb TN

Treatment	Side-dressing fertiliser formulation	N applications (kg N/ha)			Fertiliser cost ($/kg N)		Mean yield [no significant difference (Table 6.71)]		NUE (tc/kg N applied)	Partial net return	
		Initial	Total side-dressings	Total N applied	Initial	Split formulation	tc/ha	CCS		($/ha)	Ranking
12	Control	0	0	40	1.30	1.30	82.8	18.2	n/a	3135	1
2	Urea	40	80	120	1.30	1.30	82.8	18.2	0.69	2859	7
1	Urea	40	80	120	1.30	1.30	82.8	18.2	0.69	2899	5
6	Urea	120	0	120	1.30	1.30	82.8	18.2	0.69	2979	2
8	DMPP-urea[1]	120	0	120	1.30	1.65	82.8	18.2	0.69	2937	3
10	PC-urea[2]	120	0	120	1.30	4.15	82.8	18.2	0.69	2637	11
4	Urea	40	120	160	1.30	1.30	82.8	18.2	0.52	2847	8
3	Urea	40	120	160	1.30	1.30	82.8	18.2	0.52	2807	9,10
11	Urea	40	120	160	1.30	1.30	82.8	18.2	0.52	2807	9,10
7	Urea	160	0	160	1.30	1.30	82.8	18.2	0.52	2927	4
5	DMPP- urea[1]	160	0	160	1.30	1.65	82.8	18.2	0.52	2871	6
9	PC-urea[2]	160	0	160	1.30	4.15	82.8	18.2	0.52	2471	12

Assumptions: Sugar price = $370/ts; harvesting and levies = $10/tc; fertiliser costs: urea = $1.30/kg N, DMPP-urea = $1.65/kg N and PC-urea = $4.15/kg N; additional cost of applying each split application = $40/ha.

6.2.5.6. Conclusions: Bdb TN

- Trial Bdb TN is the only current sugarcane trial in which standard urea inputs are compared to equivalent N rates using EEFs (DMPP-coated urea and poly-coated urea) and split applications of urea.

- The measured rainfall during the seasons Sep 2015 – Oct 2017 were not characterised by rainfall that would have caused excessively wet conditions at the trial site.
- Nitrogen application rates and N fertiliser formulation did not generally have a significant effect on soil mineral N values
- Differences in soil min-N was most apparent to depth with evidence of leaching down the soil profile. This appeared to occur across the N treatments (including the control).
- There were no significant yield (tc/ha, CCS and ts/ha) responses to applied N, split applications or use of EEFs. This was supported by no differences in third leaf N values.
- Nitrogen uptake values associated with the various N treatments (rates, split applications and use of EEFS) were generally not different from the control treatment (40 kg N/ha applied as DAP). The exception was poly-coated urea applied at 120 kg N/ha following an initial 40 kg N/ha application as DAP.
- Differences in N uptake were apparent with some of the N strategies. In particular, there was increased N-uptake with DMPP-coated applications, urea applied at the higher rates (160 kg N/ha) applied as multiple splits, and poly-coated urea applied at the higher rate (160 kg N/ha).
- Increased N-uptake by the crop, due to the choice of N strategies away from the standard practice, did not translate into any improvements in yield.
- Due to the lack of yield responses, NUE (tc/kg N applied) only reflected the difference in N rate (120 kg N/ha versus 160 kg N/ha).
- The highest partial net return in the plant and 1R crop corresponded to the control treatments. This was due to the lack of yield responses.
- Urea applied at the lower N rates in single applications results in the next best partial net returns in both crops. This appeared to be the most appropriate strategy to minimise risk to growers.
- The cost of EEF fertilisers negatively affected the partial net returns. DMPP-coated urea being more affordable than the poly-coated urea option.
- The strength of this assessment is that the N strategies were evaluated according to agronomic, economic and environmental criteria.

6.2.6. Herbert temporal N trial

6.2.6.1. Rainfall

The rainfall data and information provided for trials Mkd NxFS1 and Mkd NxFS2 in Section 6.2.3.1. for the Macknade Mill weather station is also applicable here.

6.2.6.2. Third leaf N

The third leaf N values (N%DM) for the plant and 1R crops are shown in Table 6-75. Significant responses to the rate of N applied occurred in both crops. In both seasons the values were above the established critical value (1.7%NDM for samples collected in Mar/Apr). Fertiliser formulation had no significant effect on the third leaf N values in the plant crop. However, in the 1R crop, the application of PC-urea resulted in increased third leaf N values compared with the use of urea. The interactive effect indicated that this was more apparent at the higher N application rates.

6.2.6.3. N uptake

Nitrogen uptake by the crop calculated from the final yields at harvest and the N content of the biomass (stalks, and leaves and tops) at 9 months after planting or harvest of the previous crop are shown in Table 6-76. There was no significant response to applied N or N fertiliser formulation in the plant crop. However, in the 1R crop the rate of N applied and N fertiliser formulation affected N uptake. Poly-coated urea resulted in increased N uptake compared with urea, especially at the higher rates of N applied. This reflected the significant responses that occurred in the third leaf N values (Table 6-75).

Table 6-75 Third leaf N concentration (%DM) as influenced by fertiliser formulation and N application rates for the plant and 1R crops: Hbt TN trial at Tara.

Crop	Fertiliser formulation	Third leaf N values ((%DM)					
		N applied (kg/ha)					Means for N applied
		0	60	120	160	200	
Plant	Urea	2.13	2.18	2.26	2.22	2.28	2.21^{A}
	DMPP-urea	2.12	2.18	2.20	2.34	2.45	2.26^{A}
	PC-urea	2.09	2.18	2.29	2.25	2.44	2.23^{A}
	Mean	2.11^{C}	2.18^{BC}	2.25^{ABC}	2.27^{AB}	2.35^{A}	
	Tukey $HSD^{0.05}$: Product = ns (P=0.44); N = 0.14 (P<0.0.01); Prod x N = ns (P=0.48)						
1R	Urea	1.78	1.90	1.90	1.89	1.94	1.88^{B}
	DMPP-urea	1.85	1.91	2.03	2.05	2.08	1.98^{AB}
	PC-urea	1.67	1.92	2.06	2.24	2.35	2.05^{A}
	Mean	1.76^{C}	1.91^{BC}	1.99^{AB}	2.06^{AB}	2.12^{A}	
	Tukey $HSD^{0.05}$: Product = 0.11(P<0.01);N = 0.16 (P<0.001); N x FS = 0.37 (P=0.05)						

[1]DMPP-coated urea; [2]Poly-coated urea

[A,B,C] Mean values accompanied by the same letter in a group are “not significantly” different

Table 6-76 N uptake of the plant and 1R crops calculated from the yield at harvest and the N content of the biomass (stalks, and leaves and tops) at 9 months after planting or harvest of the previous crop.

Crop	Fertiliser formulation	N-uptake (kg N/ha)					
		N applied (kg/ha)					Means for N applied
		0	60	120	160	200	
Plant	Urea	75.7	70.7	85.5	81.9	73.8	77.5^{A}
	DMPP-urea	75.3	67.3	83.6	78.6	87.6	78.5^{A}
	PC-urea	54.3	66.6	88.0	68.2	98.2	75.1^{A}
	Mean	68.4^{A}	68.2^{A}	86.7^{A}	76.2^{A}	86.5^{A}	
	Tukey $HSD^{0.05}$: Product = ns (P=0.92); N = ns (P= 0.30); Prod x N = ns (P=0.85)						
1R	Urea	32.0	39.0	52.7	63.1	49.4	47.2^{B}
	DMPP-urea	43.8	46.4	57.0	60.6	59.6	53.5^{AB}
	PC-urea	29.3	40.3	74.1	61.1	88.2	58.6^{A}
	Mean	35.0^{B}	41.9^{B}	61.2^{A}	61.6^{A}	65.7^{A}	
	Tukey $HSD^{0.05}$: Product = 10.4(P<0.05); N = 15.9 (P<0.001); Prod x N = 35.7 (P<0.05)						

[1]DMPP-coated urea; [2]Poly-coated urea

[A,B,C] Mean values accompanied by the same letter in a group are “not significantly” different

6.2.6.4. Yield

Sugarcane yield responses to N applied as three different N formulations (urea, DMPP-coated urea and PC-coated urea are shown for the plant and 1R crop in the Hbt TN in Figures 6-17 and 6-18 respectively. In the plant crop there were no significant differences in yield across the rates of N applied or N formulations used (Figure 6-17). This was not unexpected, as responses to applied N in initial plant crops do not often occur in rates of N trials.

Sugarcane yields were increased significantly by the rates of N applied in the 1R crop (Figure 6-18). However, there were no differences in yield associated with the N fertiliser formulations, nor interactive effects due to N rate and N formulation. The optimum N rate (corresponding to 95% of the maximum yield as determined from the production function) occurred at 120 kg N/ha. This was not unlike the SIX EASY STEPS N rate for ratoon cane grown on a soil with an Org C content of about 2.0%.

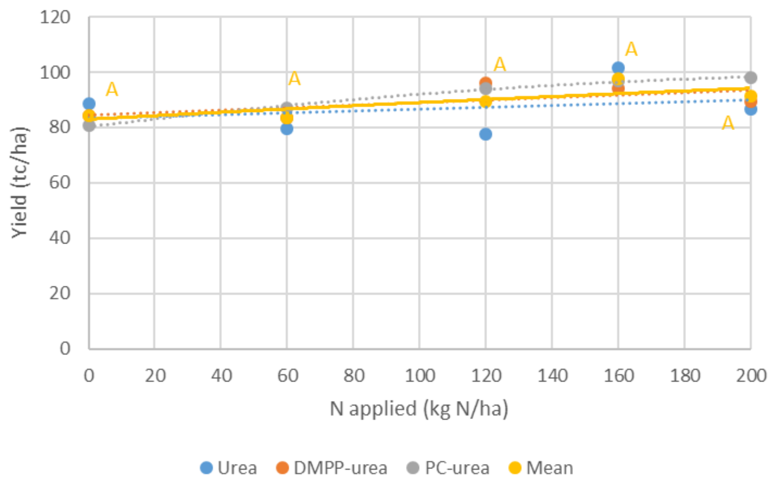


Figure 6-17 Sugarcane plant crop yield responses to N applied as three different N formulations: urea, DMPP-coated urea and PC-coated urea.

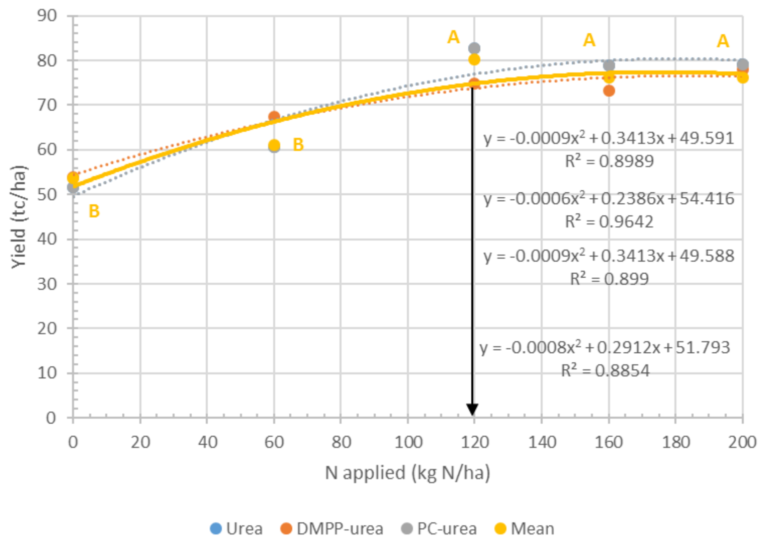


Figure 6-18 Sugarcane yield response curves for three different N fertiliser formulations: urea, DMPP-coated urea and PC-coated urea.
The black downward pointing arrow represents the optimum N rate (corresponding to 95% of the maximum yield associated with the quadratic function based on the mean yield values).

6.2.6.5. NUE indicators

As there were no significant yield differences associated with the different N fertiliser formulations, mean values were used to calculate a range of NUE indicators for the plant and 1 R crops (Table 6-77). As expected, NUE (expressed as tc/kg N applied) decreased as the rate of N increased in both the plant and 1R crops. The lower yields in the 1R crop resulted in these values being lower across the rates of N applied. The reciprocal value (kg N/tc) increased as the rate of N increased in both crops. The agronomic NUE [Agron Eff_{fert}(kg N/additional TCH)] values for the 1R crop indicated improved efficiency compared with the plant crop due to the significant response to applied N (in the 1R crop).

Table 6-77 N application rates, yield data and calculated N use efficiency factors for the plant and 1R crop across all the fertiliser formulations used: Hbt TN.

Yield and efficiency factors	Treatments (kg N applied/ha)				
	0	60	120	160	200
Plant crop (2015/16)					
Yield (tonnes cane/ha)	84.4	83.5	89.3	97.5	91.3
tonnes cane/N applied	-	1.39	0.74	0.61	0.46
kg N applied/tonne cane	-	0.72	1.35	1.64	2.17
Agron Eff_{Fert} (kg N/additional TCH)	-	-	22.6	11.9	27.4
NUtE (TCH/kg crop N)[1]	1.23	1.22	1.04	1.28	1.06
Crop N uptake (kg N/ha)[1]	68.4	68.2	85.7	76.2	86.5
Fertiliser N uptake (kg/ha)	-	-	17.3	7.8	18.1
NUpEfert(additional kg uptake/kg fert applied) %	-	-	14	5	9
1R crop (2016/17)					
Yield (tonnes cane/ha)	53.6	61.0	80.1	76.1	76.1
tonnes cane/N applied	-	1.02	0.67	0.48	0.38
kg N applied/tonne cane	-	0.98	1.49	2.08	2.63
Agron Eff_{Fert} (kg N/additional TCH)	-	8.11	4.53	7.11	8.89
NUtE (TCH/kg crop N)[1]	1.53	1.46	1.31	1.24	1.16
Crop N uptake (kg N/ha)[1]	35.0	41.9	61.2	61.6	65.7
Fertiliser N uptake (kg/ha)	-	6.9	26.2	26.6	30.7
NUpEfert(additional kg uptake/kg fert applied) %	-	12	22	17	15

[1]Calculated on final yield and N uptake at 9 months after planting or harvest of the previous crop.

6.2.6.6. Conclusions: Hbt TN

- Trial Hbt TN is the only current sugarcane trial in which full N response curves are obtainable from a range of N rates (include zero N) applied as urea, DMPP-coated urea and poly-coated urea.
- Despite reports of reduced N losses and potential maintenance of sugarcane yields when EEFs were used at lower N application rates, the results from this trial indicated that an N rate of 120 kg N/ha would have been appropriate irrespective of the choice of N fertiliser formulation (urea, DMPP-coated urea or PC-coated urea)
- This may be explained by the rainfall pattern during these particular seasons where excessive rainfall presumably did not cause marked N losses due to waterlogging or leaching.
- Increased crop N uptake at higher rates of N did not necessarily result in increased yields.
- Although NUE values were lower at the low N rates (less than 120 kg N/ha) in the 1R crop, applying less N fertiliser than the optimum N rate would have resulted in decreased yields.
- Further work, across seasons, is needed to fully evaluate the potential of EEFs for use in specific circumstances.

6.3. Pot experiments conducted in semi-controlled environments

6.3.1. N Uptake by sugarcane

6.3.1.1. Pot experiment USQ1

Biomass and N uptake

Sequential harvests of the sugarcane plants in the pots indicated that total dry matter (excluding the remains of the original set) and N-uptake over time differed according to cultivar: Q200 > Q240 > Q208 (Figures 6-19 and 6-20). However, it is unlikely that the differences between treatments were significant based on the standard deviation of the means. When N-uptake was partitioned between the roots and the above-ground plant parts, there was little difference in N content in the roots between varieties (Figure 6-21).

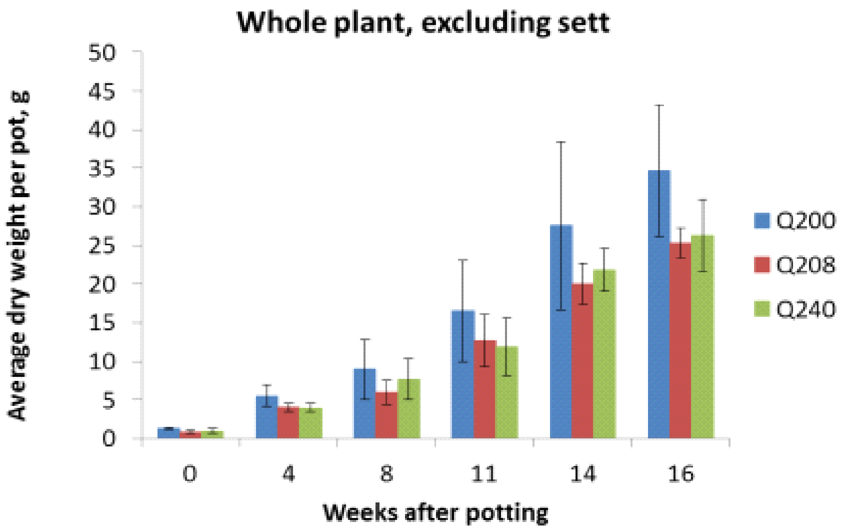


Figure 6-19 Mean plant material dry weight per pot (g) excluding the setts at each harvest for each variety.
Error bars show the standard deviation.

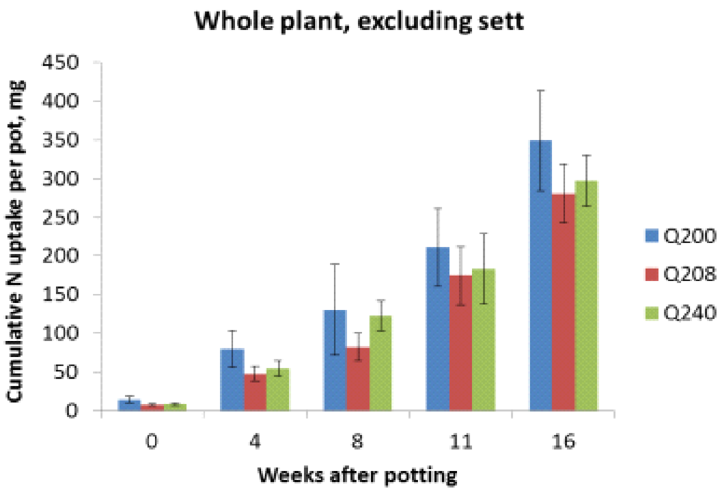


Figure 6-20 Mean total N content of plant material per pot excluding the setts at each harvest for each variety.
Error bars show the standard deviation.

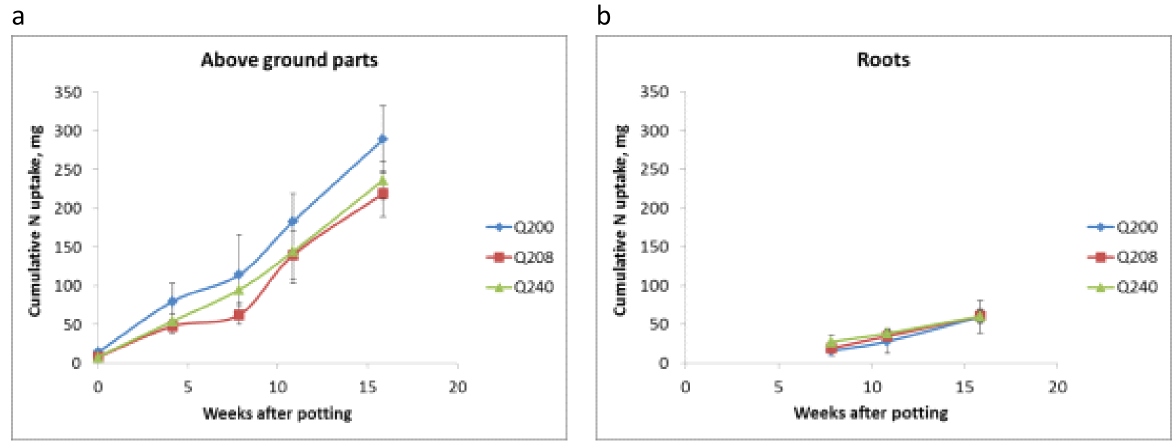


Figure 6-21 Mean total N content of (a) above ground plant material and (b) root material per pot at each harvest for each variety.
Error bars show the standard deviation.

The mass-weighted N concentration (N uptake/dry matter) in the whole plant excluding the original sett was compared with the yield (dry matter) as an indicator of the efficiency of N uptake. For the three cultivars, this agronomic N efficiency initially decreased over the first 10 weeks of growth and then increased over time up until the final harvest at 16 weeks (Figure 6-22). The increased efficiency after 10 weeks growth coincided with the second N fertiliser application. Contrary to expectations, there appears to be a general trend for the agronomic N use efficiency for cultivar Q240 to be less than that of cultivars Q208 and Q200.

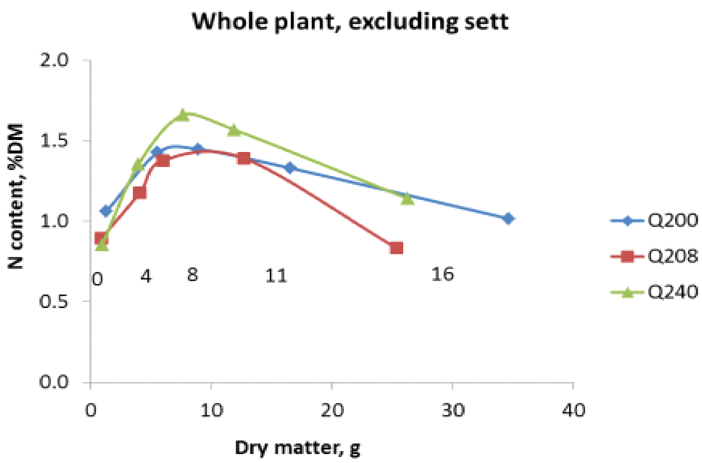


Figure 6-22 Nitrogen content (% dry matter) of the whole plant excluding the original set compared with average dry matter per pot (excluding the sett) at each harvest.
Labels within the chart area broadly indicate the week of harvest. Increasing agronomic N use efficiency is indicated by low N contents and high dry matter production.

Conclusions (USQ1)

- There was little difference between cultivars in the N uptake dynamics using the artificial growth medium within the first 16 weeks (111 days) of growth.
- There was some indication that Q240 was less, rather than more, N efficient. Variety Q208, which is a popular variety amongst growers, would be a suitable variety for testing EEFs.
- It appears unlikely that studies investigating N uptake dynamics using EEFs (in similar growth conditions) would be confounded by cultivar effects.

6.3.1.2. Pot experiment USQ2

As intended in this experiment, the sandy soil that was chosen had low nutrient, C and potentially mineralisable N content at the outset. Low soil mineral N throughout the experiment indicated that fertiliser N (urea-N) was hydrolysed, nitrified and used by the plant and/or leached quickly after application.

Above-ground total biomass was significantly higher ($P<0.05$) in the HighN plants than in the LowN plants at all harvest times except week 6 (Figure 6-23a) When measured (weeks 15, 18 and 21) below-ground total biomass was also significantly higher ($P<0.05$) in the HighN plants than in the LowN plants (Figure 6-23b).

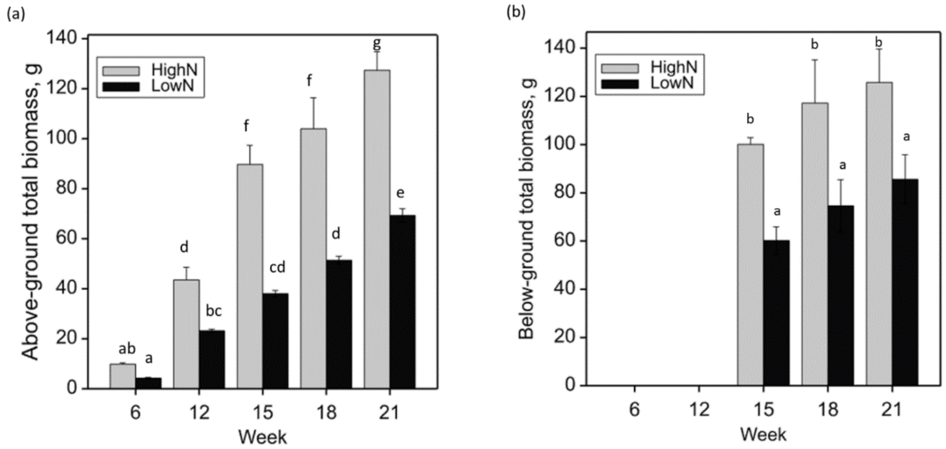


Figure 6-23 Biomass (g) per pot at each harvest for the HighN and LowN treatments for (a) all above-ground plant material and (b) all below-ground plant material (when measured). Data are means + sem. Letters that differ denote significant differences (*P*<0.05).

After an initial difference in N application rates applied at planting, with 150 kg N/ha applied in the High N treatment and nil N applied in the LowN treatment, N application rates then continued over time with 50 kg N/ha applied every 3 weeks from weeks 12 to 18. Despite the constant N supply throughout the second half of the experimental period, N uptake in above-ground material plateaued after 15 weeks in the High N treatment, with no significant difference ($P<0.05$) in uptake between weeks 15, 18 and 21 (Figure 6-24a). In the Low N treatment there was also no significant difference ($P<0.05$) in uptake between 15 and 18 weeks but N uptake increased significantly ($P<0.05$) before and after this period. In below-ground material in the current experiment, N uptake also plateaued from week 15 to 18 but then increased significantly ($P<0.05$) from 18 to 21 weeks in both the HighN and LowN treatments (Figure 6-24b). Overall, the trends suggest that N was applied surplus to requirements for this 21-week growth period in the HighN treatment.

Peak N uptake in above-ground material was between weeks 12 and 15 (84 to 105 days after planting) in both treatments. These peak rates of N uptake were 16 kg N/ha/week in the HighN and 8 kg N/ha in the LowN treatments. In below-ground biomass, peak N uptake over the period of measurement (weeks 15-21) was between weeks 18 and 21 (126 to 147 days after planting) in both treatments. These peak rates of N uptake were 7 kg N/ha/week in the HighN and 4 kg N/ha in the LowN treatments.

Whilst there was a delay in N uptake in the LowN treatment, commensurate with the delay in fertiliser application, the average rate of N uptake in the 6 weeks following first fertiliser N supply was similar between treatments, at about 5 kg N/ha/week (Figure 6-25 C).

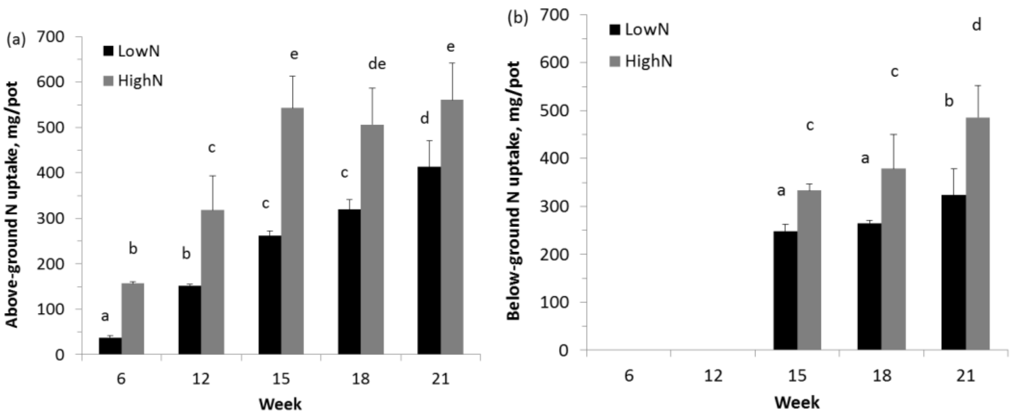


Figure 6-24 Mean total N uptake (mg/pot) of a) above-ground plant material and b) below-ground plant material per pot per treatment at each harvest. Error bars are one standard deviation. Letters that differ denote significant differences (*P*<0.05).

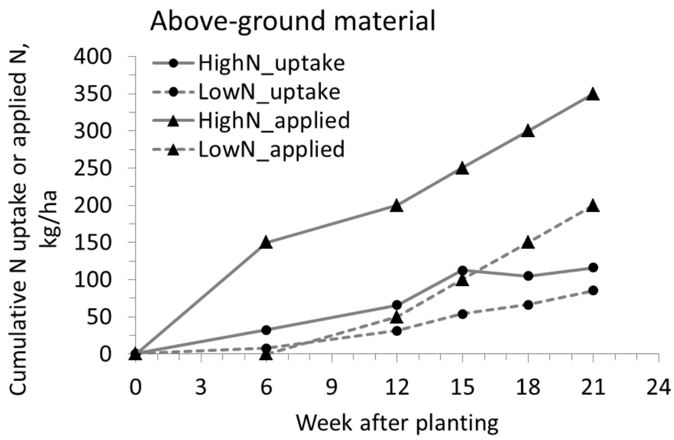


Figure 6-25 Cumulative crop N uptake and cumulative N applied as fertiliser for the HighN (solid line) and LowN (dashed line) treatments over time.
● crop N; ▲ fertiliser N applied

The mass-weighted N concentration (N uptake/dry matter) in the total above-ground material was compared with the yield (dry matter) as an indicator of the efficiency of N uptake over time (Figure 6-26a). Higher efficiency is reflected by low N concentrations and high dry matter production. For both treatments, efficiency gradually increased after week 12 over a plant N concentration range of about 0.5-0.7%. The effect of the initial N application (150 kg/ha) to the High N treatment is evident with an increase in N concentration by 6 weeks in comparison to the decrease in N concentration in the Low N treatment, which received no N fertiliser at planting. Despite receiving identical N applications after planting, there was a lag in the Low N treatment biomass response compared with the High N treatment over the 21-week period.

A related way of describing the N use efficiency is via the N utilisation efficiency, defined as the efficiency with which a crop utilises accumulated N to produce a unit of crop growth [e.g. t dry matter/kg crop N, (Bell *et al*., 2015b)] (Figure 6-26b). For the above-ground material, this N utilisation efficiency increased gradually over time in the Low N treatment. In the High N treatment, the N utilisation efficiency increased to higher levels by week 21 than the Low N treatment despite an initial decrease over the first 6 weeks. Because there was likely negligible N supplied by the sandy soil, fertiliser N recovery (i.e. fertiliser N uptake efficiency (Bell *et al*., 2015b)) over the 21 weeks was calculated as kg crop N/kg fertiliser N applied for both the above- and below-ground harvested material. For above- and below-ground material, fertiliser N recovery was higher, but not significantly so, in the LowN treatment than in the HighN treatment (Figure 6-27). In total, 76% and 62% of total applied N was recovered in the LowN and High N (above-and below-ground) biomass, respectively. Some N was probably leached form the outdoor pots.

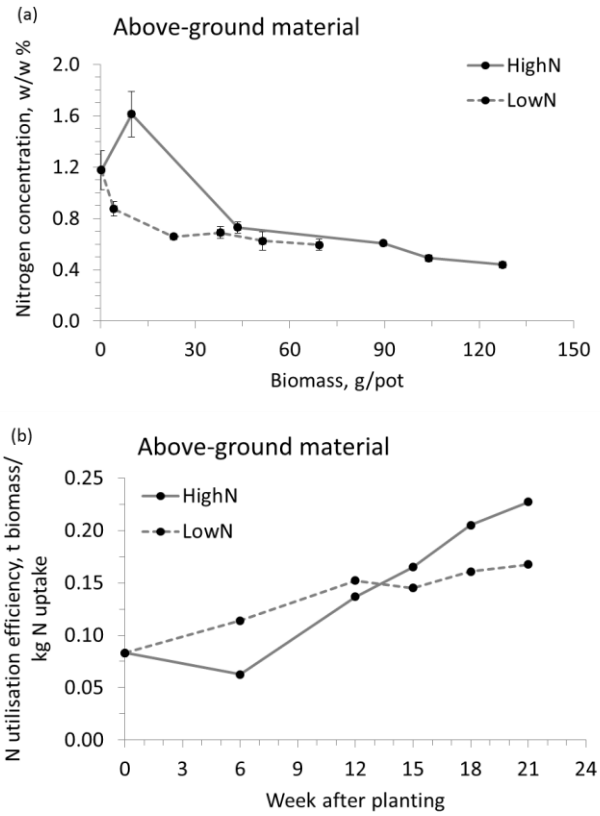


Figure 6-26 Nitrogen concentration (w/w, % dry matter) of the total above-ground plant material compared with average dry matter per pot at each harvest (0, 6, 12, 15, 18 and 21 days after planting) and b) N utilisation efficiency (t biomass/kg N uptake) over time.

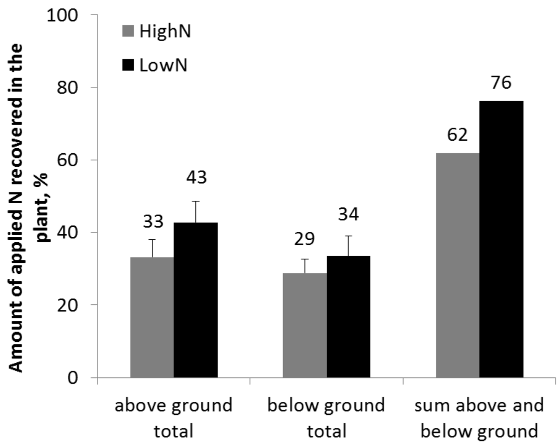


Figure 6-27 Percentage of applied N recovered over 21 weeks in the total above ground, total below ground and total above plus below-ground plant material for each treatment.

Conclusions (USQ2)

- This outdoor pot cane growth experiment demonstrated that a decrease in N supply to the crop by a reduced rate (and a 5-week delay in initial application of N) in the Low N treatment commensurately delayed the uptake of N and reduced cane biomass measured at 147 days after planting compared with higher and earlier (initial N supplied at planting) N supply in the High N treatment.
- Nitrogen uptake in the High N treatment peaked by 105 days after planting (15 weeks) whereas the Low N treatment uptake of N had not peaked by the conclusion of the experiment (147 days).
- The rate of uptake of N was similar between the High N and Low N treatments in the first 6 weeks after their respective initial N supplies, however, the High N treatment, which had 150 kgN/ha applied at planting, demonstrated increased N uptake from 84 days after planting (2.8 months) compared to the Low N treatment.
- The treatments demonstrated a similar efficiency in recovery of applied N. Use of an enhanced efficiency fertiliser regime to minimise N losses to the environment early in the growth season could aim to maintain a constant supply of N to the crop over the first 15 weeks to match the observed growth patterns under non-limiting N supply. This will need further investigation.

6.3.2. Supply and uptake of N when enhanced efficiency fertilisers are used

6.3.2.1. Pot experiment Bdb1

Yields of millable stalk, and leaves and tops harvested from the Bdb1 pot experiment are shown in Tables 6-78 and 6-79 respectively. Significant responses to applied N occurred in both cases, but without significant differences due to the use of the different fertiliser formulations (urea, DMPP-coated urea or PC-coated urea). Mean yields of millable stalks, and leaves and tops varied according to cultivar (Q200 and Q208).

The amount of N in stalks, leaves and tops, and roots are shown in Tables 6-80, 6-81 and 6-82 respectively. In all cases, significant differences occurred due to N applied, but no significant effects due to the fertiliser formulation used.

The total N uptake in the whole plants (stalks, leaves and tops, and roots) of cultivar Q200 at a treatment rate of 150 kg N/ha minus the N-uptake at zero N applied allowed the percentage N in the different plant parts to be calculated. It was found that 18% of the applied N was in the stalks, 34% of the applied N was in the leaves and tops, and 20% of the applied N was in the roots. In total, 28% of the 150 kg N/ha application (42 kg N/ha) could not be accounted for in this way. This amount of N was either held within the soil reserves or lost by denitrification. Leaching losses were unlikely as leachates were returned to the pots on a routine basis. Similar figures were obtained for cultivar Q208.

The NUE indicators based on N application rates, mean stalk yields and N content of the stalks are shown in Table 6-83. NUE (tonnes 'cane'/kg N applied) ranged from 0.69 (at 75 kg N/ha) to 0.31 (at 225 kg N/ha). As expected the Agron EffFert (kg N/additional TCH) increased with increased rates of N applied. The NUpEfert (additional kg uptake/kg fert applied was more or less stable at 18 – 19% at the 150 – 225 kg N/ha application rates.

Table 6-78 Effect of N fertiliser formulation, rate of N applied and cultivar on the yield of millable stalks: pot experiment Bdb1.

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

[1]DMPP-coated urea; [2]Poly-coated urea

[A,B,C,D] Mean values accompanied by the same letter in a group are "not significantly" different

[3]Mean yield of millable stalks for cultivars Q200 and Q208 are significantly different (P<0.01)

Table 6-79 Effect of N fertiliser formulation, rate of N applied and cultivar on the yield of leaves and tops: pot experiment Bdb1.

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

[1]DMPP-coated urea; [2]Poly-coated urea

[A,B,C,D] Mean values accompanied by the same letter in a group are "not significantly" different

[3]Mean yield of leaves and tops for cultivars Q200 and Q208 are significantly different (P<0.01)

Table 6-80 Effect of N fertiliser formulation, rate of N applied and cultivar on the amount of N in stalks

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

[1]Mean yield: millable stalks for cultivars Q200 and Q208 are significantly different (P<0.01).
[A,B,C,D] Mean values accompanied by the same letter in a group are "not significantly" different.

Table 6-81 Effect of N fertiliser formulation, rate of N applied and cultivar on the amount of N in leaves and tops.

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

[1]Mean yield of leaves and tops for cultivars Q200 and Q208 are significantly different (P<0.01).
[A,B,C,D] Mean values accompanied by the same letter in a group are "not significantly" different

Table 6-82 Effect of N fertiliser formulation, rate of N applied and cultivar on the amount of N in roots

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

[1]Mean yield of roots for cultivars Q200 and Q208 are significantly different (P<0.01)
[A,B,C,D] Mean values accompanied by the same letter in a group are "not significantly" different

Table 6-83 N application rates, mean cane stalk yields and calculated N use efficiency factors associated with cane grown in pot experiment Bdb1 for cultivar: Q200

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

6.3.2.2. Pot experiment Bdb2

A second N fertiliser formulations / temporal N pot experiment established in Bundaberg in July 2016 was harvested on 19 Dec 2016. The yields (expressed as tonnes/ha) of 'wet' and 'dried' stalks, and total 'wet' and 'dried' above-ground biomass (total stalks, leaves and tops) are shown in Figures 6-28 and 6-29 respectively. Highly significant yield responses occurred across the rates of N applied irrespective of the N-fertiliser formulation. The choice of N formulation resulted in a significant yield response but this was due to an interactive effect caused by a highly significant yield difference between DMPP-coated urea and the other formulations (urea and PC-coated urea) at 150 kg N/ha. There were no significant differences in yields associated with the N fertiliser formulations at zero, 75 and 225 kg N/ha. As this yield effect occurred across all the yield parameters considered, wet stalk yield was used to illustrate the use of response curves to separate the effects of the different N fertiliser formulations (Figure 6-30). The data suggests that in this pot experiment standard urea and the poly-coated urea (Agromaster 44) behaved in similar ways with respect to yield. As mentioned previously, no significant differences occurred due to the choice of N formulations at the lower rates of N applied (0 – 75 kg N/ha). However, DMPP-coated urea (urea coated with a nitrification inhibitor) resulted in higher yields than those associated with the other products applied at rates of from about 120 to 180 kg N/ha (Figure 6-30). At the highest rate (225 kg N/ha) significant yield differences were no longer apparent. Whereas the HUE was 0.5 tonnes cane/kg N applied for the DMPP-coated urea at 150 kg N/ha, it was somewhat lower for the other two N formulations (mean of 0.37 tones cane/kg N applied).

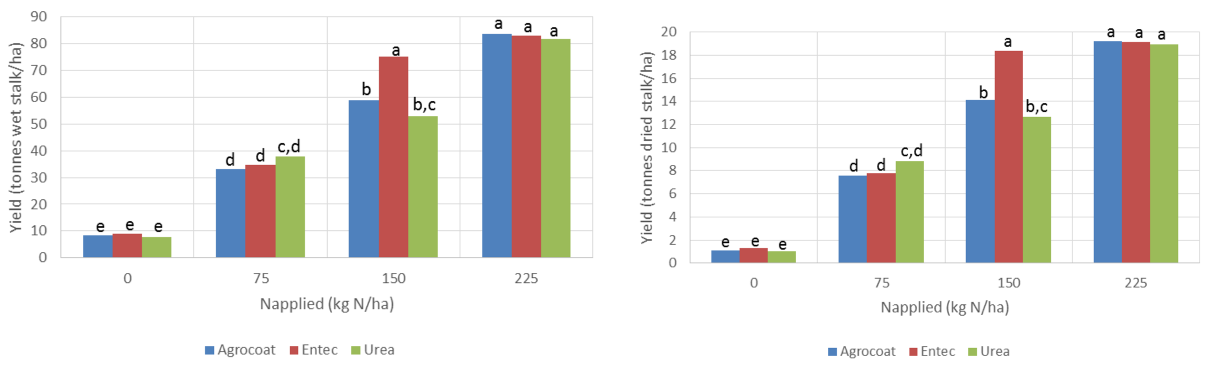


Figure 6-28 Yield of 'wet' and 'dried' stalks of sugarcane harvested from a pot experiment plotted against rates of N applied as poly-coated urea (Agromaster 44), DMPP-coated urea (Entec) and standard urea.
Means with the same letter are not significantly different (p=0.01) using a Tukey HSD test.

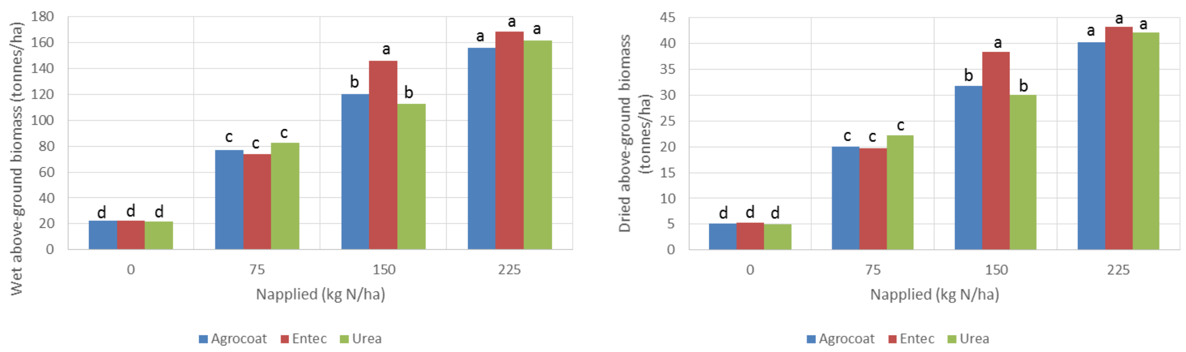


Figure 6-29 'Wet' and 'dried' total above-ground biomass (stalk, leaves and tops) harvested from a pot experiment plotted against rates of N applied as poly-coated urea (Agromaster 44), DMPP-coated urea (Entec) and standard urea.
Means with the same letter are not significantly different (p=0.01) using a Tukey HSD test.

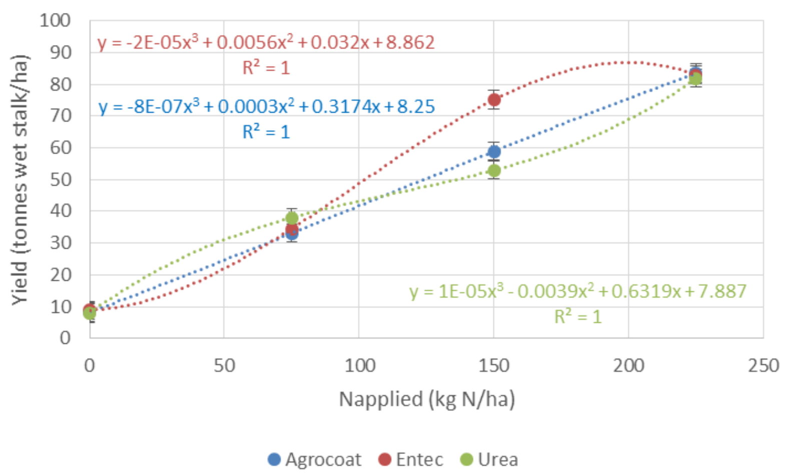


Figure 6-30 Yield ('wet' stalks of sugarcane/ha) harvested from a pot experiment plotted against rates of N applied as poly-coated urea (Agromaster 44), DMPP-coated urea (Entec) and standard urea.

6.4. Spatial aspects of the PA and Bdb NxK trial sites

An EC map for the original PA site at Welcome Creek near Bundaberg is shown as Figure 6-31 (Bramley *et al*., 2014). A combination of this map and an underlying Queensland Government soils map is shown in Figure 6-32. Both images were sourced from a Milestone Report from SRDC/SRA Project CSE022 (Bramley *et al.,* 2014). These images indicate that the section of the PA site that contains the NxK trial (Figure 6-33) is uniform, both in terms of low EC and the indicative soil type i.e. red clay loam of the Otoo series (Donnollan *et al*., 1988). Harvester roller-opening data for the third ratoon crop (2014) from each plot in the NxK trial (Figure 6-34) is shown in Figure 6-35. This set of raw spatial data indicated that the apparent yield differences created by different rates of N and K fertiliser were sensed by the instrumentation on-board the harvester. The roller opening data was processed (kriged) to produce a yield map (Figure 6-36). The yield data for each plot was then allocated to broad categories according to the colour scale (low to high). It was found that average yields of 55 tc/ha, 75 tc/ha and 95 tc/ha could be roughly ascribed to the low/medium low, medium and medium high/high areas within the NxK trial (Figure 6-36).

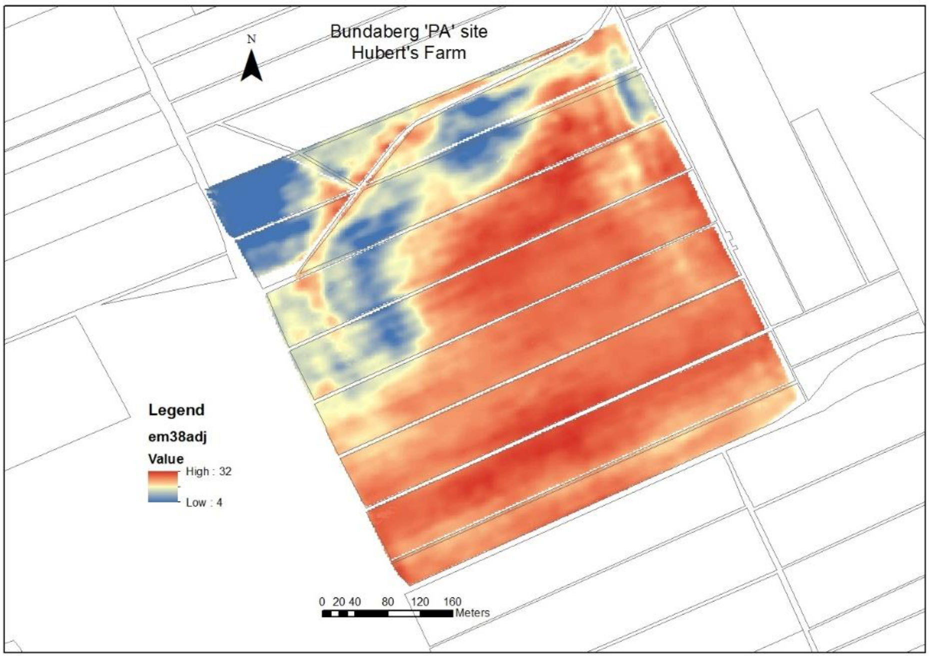


Figure 6-31 EC map of the Bundaberg PA site [source: SRA project CSE022 (Bramley *et al*., 2014)].

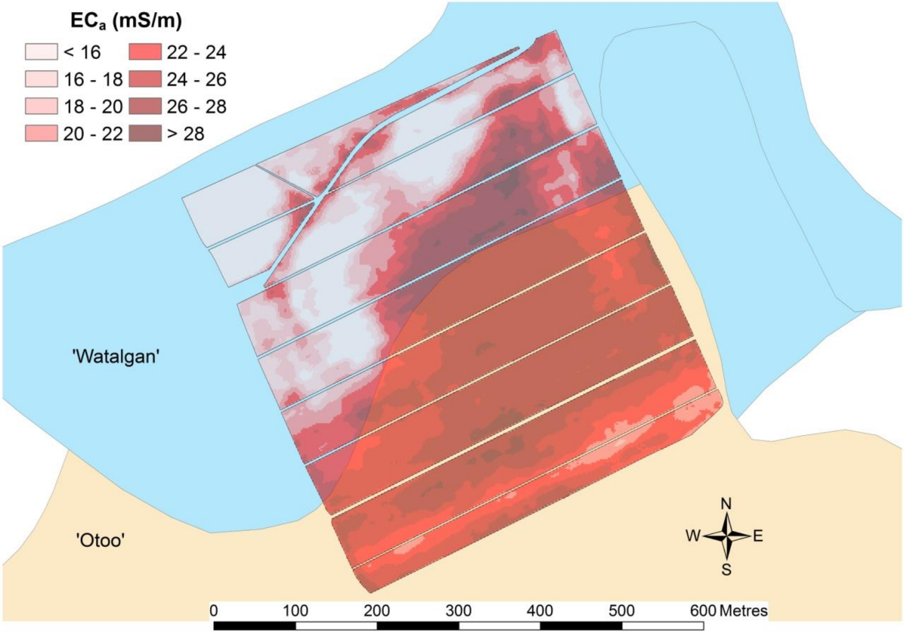


Figure 6-32 EC map and underlying soils map [SRA project CSE022 (Bramley *et al,* 2014).

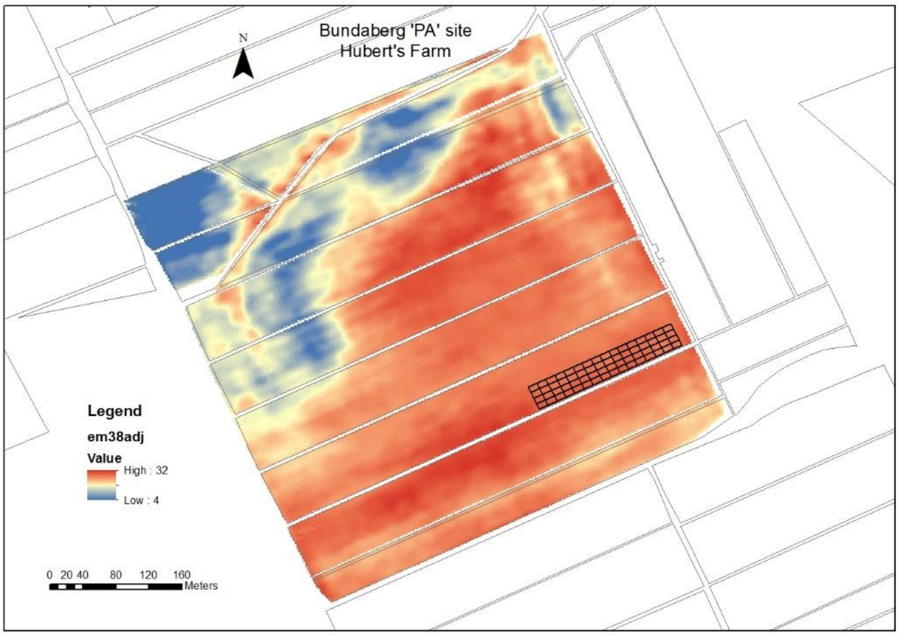


Figure 6-33 EC map of the Bundaberg PA site showing the position of the NxK trial.

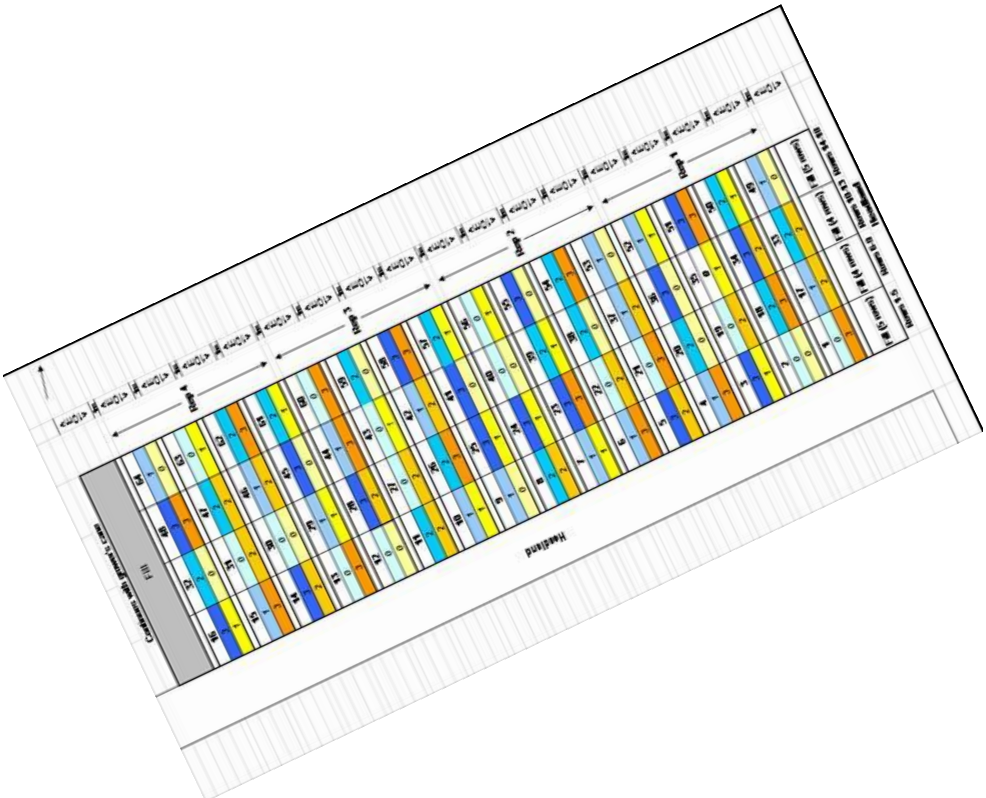


Figure 6-34 Layout of the Bdb NxK trial at Welcome Creek.

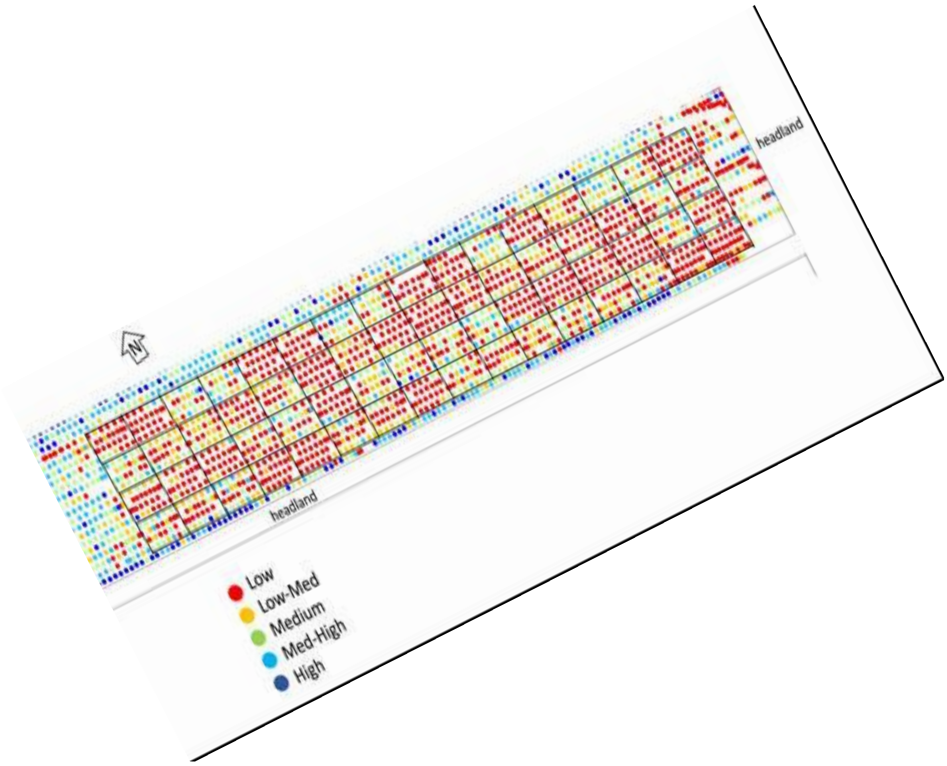


Figure 6-35 Third ratoon roller opening sensor data for each plot in the Bdb NxK trial.

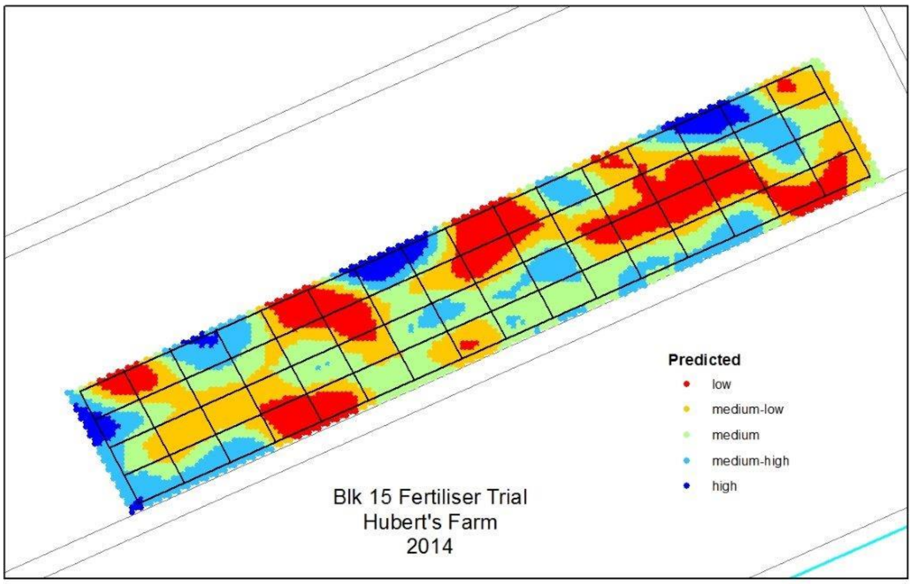


Figure 6-36 Yield map based on the harvester roller opening data for the Bundaberg NxK trial.

During the 2016 season, the PA site was harvested at various stages from mid-September to mid-October. A yield map for Blocks 15A and 15B was produced using the elevator pressure data (Figure 6-37) as opposed to roller-opening data as in Figure 6-36. In this case, yields ranged from 45 to 92 tc/ha and 63 to 113 tc/ha for Block 15A and 15B respectively. This data was used to develop an NUE representation of Block 15B expressed as tonnes cane/ha per kg N /ha applied (Figure 6-38). As expected, the higher yielding parts of the block showed better NUE than the lower yielding sections.

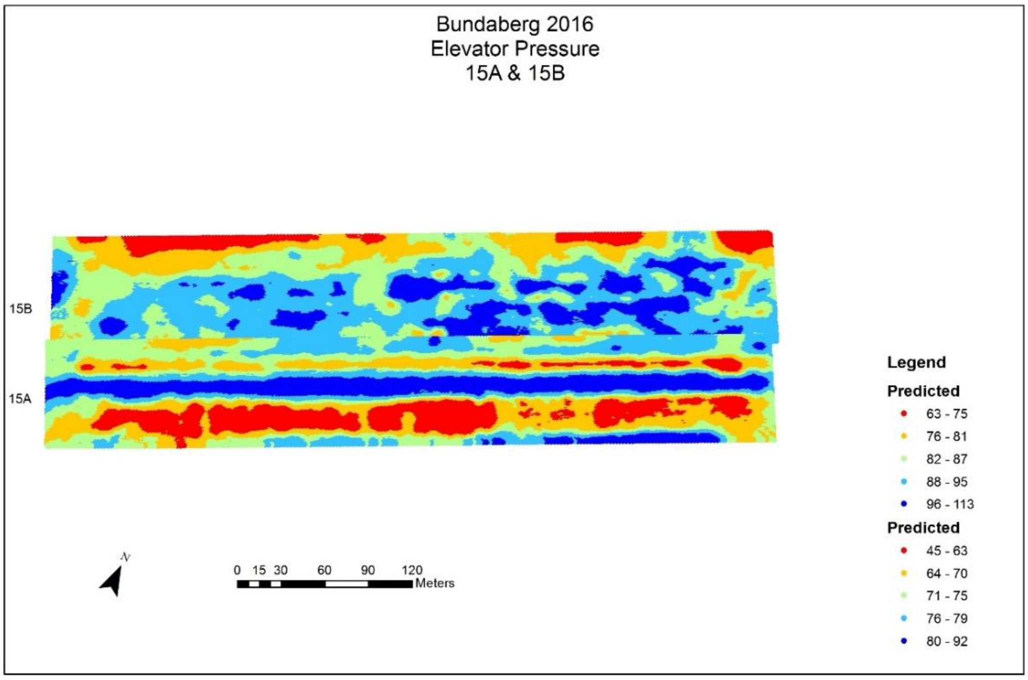


Figure 6-37 Yield map for plant cane (2016): Blocks 15A and 15B that form part of the PA site in Bundaberg.

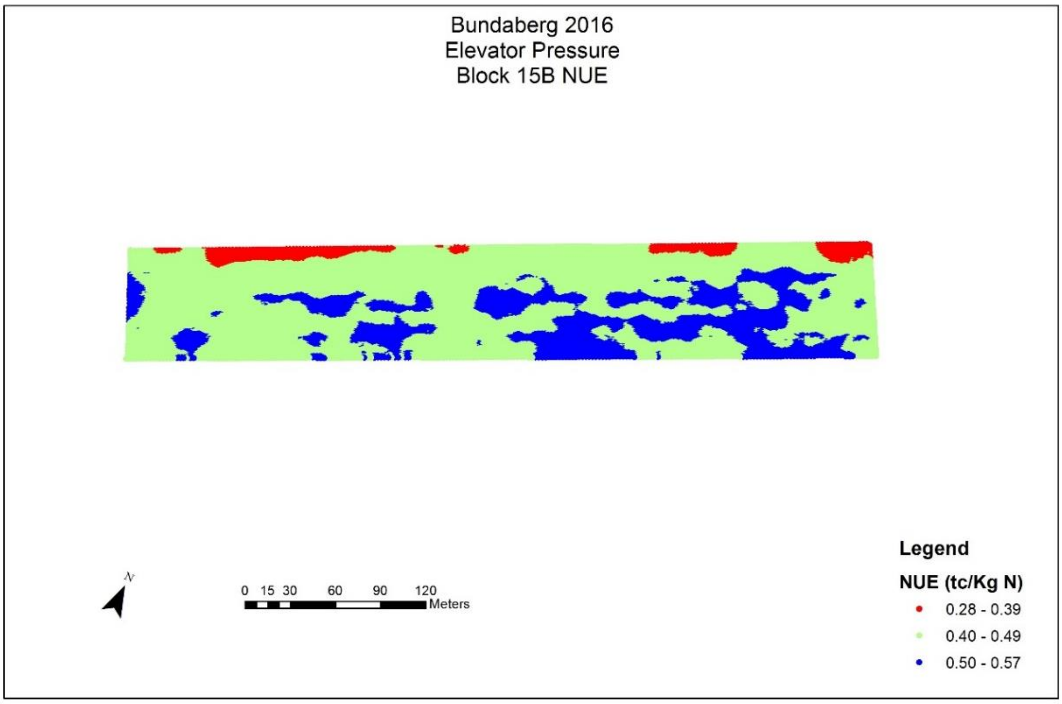


Figure 6-38 A NUEmap (expressed as t cane/kg N applied) for plant cane (2016): Blocks 15A and 15B that formed part of the PA site.

Conclusions

- Sugarcane yield differences created by varying nutrient inputs may be detected by yield monitoring and PA processes / technologies. This provides another possible means of determining the adequacy of nutrient management strategies in particular blocks of cane.
- NUE maps developed using data from yield monitors and the rate of N applied across or within blocks provide a means of identifying areas where alternative farm management options could be considered.

6.5. Adjustments to the N guidelines (if appropriate) within the SIX EASY STEPS program

6.5.1. SIX EASY STEPS framework

As mentioned before, the SIX EASY STEPS program resulted from an eleven-stage framework (Table 6-2) that was used to refine the previous generalised nutrient recommendations into soil-specific nutrient management guidelines (Schroeder *et al*., 2008a). This was achieved by the integration of previous knowledge and information with results more recent investigations (Schroeder *et al*., 2006).

The SIX EASY STEPS program (as described in Section 1.4.1) and illustrated in Figure 6-1 may be used by growers and their advisors for determining nutrient inputs on-farm, and by researchers and extension specialists for RD&E and adoption purposes. STEPS 1 and 2 bring together knowledge of the farm/area, the occurrence of different soil types, positions in the landscape and opportunities/challenges for improving nutrient management. STEPS 3 and 4 are used for interpreting soil test results from accredited laboratories with sets of district-specific SIX EASY STEPS nutrient management guidelines. They enable nutrient requirements to be identified for blocks of sugarcane and for developing nutrient management plans (NMPs). STEPS 5 and 6 enable expansion of the system to include a range of options for further fine-tuning of nutrient management options. These include refinements for specific circumstances, when new information becomes available and/or to meet an individual grower's needs and appetite for risk. STEPS 5 and 6 also provide the basis for continuous improvement with loops back to the previous steps in the program (Figure 6-39).

6.5.2. Developments in nutrient management

6.5.2.1. General improvements to the SIX EASY STEPS program

Short-courses/workshops

Ongoing developments and refinements to the SIX EASY STEPS program began soon after it was initiated within the former BSES Limited and the Cooperative Research for Sustainable Sugar Production (CRC Sugar) in 2002 (Schroeder *et al*., 2003). This followed an initial CRC Sugar train-the-trainer type short-course presented on several occasions to about 120 industry advisors and stakeholders. This short-course (Bruce, 1999) provided technical information that was subsequently simplified and summarised into a grower-orientated nutrient management short-course entitled "An integrated approach to sustainable nutrient management for sugarcane". With time the short-course developed into comprehensive district-specific SIX EASY STEPS nutrient management workshops supported by purpose developed SIX EASY STEPS workshop manuals. The workshops include practical exercises that are aimed at illustrating the process and components of developing a NMP for a hypothetical farm. They have been presented to more than 1 700 attendees (about 1 400 growers and > 250 advisors and other stakeholders) from FNQ to NSW.

Decision support applications

In 2003 a simple Excel-based decision support spreadsheet application based on the SIX EASY STEPS nutrient management guidelines was developed. It enabled determination of nutrient requirements from soil test values in a semi-automated way, and included the ability to take account of nutrients from legumes fallows, mill mud/mill ash, etc. This spreadsheet application was further developed by BSES and the University of Southern Queensland (USQ) into a web-based online nutrient management tool called SIX EASY STEPS NutriCalc™ (Schroeder *et al*., 2010b). It is a versatile package that integrates the ability to identify the location of specific farms and blocks (using Google Maps) with appropriate nutrient management strategies from soil test values using the nutrient management guidelines in STEP 4 of the SIX EASY STEPS program. It also enables indicative costs of fertilisers to be determined from unit prices of nutrients, the ability to select appropriate fertiliser carriers and record actual nutrient inputs and rates of applications, and review on-farm nutrient management trends with time (Anon., 2017d). It has been accessible to all bona-fide growers and advisors via the BSES/SRA website since 2011. Given the multitude of fertiliser products on the market, SRA developed the user-friendly FertFinder application in 2017. It enables the best combination of products to be determined for supplying the nutrients required per block. It can be downloaded from the SRA website (Anon., 2017e).

Nutrient management planning

Although nutrient management planning is promoted in the SIX EASY STEPS workshops, widespread adoption of a formal process has not occurred, seemingly because of time pressures on-farm. More recently the Wet Tropics Sugar Industry Partnership (WTSIP) initiated the development of NMPs to assist growers in making meaningful decisions about on-farm nutrient application rates using a simple yet effective grower-focus approach (Skocaj *et al*., 2018). It consists of a five (5) stage process: 1) Identifying soil types and nutrient requirements on-farm; 2) Grower profiling; 3) Drafting a whole-of-farm NMP; 4) Finalising the NMP in consultation with the grower; and 5) Reviewing and updating the NMP. An important output from this initiative are rationalised whole-of-farm fertiliser requirements based on a limited/practical number of products (Figure 6-39).

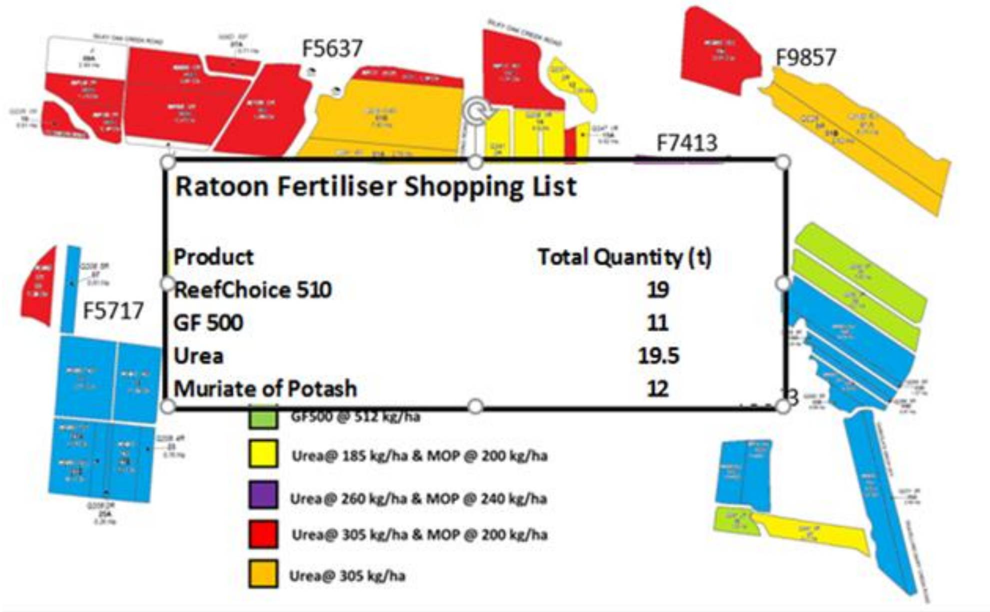


Figure 6-39 An example of a rationalised whole-of-farm nutrient management plan using the logical five stage process (Skocaj *et al*., 2018).

6.5.2.2. Developments that have implications for STEPS 5 and 6

As mentioned previously, there has been much progress over the last few years in getting growers and their advisors attuned to, and using, the SIX EASY STEPS program. This is especially the case with STEPS 3 and 4. As indicated above, STEPS 5 and 6 aim at developing expertise beyond the 'routine' guidelines included and used in STEP 4. STEPS 5 and 6 therefore enable expansion of the system to include a range of options for fine-tuning nutrient management, using specific 'tools' within a "SIX EASY STEPS TOOLBOX". Several possible options or 'tools' are becoming available from various R&D projects that could enable growers and/or their advisors to implement nutrient management strategies that are beyond current BMPs.

Nitrogen management options

The aforementioned need to reduce dissolved inorganic nitrogen (DIN) levels in water draining to the GBR lagoon (Anon., 2017b) resulted in increased emphasis on the SIX EASY STEPS nitrogen (N) guidelines. The NUE workshop and report (Bell, 2015) commissioned by SRA identified opportunities for improving N management and NUE. Chapters of the report included a summary of N usage (Bell *et al*., 2015a), evolving nature of N management in the Australian sugar industry (Schroeder *et al*., 2015), agronomy and physiology of N use (Bell *et al*., 2015b), genetic improvement of NUE (Robinson *et al*., 2015), remote sensing technologies (Robson *et a*l., 2015), increasing NUE through simulation modelling (Thorburn *et al*., 2015), use of enhanced efficiency fertilisers (EEFs) to improved NUE (Verburg *et al*., 2015) and an overview of N use and future opportunities (Bell and Moody, 2015).

Several suggestions within that report are being investigated within various projects and potentially provide information that could allow improvements to the SIX EASY STEPS program. Some of these are described below, some of which have been mentioned previously within this report:

- **N requirement based on yield**

The SIX EASY STEPS uses district yield potential (DYP) as a means of discriminating N requirements between districts such as the Burdekin and Tablelands, which have higher average annual yield due to irrigation and higher solar radiation, and other districts where yields are constrained by too much rainfall, too little or poorly distributed rainfall patterns (Schroeder *et al*., 2010a). In addition to DYP, the SIX EASY STEPS program provides soil specific N guidelines (Schroeder *et al*., 2009a) by using an N mineralisation index based on soil organic carbon (Org C). Equations 1 and 2 indicate how this is done. Importantly, the suite of concepts that are contained in these relationships have been calibrated using yield response curves obtained from a number of field trials (Schroeder *et al.*, 2010).

General relationship: N application rate (kg N/ha) = [“Yield term” (t cane/ha) x multiplier (kg N/t cane)] – N discount ………………. Eqn 1

Specific SIX EASY STEPS relationship: N application rate (kg/N/ha) = (DYP x CSIRO-developed bench mark[1]) – N based on mineralisation index ..…. Eqn 2

[1]CSIRO-developed bench mark = 1.4 kg N/t cane up to a cane yield of 100 t cane/ha and 1 kg N/t cane thereafter (Keating *et al*., 1997)

Concepts such as block yield potential (BYP), production unit yield potential (PUYP) and management unit yield potential (MUYP) have been suggested by others as alternatives to DYP. However, long-term N application rate trials in the Herbert, Tully, Bundaberg and Mackay districts (Schroeder *et al*., 2015) do not show a direct relationship between N rate and crop yield. An example is shown in Figure 6-4. Recommended N rates based on 95% of the highest attained yield, referred to as the Optimum N rate (Opt N) remain relatively stable across seasons, despite yield fluctuations, and support the basis of the SIX EASY STEPS N guidelines. In addition, recent investigations conducted by Thorburn *et al*. (2018) show there is little correlation between sugarcane yield and the corresponding Opt N values.

Recent analyses of yield data from the Herbert district have indicated that spatial patterns of yield are generally stable from year to year (Bramley *et al*., 2017). This information is valuable in identifying productivity zones within the district and their relationships to the distribution of soils and within-district climate differences. However, the use of productivity zones as a predictor of N rate within a region would require nutrient response experiments to be conducted across soil types within the full range of productivity zones. As an alternative, growers within the various productivity zones could use this additional information to consider whether any adjustments away from the SIX EASY STEPS N guidelines could be justified as part of STEPS 5 and 6. Such adjustments would need to be validated on-farm prior to adoption across an entire enterprise.

The introduction of variable rate fertiliser applicators has encouraged growers to search for methods to vary fertiliser application rates. This has included patterns of variability provided by yield maps generated by harvest yield monitors (Bramley and Jensen, 2013) or remotely sensed images based on variations in normalised difference vegetation index (NDVI) values (Robson *et al*., 2015). However, a sound basis for using this technology to determine required nutrient rates is not yet a reality. Similarly, although soil sampling strategies using electrical conductivity (EC)-generated maps is increasing (Schroeder *et al*., 2018), proximal sensed images based on EC and other digital soil mapping technologies (e.g. gamma ray spectrometry) for determining nutrient requirements are still being investigated (Robson *et al*., 2015).

- **Decision support tools for N**

Apart from SIX EASY STEPS NutriCalc™, various other decision support tools have been developed. These include SafeGauge for Nutrients (SfN) that assesses the risk of N and P losses from different fertiliser formulations applied at different stages within the crop growth period (Moody *et al*., 2008). More recently, an electronic application (App) has been proposed as a means of determining N application rates based on soil type, climate forecast and time of harvest (Thorburn *et al*., 2018). Previous research indicated the potential for linking predictions of climatic conditions during the sugarcane-growing season to N management strategies (Skocaj, 2015; Skocaj *et al*., 2013). As mentioned before, recent investigations that included data from a large number of field trials (Thorburn *et al*., 2018) showed that there is little correlation between sugarcane yield and the corresponding Opt N values (Figure 6-40). Rather than trying to improve N recommendations by changing concepts of yield potential (i.e. DYPs to BUPs or PUYPs, etc.), the proposed App would use future climate scenarios based on statistical and mathematical models and outputs from the crop simulation model (APSIM Sugar) to suggest modified N rates for particular circumstances (Thorburn *et al*., 2018). These could relate to different soil types, positions in the landscapes, harvest times and predicated climate (rainfall) scenarios. The App could also provide N application rate options for consideration by growers and /or advisors depending on their tolerance to risk.

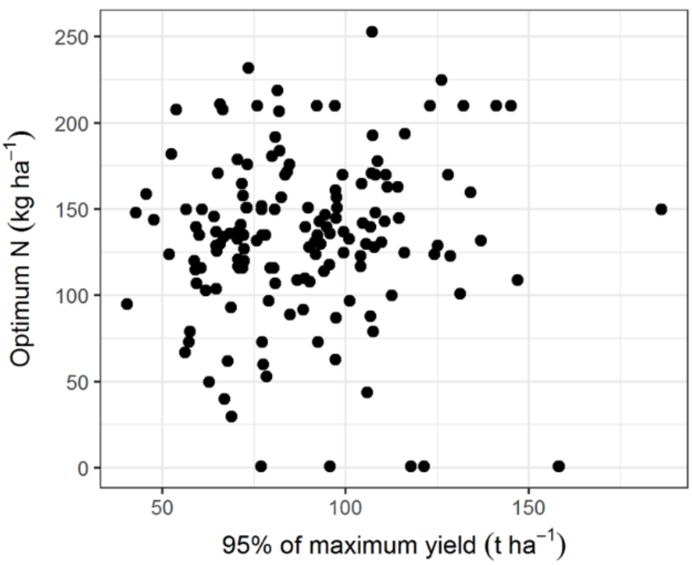


Figure 6-40 Data from a larger number of N field trials indicating that there is no robust relationship between 95% of maximum yield and the N rate corresponding to that yield (Thorburn *et al*., 2018).

- **Nitrogen use efficiency**

The aforementioned NUE review prompted attention to the actual meaning of NUE. Several terminologies and acronyms (Bell *et al*., 2015b) exist for expressing NUE (Table 6-84). The most common and easy to understand expression of NUE is the Agronomic Efficiency of Fertiliser N ($AgronEff_{Fert}$). It is often referred to simply as the Fertiliser NUE (Equation 3). However, it is still open to misinterpretation. For example, a low yielding crop is likely to have a low NUE, but the reasons for the low yield may have nothing to do with the amount of N applied. This is illustrated by the data in Table 6-85). In this case, the NUE values differed from season to season because the rainfall patterns (not shown here) resulted in variable yields that were unrelated to the amount of N applied (140 kg

N/ha in all three seasons). Data from a rates of N trial conducted on a sandy loam soil in the Herbert district (Figure 6-41) illustrate the improvement of NUE as lower rates of N were applied but with decreased sugarcane yields. Differences in yield and NUE values across seasons were unrelated to the N applied. Therefore, setting meaningful NUE targets to guide N fertiliser inputs is difficult, and we suggest the use of NUE would be more beneficial as part of a multi-facetted approach (discussed later). However, NUE values can be useful in identifying farms, blocks of cane and/or areas within blocks that may be affected by factors other than N causing poor growth, N losses, etc.

Fertiliser NUE (t cane/kg N) = Cane yield (t cane/ha) / N fertiliser applied (kg N/ha) ……………. Eqn 3

Table 6-84 Terminology and acronyms used to quantify crop responses to applied N fertilizer (Bell *et al.*, 2015b)

Description	Acronym
N utilisation efficiency - the efficiency with which a crop utilises accumulated N to produce a unit of crop growth (e.g., t dry matter/kg crop N)	NUtE
Fertiliser N uptake efficiency – the efficiency with which applied N fertiliser is accumulated in crop biomass (kg crop N/kg fertiliser N applied)	$NUpE_{Fert}$
Agronomic Efficiency of Fertiliser N – the efficiency with which fertiliser N is used to produce crop yield (e.g. t cane yield/kg fertiliser N applied)	$AgronEff_{Fert}$

Table 6-85 Crop data from a block of commercial sugarcane grown on a Tully series soil in the Tully district (after Skocaj *et al.*, 2012)

Year	Crop class	Yield (t cane/ha)	N application rate (kg N/ha)	NUE (t cane/kg N)
2007-08	1st Ratoon	132	140	0.94
2008-09	2nd Ratoon	96	140	0.69
2009-10	3rd Ratoon	107	140	0.76

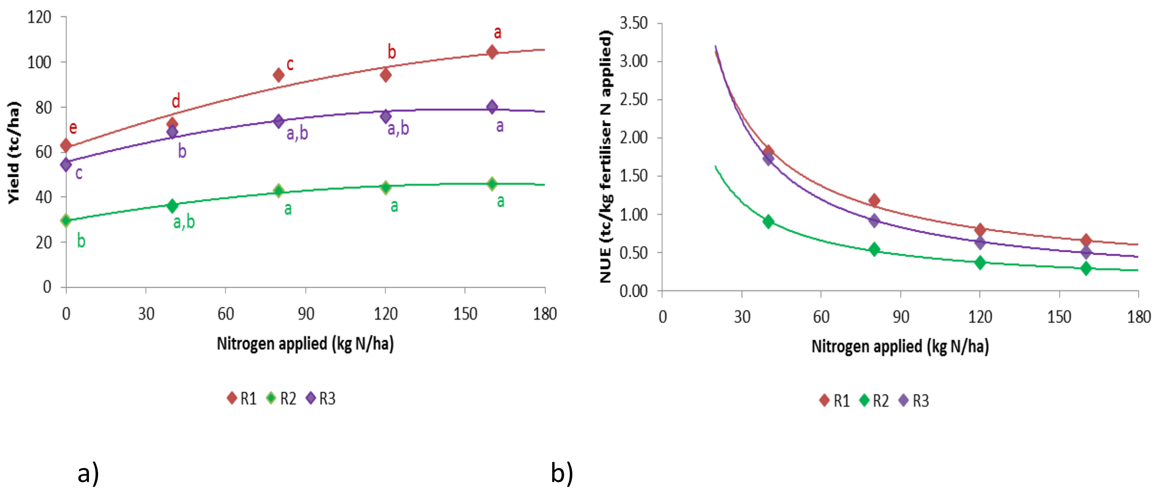


Figure 6-41 (a) Yield response curves and (b) NUE (t cane/kg N applied) values plotted against N applied for a rates of N trial conducted in the Herbert district.

1st ratoon (1R shown in red), 2nd ratoon (2R shown in green) and 3rd ratoon (3R shown in purple). Significant differences in yield ($p<0.05$) occurred where data points are accompanied by different letters (same colour).

- **Multi-facetted analyses of data**

Traditionally, data from nutrient management field trials have been assessed according to agronomic criteria, i.e. what inputs and/or practices resulted in increased or maximum yield (t cane/ha or t sugar/ha), etc. This was often achieved by fitting production functions to yield data (Schroeder *et al*., 1998). With increased awareness of environmental issues (Anon., 2017b), using NUE as a basis for determining N application rates has been topical. However, the evidence provided above showed that NUE alone is not a suitable means of assessing the adequacy of N inputs. A multi-facetted approach, such as a triple-bottom line analysis is more appropriate (Thompson, 2007). This is supported by Poggio *et al*. (2016), who indicated the evaluation of changed practices is best undertaken when multiple objectives/consequences [agronomic, social, economic and environmental and social (ASEE)] are considered. This will at least minimise bias or over-emphasis of one objective over others (Poggio *et al*., 2016).

The advantages of a multi-facetted approach is illustrated in Figure 6-42. Yield data for the first ratoon crop of the Herbert trial described above were used here. The optimum N rate (145 kg N/ha) is indicated by the downward pointing thin brown line. The NUE at this point is 0.74 t cane/kg N (Figure 6-41b). The SIX EASY STEPS N rate for ratoon cane grown on the soil at this site is 150 kg N/ha, resulting in a NUE of 0.73 t cane/ha for this crop. The calculated partial net return (PNR) for this N rate was A$4 799/ha. At a higher N rate (180 kg N/ha), the PNR increased to A$4 913/ha, but the NUE decreased to 0.63 t cane/kg N. At a lower N rate (120 kg N/ha), the NUE increased to 0.88 t cane/kg N (Figure 6-41b), but the PNR decreased to A$4 586/ha. The calculated partial net returns were based on a sugar price of A$525/t and urea costed at A$1.3/kg N (both indicative of the values at the time of the trial). The above values suggest that neither the higher nor the lower N rates are appropriate. The SIX EASY STEPS approach provides a balance between agronomic, economic (and hence social) and environmental outcomes.

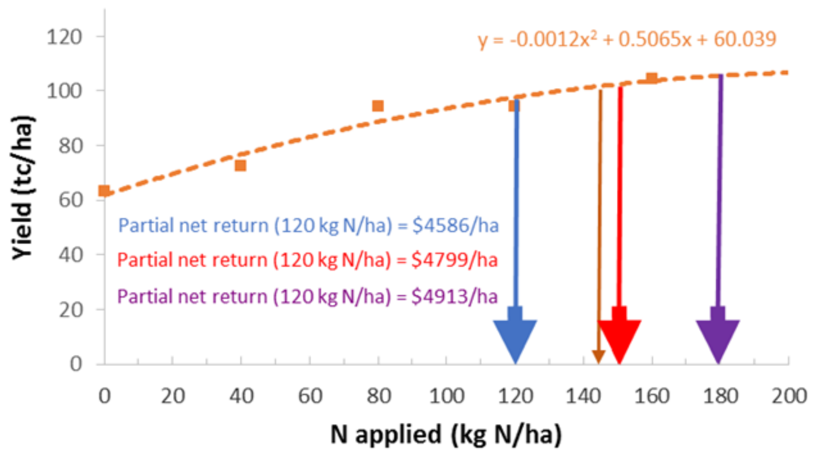


Figure 6-42 A yield response curve for a first ratoon crop from a rates of N trial conducted in the Herbert district.

The optimum N rate (corresponding to 95% of the maximum yield) is shown by the thin downward pointing thin brown arrow. The SIX EASY STEPS N rate (150 kg N/ha) is shown in red (partial net return of A$4799/ha), a higher N rate (180 kg N/ha) is shown in purple (partial net return of A$4913/ha) and a lower N rate (120 kg N/ha) is shown in blue (partial net return of A$4586/ha).

- **Enhanced efficiency fertilisers**

The use of enhanced efficiency fertilisers (EEFs), such as controlled-release fertilisers (CRFs) and DMPP-urea has been suggested as a means of improving NUE (Verburg *et al*, 2015). Nitrification inhibitors, such as DMPP have been shown to reduce nitrous oxide (N_2O) emissions from sugarcane soils (Wang *et al*., 2012), and potentially maintain sugarcane yields at lower N application rates (Wang *et al*., 2014). An increase in sugarcane yield with the use of CRFs has been reported in the Herbert district (Di Bella *et al*., 2014). This demonstrates the potential for EEFs to improve NUE and reduce N losses, but they are probably more effective in some situations than others. Trial results from a first ratoon crop detailed in Section 6.2.6 (Figure 6-18) on a clay soil in the Herbert district are provided here as an example. Fertiliser formulation had no effect on N response in a season where excessive rainfall did not occur. Given the likely variability in response to these products, suppliers of a locally available brand of DMPP-coated urea have developed a decision support tree for determining when the product has the best chances of reducing N losses. Similarly, the industry is also working to develop a decision tool that predicts where these products will be of most benefit. An adoption-focused project involving EEFs in 60 strip trials located in districts from Bundaberg northwards commenced in 2017 (Anon., 2017f). Results from these trials will help inform decision support tools.

- **Better alignment of N inputs to crop requirements**

A Smartcane BMP N Roadmap initiative was recently established within the Sugar Industry BMP Program (Anon., 2016b). The intent was to identify situations/circumstances where N inputs can be better aligned with crop requirements. A series of workshops and working group meetings was held to consider and devise updated information on particular aspects of N management. This included N from legume fallow crops and possible N management strategies for late harvested ratoons, older ratoons within crop cycles, where blocks of cane are subject to ongoing/intermittent waterlogging, seasonal climate forecasts and associated effects, and where sugarcane yields are constrained by adverse conditions (e.g. sodic soils).

Nutrients other than N

The need to investigate nutrients other that N has been identified at various stages during the past decade but have not received attention in recent times. These include:

- Phosphorus (P) in alkaline soils, particularly in relation to determining whether the BSES P soil test should be replace by Colwell for soils with pH > 7.
- Potassium (K) requirements for sugarcane grown in soils with ranges of non-exchangeable K contents and those soils that have been minimum-tilled.
- A range of nutrients and their interactions in soils that have been cropped over extended periods.

6.5.3. Managing the SIX EASY STEPS program in future

Due to the advances and developments mentioned above and other possibilities emanating from a range of projects, it is important to establish a mechanism so that options (from various sources) can be assessed in terms of their suitability for use within the SIX EASY STEPS program. It is essential that the SIX EASY STEPS program is managed appropriately by recognising a custodian of the system, providing the ability to assess scientific merit of new information, and ensuring that a process exists to incorporate accepted data and outputs into the SIX EASY STEPS.

To this end, the SIX EASY STEPS team have proposed that a SIX EASY STEPS Advisory Committee (SESAC) be established. It is envisaged that the SESAC will consist of a chairperson, three representatives from the core SIX EASY STEPS team, three or four members from outside the core SIX EASY TEAM (possibly a Queensland Government representative, at least one representative from industry peak bodies, and an industry-based extension/ adoption specialist) and a representative from the SRA Funding Unit or Panel.

The following terms of reference are proposed:

- The SESAC will set standards for accepting amendments to the SIX EASY STEPS guidelines and delivery packages.
- A group of referees with expertise and experience in sugarcane production, soil management and/or crop nutrition will be identified and appointed by the SESAC.
- These referees will assess the scientific merit of new/amended information and delivery mechanisms, and evaluate whether standards are met.
- The standards for assessing submissions will be included in a specifically developed template for use by the referees.
- The Chair will co-ordinate the activities of the SESAC, receive submissions and ensure that they are refereed in a timely manner.
- The SESAC will consider submissions and referees' reports. Decisions will be by consensus.
- The core SIX EASY STEPS team will incorporate accepted data/information into the SIX EASY STEPS program as appropriate.

6.5.4. Conclusions: adjustments to the SIX EASY STEPS

- The SIX EASY STEPS program is evolving with time, adapting to stakeholder (industry, government, community and environmental) needs, and remaining at the forefront of advances in research and development (R&D) and extension and adoption (E&A).
- It is accepted as the basis for nutrient BMP in growing sugarcane in Australia.
- This means that it provides sound guidelines for implementing practices that are supported by well-researched and validated data/information.
- Developments such as the short-course and workshop programs, decision support applications and nutrient management planning have, and continue to, provide 'tools' for achieving this outcome largely within STEPS 3 and 4 of the program.
- Recognition as the BMP standard also means that the SIX EASY STEPS program provides a mechanism for more innovative concepts to be tested and validated into the future. This is facilitated by the fundamental concepts of continuous improvement and cyclical learning in the program. STEPS 5 and 6 are aimed at providing such opportunities to researchers and users (growers and advisors).
- Developments and results from current and future R&D projects that potentially link to STEPS 5 and 6 needs to be assessed for their compatibility with the intent of the SIX EASY STEPS program.
- The formation and operation of the SESAC is critical for this process to occur. This particular mechanism will ensure that researchers have a means of contributing project outputs to the industry's nutrient management program.
- The SESAC will also ensure that growers, extension providers and advisors have confidence in the SIX EASY STEPS 'tools' they choose, use and/or promote for specific on-farm

circumstances. The process will therefore support the concept of the SIX EASY STEPS TOOLBOX and the 'tools' within it.
- The SIX EASY STEPS program continues to have a balanced approach that considers the agronomic, economic, social and environmental aspects of nutrient management.

6.6. Development of an updated SIX EASY STEPS short-course

The project team were of the opinion that it was best to use the existing SIX EASY STEPS short course PowerPoint presentation as the framework for any updated version. In particular, an amended version entitled SIX EASY STEPS Water Quality Update was discussed and developed in this way. A copy of the PowerPoint presentation (in excess of 200 slides) is available. In particular, the following revisions, amendments or insertions were made:

1. Revised objectives.
2. Amended operational boundaries.
3. Description of issues relating to N usage.
4. Information about NUE.
5. Descriptions of EEFs – fertilisers containing nitrification inhibitors (such as DMPP-coated urea) and poly-coated urea.
6. Example of a 'decision support tree' for using EEFs.
7. Timing of N fertiliser applications.
8. Information on projects investigating NUE and EEFs.
9. Information on the derivation of the N guidelines in the SIX EASY STEPS program.
10. Possibilities for using seasonal climate forecasting to guide N application rates.
11. Information on alternative and non-traditional fertilisers.
12. Concepts and guidance relating to nutrient management plans.

6. OVERALL CONCLUSIONS

Although conclusions have been included in most of the sub-sections in Section 6 of this report, the following is a summary of more general observations pertinent to the project as a whole:

- The importance of appropriate nutrient management in sugarcane production has been recognised in Australia ever since the early 1900s. Ongoing RD&E has occurred due to changing circumstances, the need for improved industry efficiency, productivity and profitability, and to meet environmental expectations.
- The SIX EASY STEPS program was developed using a logically based 'systems' framework with the aim of promoting sustainable practices.
- Nitrogen, in particular, rose to prominence because of identified water quality issues in the Great Barrier Reef lagoon.
- In reaction, the development, delivery and adoption of nutrient BMPs in sugarcane are aimed at minimising, or at least curbing, effects due to land-based fertiliser inputs.

The following are specific outcomes and conclusions from the longer-term N trials that were continued within this project:

Balanced nutrition

- The response to applied K in the Bundaberg NxK trial was due to insufficiency of K in plots that received zero or rates below the amount removed by crops over an extended period. Yield responses to applied N were markedly affected by low K in these circumstances. This illustrate the importance of applying K when it is required and re-iterates the need for, and importance of, “balanced nutrition”.

Farming systems impacts on N fertiliser requirements

- The SIX EASY STEPS program already recognises that sugarcane plant cane grown after a bare fallow requires less N fertiliser than replant cane (sugarcane grown without a fallow period between crop cycles).
- However, a long uncropped fallow period (12 months), as was the case prior to the current crop cycle at the trial site in Bundaberg, was found capable of generating sufficient N to supply the total needs of the ensuing sugarcane plant crop. This amount of N, presumably from mineralisation processes, was unlikely to have been generated solely from the inherent soil organic matter. It suggested that continuing mineralisation of N in the ‘biological pool’ resulted from legume fallow crops grown prior to previous crop cycles. This supports the opinion that the N from such legume fallow crops is retained in the soil, and is not all subject to loss by leaching during the crops immediately after the fallow period.
- The first of two N x Farming Systems trials in Mackay showed that long-term burnt and GCTB farming systems had similar response to applied N. There was no indication of greater N availability in the long-term GCTB system despite the retention of trash blankets between crops for over two decades. Productivity increases in the GCTB farming system was most likely due to soil moisture retention.
- The N x Farming Systems trial in Mackay also showed that crop N uptake and biomass development were slow in the first 3 months after harvest, and there were few differences due to N rates at this time. This suggests that the crop had low N demand and that background N in the soil pool was mostly able to support growth during this period. This result is consistent with recommendations that suggest a delay to fertiliser application after harvest by up to 6 weeks is unlikely to have any impact on yield. It should, however, be noted that this is not a practical management practice for crops harvested late in the season.
- The second N x Farming Systems trial in Mackay showed that ratoon crops following a soybean fallow did not acquire additional N in comparison to a bare fallow. There was evidence from the first ratoon crop that there may have been less N in the soil pool in the soybean fallow system due to lower sugarcane yield at the 0 kg N/ha rate. This was possibly due to the significantly reduced fertiliser N rate in the plant crop following the soybean fallow. Given this result, recommendations to apply ‘normal’ N rates to ratoon crops following a soybean fallow are justified, particularly if N applications are reduced in the plant crop to account for the legume N.
- The N x Farming Systems trials at Macknade showed that soil NO_3^--N, NH_4^+-N and min-N concentrations in the uncropped/ unfertilised areas adjacent to the experimental plots, had relatively high initial values. This was most likely due to residual N fertiliser, and/or mineralisation of ‘inherent’ soil Org C, trash from previous crop cycles and/or the remains of fallow crops grown previously at these sites. The values declined with time, but ‘flushes’ of N were evident due to assumed mineralisation processes. As expected seasonal rainfall and particularly excessive events appeared to have a marked effect on the distribution of min-N with depth.
- The Macknade trials also showed that conventional tillage and minimum/zero tillage treatments in permanent beds had no significant effect on N uptake by the crops in either trial (on different soil types) or in any of the seasons.

- Although similar yields were produced at these two sites where zero N was applied, the response to applied N was greater and larger crops were produced at the higher rates of N on the River Bank silty loam than on the Clay Loam (which is in a lower position in the landscape) in both seasons. There was strong evidence that optimum N rates were affected by positions in the landscape and the interaction with seasonal climatic conditions.
- As expected, the commonly used and industry understood NUE expressed as tonnes cane/ha decreased as the N rates increased across the trials and seasons. Conversely, NUE expressed as kg N/t cane increased with the rate of N applied, as did the Agron Eff_{fert}. The various NUE indicators were not particularly well-aligned with optimum N rates (as determined from response curves). These results show that it would have been inappropriate to set NUE targets because of the range and variability in values, particularly due to seasonal climatic conditions.
- As the underlying 'farming systems' treatments did not result in significant differences in soil min-N, crop N-uptake or yields, the existing SIX EASY STEPS guidelines are appropriate for both conventional and permanent bed/minimum tillage systems.

Impact of ratoon age on N fertiliser requirements

- The rates of N trials in Tully showed clearly that the amount of N applied had a statistically significant effect on dry biomass, crop N uptake and yields (cane and sugar yield) for most crops at both sites, but there was no statistically significant effect of N rate measured for CCS in any crop.
- The Tully data provided no clear indication if less N is required in older ratoon crops. Despite the 4R and 5R crops considered as older ratoons, mean sugarcane yields were comparable to the Tully mill average in the respective seasons. Sugarcane yields declined in the 6R crop but climatic conditions, especially the timing and extent of rainfall appeared to have a more significant influence on N response than crop age.

The following are specific outcomes and conclusions from the temporal N trials that were established within this project:

Comparison of EEFs to split applications of urea

- The temporal N trial (Bdb TN) is the only current sugarcane field trial in the Australian sugar industry in which standard urea inputs are compared to equivalent N rates using EEFs (DMPP-coated urea and poly-coated urea) and split applications of urea.
- Nitrogen application rates and N fertiliser formulation did not have a significant effect on soil min-N values. Differences in soil min-N were most apparent to depth with evidence of leaching down the soil profile. This appeared to occur across the N treatments (including the control).
- There were no significant yield (tc/ha, CCS and ts/ha) responses to applied N, split applications or use of EEFs. This was supported by the lack of responses observed in the third leaf N values.
- Increased N-uptake by the crop, due to the use of N strategies away from the standard practice (use of EEFs or split applications of urea), improved NUE values based on crop N (fertiliser N uptake efficiency), but this did not always translate into any improvements in yield.
- The highest partial net return in the plant and 1R crop corresponded to the control treatments. This was due to the lack of yield responses. Urea applied at the lower N rates in single applications resulted in the next best partial net returns in both crops. This appeared

to be the most appropriate strategy to minimise risk to growers. The cost of EEF fertilisers negatively affected the partial net returns. DMPP-coated urea being more affordable than the poly-coated urea option.

- The rainfall measured in Bundaberg during the seasons Sep 2015 – Oct 2017 would not have resulted in excessively wet conditions at the trial site. This may have contributed to the lack of responses to EEFs described above.

Response curves associated with EEF and standard urea

- The temporal N trial at Tara near Ingham (Hbt TN) is the only current sugarcane trial in the Australian sugar industry in which full N response curves are obtainable from a range of N rates (include zero N) applied as urea, DMPP-coated urea and poly-coated urea.
- Trial results from a first ratoon crop on this clay soil showed significant responses to applied N but no differences were apparent between the fertiliser formulations used (EEFs versus standard urea) in the particular season where excessive rainfall did not occur.
- Despite reports from other projects of reduced N losses and potential maintenance of sugarcane yields when EEFs were used at lower N application rates, the results from this trial indicated that an N rate of 120 kg N/ha would have been appropriate irrespective of the choice of N fertiliser formulation (urea, DMPP-coated urea or PC-coated urea).
- The lack of response to EEFs was possibly due to the rainfall pattern during these particular seasons where rainfall was not sufficient to cause marked N losses due to waterlogging or leaching.
- Increased crop N uptake that occurred in several of the aforementioned trials due to higher N rates, use of EEFs, split N applications, etc, did not necessarily result in increased yields.
- Further work, across seasons, is needed to fully evaluate the potential of EEFs for use in specific circumstances.

The following are specific outcomes and conclusions from the pot experiments conducted in semi-controlled conditions:

Nitrogen uptake

- There was little difference between cultivars in the N uptake dynamics using the artificial growth medium within the first 16 weeks (111 days) of growth.
- Having tested several cultivars in a pot experiment, Q208, which is a popular current cultivar, was considered suitable for testing EEFs. It appears unlikely that studies investigating N uptake dynamics using EEFs (in similar growth conditions) would be confounded by cultivar effects.
- An outdoor pot experiment demonstrated that a decrease in N supply to the crop by a reduced rate commensurately delayed the uptake of N and reduced cane biomass measured in the first 150 days after planting compared with higher and earlier N supply.
- Nitrogen uptake in a high N environment peaked by 100 days after planting whereas N uptake in a low N environment had not yet peaked 150 days after planting.
- In the first pot experiment in Bundaberg, N uptake by sugarcane plants (cv. Q200), grown with an equivalent rate of 150 kg N/ha (but with discounts for the N uptake at zero N applied), was found to contain 18% of the applied N in the stalks, 34% of the applied N in the leaves and tops, and 20% of the applied N in the roots. In total, 28% of the 150 kg N/ha application (42 kg N/ha) could not be accounted for in the crop. This N was probably held within the soil reserves as denitrification losses were unlikely and leaching losses were

minimised due to leachates being returned to the pots on a routine basis. A similar distribution pattern of N in the crop was obtained for cultivar Q208.

EEFs versus standard urea

- The second N fertiliser formulations / temporal N pot experiment in Bundaberg, showed that there were highly significant yield responses to applied N irrespective of the N-fertiliser formulation. However, DMPP-coated urea resulted in higher yields than those associated with the other products applied at assumed rates from about 120 to 180 kg N/ha. At the highest rate (225 kg N/ha) significant yield differences were no longer apparent. This difference may be associated with the irrigation regimes used in the pot experiment.
- The results of the pot experiments suggest the return of leachates to the pots was not appropriate when assessing EEFs. In future, this practice should be avoided, as it may enable easier separation of yields according to the various N supply mechanisms.

The following are specific outcomes and conclusions from the investigation of spatial aspects of trial results:

Yield and NUE mapping

- Harvester-derived yield data from a small plot experiment were found to be suitable for producing a yield map according to relatively broad yield categories. It was found that average yields of 55 tc/ha, 75 tc/ha and 95 tc/ha could be roughly ascribed to the low/medium low, medium and medium high/high areas within the NxK trial. Previously it was thought that yield monitors would not be appropriate for this scale of operation.
- Similarly, another set of harvester-derived yield data was used to develop a map showing areas of different NUE across two adjacent blocks of cane. As expected, the higher yielding parts of the block showed better NUE than the lower yielding sections. This may provide a further tool for growers to identify areas within block that need specific management to improve yields and NUE.

The following are general outcomes and conclusions from the project activities:

General conclusions

- Agronomic analyses based on response curves from replicated rates of N trials have shown that optimum N rates produced yields comparable to maximum attainable yield in various seasons.
- It was most apparent, and not unexpected, that the rainfall within different seasons has the greatest effect on cane productivity.
- The various economic assessments showed that reductions in N rates below BMP standards, although environmentally desirable (due to improved NUEs), had the potential to reduce industry revenue and net returns to growers and millers.
- It is essential that the impacts of water quality targets on the sugar industry and the Great Barrier Reef are assessed using multi-facetted analyses that incorporate at least agronomic, socio-economic and environmental considerations.
- Assessments based on a single over-riding factor (e.g. when only agronomic, economic, social or environmental aspects are considered in isolation of the others) have the potential to produce a result that is biased towards a particular outcome.

- Current DIN reduction targets, although environmentally favourable, have the potential to cause negative effects on cane productivity and profitability, and viability of mills and regional economies.
- Notwithstanding this, it is important that the sugar industry continues to commit to widespread adoption of BMPs. This dual awareness of economic and environmental sustainability will ensure that any water quality impacts on the sugar industry and the GBR are considered in a mutually beneficial way.

Strategies to balance sustainable sugarcane production and water quality targets

- The following strategies could contribute to solving the conundrum of balancing sustainable sugarcane production and water quality N targets in the GBR lagoon:
  - All stakeholders recognise that the proximity of much of the Australian sugar industry and the GBR results on mutual impacts.
  - Robust relationships between DIN targets and N rates be quantified so that those setting the targets and those expected to meet the targets have common goals.
  - Recognition in DIN models that improving farming practices (aimed at maximising cane yield) will improve NUE and lower N available for off-site impacts.
  - Changes in N management practices be assessed using multi-facetted analyses (agronomic, social, economic and environmental) as suggested by Poggio *et al*. (2016).
  - Use of BMPs to guide N inputs on-farm will enable profitable and environmentally responsible sugarcane production. This is best achieved through well-considered and implemented farm-specific nutrient management plans.
  - Credit be given to those growers who are striving for profitable sugarcane production in combination with environmental responsibility.
  - Growers who are yet to practice BMPs on their farms are encouraged to do so in a positive and supportive manner.
  - Future projects should include multi-faceted analyses to provide unbiased outcome.

SIX EASY STEPS program

- The SIX EASY STEPS program is evolving with time, adapting to stakeholder (industry, government, community and environmental) needs, and remaining at the forefront of advances in research and development (R&D) and extension and adoption (E&A).
- It is accepted as the basis for nutrient BMP in growing sugarcane in Australia.
- This means that it provides sound guidelines for implementing practices that are supported by well-researched and validated data/information.
- Developments such as the short-course and workshop programs, decision support applications and nutrient management planning have, and continue to, provide 'tools' for achieving this outcome largely within STEPS 3 and 4 of the program.
- Recognition as the BMP standard also means that the SIX EASY STEPS program provides a mechanism for more innovative concepts to be tested and validated into the future. This is facilitated by the fundamental concepts of continuous improvement and cyclical learning in the program. STEPS 5 and 6 are aimed at providing such opportunities to researchers and users (growers and advisors).
- Developments and results from current and future R&D projects that potentially link to STEPS 5 and 6 needs to be assessed for their compatibility with the intent of the SIX EASY STEPS program.

- Regular updating of the SIX EASY STEPS short course has ensured that it continues to provide the backbone of nutrient management training in the Australian sugar industry.
- The formation and operation of the SESAC is critical for this process to occur. This particular mechanism will ensure that researchers have a means of contributing project outputs to the industry's nutrient management program.
- The SESAC will also ensure that growers, extension providers and advisors have confidence in the SIX EASY STEPS 'tools' they choose, use and/or promote for specific on-farm circumstances. The process will therefore support the concept of the SIX EASY STEPS TOOLBOX and the 'tools' within it.
- Project participants have played a key role in the development of the SIX EASY STEPS TOOLBOX and SESAC concepts.
- The SIX EASY STEPS program continues to have a balanced approach that considers the agronomic, economic, social and environmental aspects of nutrient management.

7. PUBLICATIONS

The following publications resulted from efforts within this project:

Bhadha JH, Schroeder BL (2018) Best management practices for maintaining water quality in sugarcane cultivation. In P Rott (ed) Achieving sustainable cultivation of sugarcane. Burleigh Dodds Science Publishing, Cambridge, UK, pp 163-184.

Calcino DV, Hurney AP, Schroeder BL (2017) Extension of the "SIX EASY STEPS" nutrient management program to the Queensland Wet Tropics. *Proceedings of the Australian Society of Sugar Cane Technologist*s, **39**: 312-319

Poggio M, Renouf MA, Schroeder BL (2016) Balancing profitability and environmental considerations in best practice cane growing. *Proceedings of the International Society of Sugar Cane Technologists* **29**, 1840-1849.

Schroeder BL (2015) NUE: applying the right fertiliser in the right place at the right time. SRA CaneConnections Winter 2015, 6-7.

Schroeder BL, Skocaj DM (2017) Making the most of the SIX EASY STEPS nutrient management program. Sugar Research Australia CaneConnections, Spring 2017, 16-17.

Schroeder BL, Skocaj DM, Salter B (2018) SIX EASY STEPS – recognising and managing diversity. Australian Canegrower (26 Feb), 16-17.

Schroeder BL, Skocaj DM, Salter B, Calcino DV, Panitz JH, Wood AW, Hurney AP (2015) Why changing from District Yield Potential to Block Yield Potential as the basis for nitrogen guidelines is not as easy as it sounds. *Proceedings of the Australian Society of Sugar Cane Technologists***,** **37**: *18*

Schroeder BL, Skocaj DM, Salter B, Panitz JH, Park G, Calcino DV, Rodman GZ, Wood AW (2018) "SIX EASY STEPS" nutrient management program: improving with maturity. *Proceedings of the Australian Society of Sugar Cane Technologist*s, **40**: 179-193

Schroeder BL, Salter B, Moody PW, Skocaj DM, Thorburn PJ (2015) Evolving nature of nitrogen management in the Australian sugar industry. In MJ Bell (ed) A review of nitrogen use efficiency in sugarcane. Sugar Research Australia, Indooroopilly, 15-88.

Skocaj DM, Telford D, Hurney AP, Schroeder BL (2018) Process for developing farm nutrient management plans in the Wet Tropics. *Proceedings of the Australian Society of Sugar Cane Technologist*s, **40**: 194-201.

It is envisaged that several additional journal and/or conference papers, and industry focused articled will result from the comprehensive details included in this report.

8. ACKNOWLEDGEMENTS

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- Dr Peter Allsopp for his support and editing skills associated with the re-evaluation of the basic tenets of the various N management strategies and background information.
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- Angel Garmendia Garcia for assistance in generating several of the GIS images.
- SRA harvesting teams, and technical/casual staff who assisted with harvesting the field and glasshouse trials at the different locations.

9. REFERENCES

Anon. (2008) Scientific consensus statement on water quality in the Great Barrier Reef. https://www.reefplan.qld.gov.au/about/assets/scientific-consensus-statement-on-water-quality-in-the-gbr/pdf

Anon. (2013) Scientific Consensus Statement. http://www.reefplan.qld.gov.au/about/scientific-consensus-statement/ (accessed 19/01/2017).

Anon. (2016a) Australian Sugarcane Industry Overview. http://asmc.com.au/industry-overview (accessed 16/12/2016).

Anon. (2016b) About Smartcane BMP. https://www.smartcane.com.au/aboutBMP.aspx (accessed 10/11/2017).

Anon. (2016c) Bonsucro alignment secures future market for Queensland sugar. http://www.canegrowers.com.au/page/Industry_Centre/Media_Centre/Media_Releases/Bonsucro_alignment_secures_future_markets_for_Queensland_sugar/ (accessed 15/12/2016).

Anon. (2016d) Great Barrier Reef General Reference Map. http://www.gbrmpa.gov.au (accessed 16/12/2016).

Anon. (2016e) Reef Regulations. . https://www.qld.gov.au/environment/agriculture/sustainable-farming/reef-initiatives/ (accessed 17/02/2017).

Anon. (2016f) Great Barrier Reef Water Quality Science Taskforce. http://www.gbr.qld.gov.au/taskforce/ (accessed 19/01/2017).

Anon. (2017a) Facts about the Great Barrier Reef. http://www.gbrmpa.gov.au/about-the-reef/facts-about-the-great-barrier-reef (accessed 19/01/2017).

Anon. (2017b) The Reef 2050 Plan. https://www.environment.gov.au/marine/gbr/long-term-sustainability-plan (accessed 19/01/2017).

Anon. (2017c) The Reef Trust. . https://www.environment.gov.au/marine/gbr/reef-trust/ (accessed 19/01/2017).

Anon. (2107d) SIX EASY STEPS NutriCalc^{TM}. https://sugarresearch.com.au/wp-content/uploads/2017/02/IS13020-NutriCalc.pdf (accesses 1/12/2017).

Anon. (2017e) FertFinder. https://sugarresearch.com.au/growers-and-millers/farming-systems/#!panel-fertfinder-tool (accessed 5/12/2017).

Anon. (2017f) Growers needed for EEF60 on farm fertiliser trials. http://www.canegrowers.com.au/page/media/media-releases/2017/growers-needed-for-eef60-on-farm-fertiliser-trials (accessed 08/12/2017).

Bell MJ (2015) A review of nitrogen use efficiency in sugarcane. Sugar Research Australia, Indooroopilly, Australia, 320 pp.

Bell MJ, Halpin NV, Garside AL, Stirling GR, Moody PW, Robotham BG (2003) Evaluating combinations of fallow management, controlled traffic and tillage options in prototype sugarcane farming systems at Bundaberg. *Proceedings of the Australian Society of Sugar Cane Technologists,* **25,** CD-ROM.

Bell MJ, Moody PW (2015) Fertiliser N use in the sugar industry – an overview and future opportunities. In MJ Bell (ed): A review of nitrogen use efficiency in sugarcane. Sugar Research Australia, Indooroopilly, Australia, 305-320.

Bell MJ, Wood AW, Moody PW (2015a) Introduction and trends in nitrogen fertiliser use. In MJ Bell (ed): A review of nitrogen use efficiency in sugarcane. Sugar Research Australia, Indooroopilly, Australia, 9-14.

Bell MJ, Moody PW, Salter B, Connellan J, Garside AL (2015b) Agronomy and physiology of nitrogen use in Australian sugarcane crops. In MJ Bell (ed): A review of nitrogen use efficiency in sugarcane. Sugar Research Australia, Indooroopilly, Australia, 89-124.

Bramley RGV, Baillie CP, Schroeder BL (2014) A collaborative approach to Precision Agriculture RDE for the Australian sugar industry. Project CSE022 Final Report. Sugar Research Australia, Indooroopilly, 27 pp.

Bramley RGV, Jensen TA (2013) Sugarcane yield monitoring: A protocol for yield interpolation and key considerations in the collection of yield data. *Proceedings of the Australian Society of Sugar Cane Technologists,* **35**, 12 pp.

Bramley R, Ouzman J, Gobbett D (2017) Is district yield potential an appropriate concept for fertiliser decision making? *Proceedings of the Australian Society of Sugar Cane Technologists,* **39**, 67-77.

Brodie J, Fabricius K, De'ath G, Okaji K (2005) Are increased nutrient inputs responsible for more outbreaks of crown-of-thorns starfish? An appraisal of the evidence. *Marine Pollution Bulletin,* **51,** 266–278.

Bruce RC (1999) Sustainable nutrient management in sugarcane production: Course manual. CRC for Sustainable Sugar Production, James Cook University, Townsville, 166 pp.

Calcino DV(1994). Australian Sugarcane Nutritional Manual. SRDC/BSES, Indooroopilly.

Calcino DV, Schroeder BL, Hurney AP (2010) Extension and adoption of the 'SIX EASY STEPS' nutrient management program in sugarcane production in North Queensland. *Proceedings of the International Society of Sugar Cane Technologists,* **27**, CD-ROM.

Cannon MG, Smith CD, Murtha GG (1992) Soils of the Cardwell-Tully area, north Queensland. Divisional Report No. 115, CSIRO Division of Soils.

Carroll C, Waters D, Vardy S, Silburn DM, Attard S, Thorburn PJ, Davis AM, Halpin N, Schmidt M, Wilson B, Clark A (2012) A paddock to reef monitoring and modelling framework for the Great Barrier Reef: Paddock to catchments component. *Marine Pollution Bulletin,* **65**, 136-149.

Chapman LS (1994) Fertiliser N management in Australia. *Proceedings of the Australian Society of Sugar Cane Technologists,* **16,** 83 – 92.

Chapman LS (1996) Splitting N fertiliser application – Does it increase production efficiency of sugarcane. Sugarcane: Research towards efficient and sustainable production. Eds. Wilson JR, Hogarth DM, Campbell JA, Garside AL. CSIRO Division of tropical crops and Pastures, Brisbane pp. 194-197.

Chapman LS, Larsen PL, Jackson J (2001) Trash conservation increases cane yield in the Mackay district. *Proceedings of Australian Society of Sugar Cane Technologists,* **23,** 176-184.

Di Bella LP, Stacey S, Moody P, Benson A, Dowie J, Sluggett R (2014) An assessment of controlled release fertilisers in the Australian sugar industry. *Proceedings of the Australian Society of Sugar Cane Technologists,* **36**, 121-131.

Donnollan TE, Wilson PR, Zund PR, Irvine SA (1988) Soils and Irrigated Land Suitability of the Bundaberg Area, South East Queensland. Land Resources Bulletin, Department of Natural Resources, Brisbane.

Garside AL, Bell MJ (2001) Fallow legumes in the Australian sugar industry: Review of recent research findings and implications for the sugarcane cropping system. *Proceedings of the Australian Society of Sugar Cane Technologists,* **23,** 230-235.

Isbell RF (1996) The Australian Soil Classification. CSIRO Publishing, Collingwood, Australia.

Kealley MJ, Quirk MF (2016) Smartcane BMP – understanding drivers and building momentum for best management practice uptake in the Queensland sugarcane industry. *Proceedings of the International Society of Sugar Cane Technologists,* **29**, 445-453.

Keating BA, Verburg K, Huth NI, Robertson MJ (1997) Nitrogen management in intensive agriculture: sugarcane in Australia. In BA Keating and JR Wilson (eds): Intensive sugarcane production: Meeting the challenges beyond 2000. CAB International, Wallingford, UK, 273-275.

Kroon F, Thorburn P, Schaffelke B, Whitten S (2016) Towards protecting the Great Barrier Reef from land –based pollution. *Global Change Biology,* **22**, 1985-2002.

Llewellyn RS (2011) Identifying and targeting adoption drivers. In: Pannell, Vanclay (eds), Changing Land Management: Adoption of new practices by rural landholders, CSIRO Publishing.

Meier EA, Thorburn PJ (2016) Long-term sugarcane crop residue retention offers limited potential to reduce nitrogen fertilizer rates in the Australian wet tropical environments. *Frontiers in Plant Science,* **7,** 1017.

Moody PW, Blogg D, Legrand J, Schroeder BL, Wood AW (2008) 'SCAMP' and 'Safegauge for Nutrients': Two new decision support tools for minimising off-site movement of nutrients. *Proceedings of the Australian Society of Sugar Cane Technologists,* **30**, 276-284.

Moody PW, Schroeder BL, Pu G, Panitz JH (2014) Effects of the application of mill mud/mud ash on soil properties and available soil nitrogen and phosphorus. *Proceedings of the Australian Society of Sugar Cane Technologists,* **36,** 45-52.

Mooney P (2004) Democratizing rural economy: institutional friction, sustainable struggle and the cooperative movement. *Rural Sociology,* **69**, 76–98.

Page KL, Bell M, Dalal RC (2013) Changes in total soil organic carbon stocks and carbon fractions in sugarcane systems as affected by tillage and trash management in Queensland, Australia. *Soil Research,* **51,** 608-614.

Park SE, Webster AJ, Horan HL, James AT, Thorburn PJ (2010). Legume rotation crops lessen the need for nitrogen fertiliser throughout the sugarcane cropping cycle. *Field Crops Research,* **119,** 331-341.

Poggio M, Renouf MA, Schroeder BL (2016) Balancing profitability and environmental considerations in best practice cane growing. *Proceedings of the International Society of Sugar Cane Technologists,* **29**, 1840-1849.

Robertson FA, Thorburn PJ (2007) Management of sugarcane harvest residues: consequences for soil carbon and nitrogen. *Australian Journal of Soil Research,* **45,** 13-23.

Robertson MJ, Llewellyn RS, Mandel R, Lawes R, Bramley RGV, Swift L, Metz N, O'Callaghan C (2012) Adoption of variable rate fertiliser application in the Australian grains industry: status, issues and prospects. *Precision Agriculture,* **13,** 181-99.

Robinson N, Schmidt S, Lakshmanan P (2015) Genetic improvement of nitrogen use efficiency in sugarcane. In MJ Bell (ed): A review of nitrogen use efficiency in sugarcane. Sugar Research Australia, Indooroopilly, Australia, 125-156.

Robson A, Stabley J, Lamb D (2015) Investigating remote sensing technologies and their potential for improving nitrogen management in sugarcane. In MJ Bell (ed): A review of nitrogen use efficiency in sugarcane. Sugar Research Australia, Indooroopilly, Australia, 157-182.

Salter B, Schroeder BL, Perna J (2010). Farming systems and their effect on the response of sugarcane to nitrogen. *Proceedings of the Australian Society of Sugar Cane Technologists,* **32,** 201-220.

Salter B, Schroeder BL, Panitz JH, Calcino DV, Wood AW (2015a) Soil-Specific Nutrient Management Guidelines for Sugarcane Production in the Mackay Region. Technical Publication TE15001, Sugar Research Australia, Indooroopilly 82pp.

Salter B, Wang W, Schroeder B, Reeves S (2015b) Nitrogen dynamics and nitrous oxide emissions in improved sugarcane farming systems. *Proceedings of Australian Society of Sugar Cane Technologists,* **37,** 42-52.

Schroeder BL, Cameron T, Linedale AI, Allsopp PG (2009b) Realised value of RD&E in the Australian sugar industry: Economic benefits of the changing farming system. *Proceedings of the Australian Society of Sugar Cane Technologists,* **31**, 221-229.

Schroeder BL, Hubert JW, Hubert C, Hubert FG, Panitz JH, Wood AW, Moody PW (2007b) Recognising differences in soil type to guide nutrient inputs on-farm – a case study from Bundaberg. *Proceedings of the Australian Society of Sugar cane Technologists,* **29,** 138-148.

Schroeder BL, Hurney AP, Wood AW, Moody PW, Allsopp PG (2010b) Concepts and value of the nitrogen guidelines contained in the Australian sugar industry's 'SIX EASY STEPS' nutrient management program. *Proceedings of the International Society of Sugar Cane Technologists,* **27**, CD-ROM

Schroeder BL, Hurney AP, Wood AW, Moody PW, Calcino DV, Cameron T (2009a) Alternative nitrogen management strategies for sugarcane production in Australia: The essence of what they mean. *Proceedings of the Australian Society of Sugar Cane Technologists,* **31**, 93-103.

Schroeder BL, Moody PW, Wood AW (2003) Improved nutrient management in the Australian sugar industry. Sugar Research and Development Corporation Project BSS232 Final Report. Bureau of Sugar Experiment Stations, Indooroopilly, Australia.

Schroeder BL, Panitz JH, Wood AW, Moody PW and Salter B (2007a) Soil-Specific Nutrient Management Guidelines for Sugarcane Production in the Bundaberg District. Technical Publication TE07004, BSES Limited, Indooroopilly, 76 pp.

Schroeder BL, Salter B, Moody PW, Skocaj DM, Thorburn PJ (2015) Evolving nature of nitrogen management in the Australian sugar industry. In MJ Bell (ed): A review of nitrogen use efficiency in sugarcane. Sugar Research Australia, Indooroopilly, Australia, 15-88.

Schroeder BL, Webster K, Davies B, Wood AW, Kingston G (2002) Fertiliser recommendations. In: Bruce RC (ed) Managing soils, nutrients and environment for sustainable sugar production, 115-128. CRC for Sustainable Sugar Production, Townsville

Schroeder BL and Wood AW (2001) Assessment of nitrogen mineralising potential of soils in two different landscapes in the Australian sugar industry – implications for N fertiliser management. *Proceeding of the Australian Society of Sugar Cane Technologists,* **23,** 281-288.

Schroeder BL, Wood AW, Calcino DV, Skocaj DM, Hurney AP, Allsopp PG (2018) Good planting and cultivation practices in sugarcane production. In P Rott (ed): Achieving sustainable cultivation of sugarcane Vol 1. Burleigh Dodds Science Publishing Limited, Cambridge, UK.

Schroeder BL, Wood AW, Kingston G (1998) Re-evaluation of the basis for fertiliser recommendations in the Australian sugar industry. *Proceedings of the Australian Society of Sugar Cane Technologists,* **20**, 239-247.

Schroeder BL, Wood AW, Moody PW, Bell MJ, Garside AL (2005) Nitrogen fertiliser guidelines in perspective. *Proceedings of the Australian Society of Sugar Cane Technologists* **27**, 291-304.

Schroeder BL, Wood AW, Moody PW, Panitz JH (2008b) A comparison of different approaches for deriving nitrogen application rates using trial data from Macknade. *Proceedings of the Australian Society of Sugar Cane Technologists,* **30,** 359-360.

Schroeder BL, Wood AW, Moody PW, Panitz JH, Agnew JR, Sluggett RJ, Salter B (2006) Delivering nutrient management guidelines to growers in the Central Region of the Australian sugar industry. *Proceedings of the Australian Society of Sugar Cane Technologists,* **28**, 142-154.

Schroeder BL, Wood AW, Panitz JH, Salter B, Moody PW (2008a) The "SIX EASY STEPS" as a delivery mechanism for best practice nutrient management in the Australian sugar industry. Soils 2008 Conference, Massey University, Palmerston North, New Zealand, 2 pp.

Schroeder BL, Wood AW, Park G, Panitz JH, Stewart RL (2009c) Validating the 'SIX EASY STEPS' nutrient management guidelines in the Johnstone catchment. *Proceedings of the Australian Society of Sugar Cane Technologists,* **31,** 177-185.

Schroeder BL, Wood AW, Sefton M, Hurney AP, Skocaj DM, Stainlay T, Moody PW (2010a). District yield potential: An appropriate basis for nitrogen guidelines for sugarcane production. *Proceedings of the Australian Society of Sugar Cane Technologists,* **32**, 193-210.

Skocaj D (2015) Improving sugarcane nitrogen management in the Wet Tropics using seasonal climate forecasting. Research thesis, James Cook University.

Skocaj DM, Everingham YL (2014) Identifying climate variables having the greatest influence on sugarcane yields in the Tully mill area. *Proceedings of the Australian Society of Sugar Cane Technologists,* **36**, 53–61.

Skocaj DM, Everingham YL, Schroeder BL (2013) Nitrogen management guidelines for sugarcane production in Australia: Can these be modified for wet tropic conditions using seasonal climate forecasting? *Springer Science Reviews*, **1**(1-2), 51-71.

Skocaj DM, Hurney AP, Schroeder BL (2012) Validating the 'SIX EASY STEPS' nitrogen guidelines in the Wet Tropics. *Proceedings of the Australian Society of Sugar Cane Technologists*, **34**, 10 pp.

Skocaj DM, Telford D, Hurney AP, Schroeder BL (2018) Process for developing farm nutrient management plans in the Wet Tropics. *Proceedings of the Australian Society of Sugar Cane Technologists,* **40,** 194-201.

Thompson P (2007) Agricultural sustainability: What it is and what it is not. *International Journal of Agricultural Sustainability,* **5**, 5-16.

Thorburn PJ, Biggs JS, Meier EA, Empson M, Palmer J, Verburg K, Skocaj DM (2015) Increasing nitrogen use efficiency in Australian sugarcane crops: Insights from simulation modelling. In MJ Bell (ed): A review of nitrogen use efficiency in sugarcane. Sugar Research Australia, Indooroopilly, Australia, 183-228.

Thorburn PJ, Biggs JS, Skocaj DM, Schroeder BL, Sexton J, Everingham YL (2018) Crop size and sugarcane nitrogen fertiliser requirements: is there a link? *Proceedings of the Australian Society of Sugar Cane Technologists,* **40**, 210-218.

Thorburn PJ, Biggs JS, Webster AJ, Biggs IM (2011) An improved way to determine nitrogen fertiliser requirements of sugar cane crops to meet global environmental challenges. *Plant and Soil,* **339,** 51-67.

Thorburn PJ, Biggs JS, Weier KL, Keating BA (2003b) Nitrate in groundwater of intensive agricultural areas in coastal north eastern Australia. *Agriculture Ecosystems and Environment,* **94**, 49-58.

Thorburn PJ, Park SE, Biggs IM (2003a) Nitrogen fertiliser management in the Australian sugar industry: Strategic opportunities for improved efficiency. *Proceedings of the Australian Society of Sugar Cane Technologists,* **25,** CD-ROM.

Thorburn PJ, Wilkinson SN, Silburn DM (2013) Water quality in agricultural lands draining to the Great Barrier Reef: Review of causes, management and priorities. *Agriculture, Ecosystems and Environment,* **180**, 4-20.

Vallis I, Catchpoole VR, Hughes RM, Myers RL and Ridge DR (1996a) Recovery in plants and soils of $_{15}$N applied as subsurface bands of urea to sugarcane. *Australian Journal of Agricultural Research,* **47,** 355-270

Vanclay F (2004) Social principles for agricultural extension to assist in the promotion of natural resource management. *Australian Journal of Experimental Agriculture,* **44**, 213-222.

Verburg K, Harvey TG, Muster TH, Brennan McKellar LE, Thorburn PJ, Biggs JS, Di Bella LP, Wang W (2015) Use of enhanced efficiency fertilisers to increase fertiliser nitrogen use efficiency in sugarcane. In MJ Bell (ed): A review of nitrogen use efficiency in sugarcane. Sugar Research Australia, Indooroopilly, Australia, 229-295.

Walkley A, Black IA (1934) An examination of the Degtjareff method of determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil Science* **37,** 29-38.

Wang WJ, Salter B, Reeves SH, Brieffies TC, Perna J (2012). Nitrous oxide emissions from sugarcane soil under different fallow and nitrogen fertiliser management regimes. *Proceedings of the Australian Society of Sugar Cane Technologists*, **34**, 8 pp.

Wang WJ, Salter B, Reeves SH, Park G, Zahmel M, Heenan MA (2014) Effects of urea formulation on sugarcane yield, nitrogen uptake and nitrous oxide emissions in tropical Queensland. *Proceedings of the Australian Society of Sugar Cane Technologists,* **36**, 110-120.

Wilson PR, Baker DE (1990) Soils and agricultural land suitability of the wet tropical coast of north Queensland: Ingham area. Queensland Department of Primary Industries Land Resources Bulletin QV90001.

Wood AW, Kingston G (1999) Nutrient use-efficiency. In: Bruce RC (ed) Sustainable Nutrient Management in Sugarcane Production: Course Manual. CRC for Sustainable Sugar Production, James Cook University, Townville. pp 97-101.

Wood AW, Holzberger G, Kerkwyk RE, Dwyer R, Schroeder BL (2008) Trends in nutrient applications in the Herbert River District: 1996-2006. *Proceedings of the Australian Society of Sugarcane Technologists,* **30**, 260-266.

Wood AW, Schroeder BL, Dwyer R (2010). Opportunities for improving the efficiency of use of nitrogen fertiliser in the Australian sugar industry. *Proceedings of the Australian Society of Sugar Cane Technologists,* **32**, 221-233.

Wood AW, Schroeder BL, Stewart RL (2003) Soil specific management guidelines for sugarcane production: Soil reference booklet for the Herbert district. CRC Sugar Technical Publication, CRC for Sustainable Sugar Production, Townsville, 92pp.