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CRDC

Rural R&D for Profit Program

More Profit from Nitrogen

RRDP1717 (July 2016 - May 2020)

**Improved nitrogen use efficiency through
accounting for deep soil and mineralisable N
supply & deployment of EEF to better match crop
N demand**

Final Report

31 May 2020

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Sugar Research
Australia



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Project team details

Provide details of all personnel involved in the project.

Name	Position	Organisation	Role	Duration of involvement
Lukas Van Zwieten	Principal Research Scientist	NSW DPI	Key researcher	Entire project (0.1FTE)
Josh Rust	Technical officer	NSW DPI	Key researcher	Entire project (0.1FTE)
Terry Rose	Professor	Southern Cross University	Key researcher	Entire project (0.1FTE)
Rick Beattie	Agricultural Manager	Sunshine Sugar	Key advisor- agronomy	Entire project (0.05FTE)
Scott Petty	Technical assistant	NSW DPI	Field site management	Entire project (0.2FTE)
Ken Lisha	Technical assistant	NSW DPI	Soil preparation/ analysis	Entire project (0.6 FTE)

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Plain English Executive Summary

Nitrogen (N) is an essential plant macronutrient used for photosynthesis and amino acid production. While soils can provide N to plants, deficiencies often occur when the removal of N (ie, through harvest of product) exceeds the ability of soil to provide N through mineralisation of organic matter stocks. To optimise the yield potential of the crop, farmers will often fertilise crops with N, and other macro- and micro- nutrients.

Nitrogen use efficiency (NUE) is the amount of applied fertiliser N that contributes to plant production and is recovered in the crop. NUE is generally low in sugarcane farming systems due to losses of N via denitrification, leaching and surface runoff (Bell, 2014). While N loss from farms can be a financial consideration for farmers, it can also impact on water quality and can contribute to Australia's greenhouse gas inventory through emissions of nitrous oxide (N₂O). There is evidence that enhanced efficiency nitrogen fertilisers (EENFs) can lower N₂O emissions from soils, but data are generally lacking in the literature on the benefits of EENFs such as controlled release fertilisers on crop production and profitability. Controlled release fertilisers are designed to better match N supply with crop demand, thus theoretically minimising N loss pathways and improving fertiliser N use efficiency.

Nitrogen can also be supplied to the crop from existing stores of plant available nutrient in soil, as well as through potentially mineralisable N (PMN). The breakdown of organic material such as harvest residues (ie, sugarcane trash) and soil organic matter (SOM) releases plant available N to the crop, but the amounts added are currently difficult to incorporate into decision support tools as predictive measurements of organic N contribution have not been available.

Therefore, the aims of this project were to better quantify and understand the existing inorganic and organic N stocks available in soils of the NSW sugarcane growing region and to evaluate the ability of controlled release fertilisers (polymer coated urea [PCU]) to better match sugarcane N demand. The objective was to increase fertiliser NUE and crop productivity.

An assessment of 41 sugarcane paddocks in NSW revealed that there was variability in both the quantity of mineral N (ie plant available N) in soil, as well as PMN. For example, both soil nitrate (NO₃⁻) and soil ammonium (NH₄⁺) content ranged from less than 25kg N/ha in to top 40cm of soil to around 100kg N /Ha. In a 14-day laboratory incubation (14 day PMN), the soils mineralised 25–225 kg N/ha. Summing the mineral N and 14 day PMN, plants then would have had access to stores of N in the range of 50–400 kg N/ Ha. Actual in-field mineralisation of N over the cropping season (300 days) ranged between 100–560 kg N/ha. However, knowing the quantity of PMN before applying the industry's decision support tool, the Six Easy Steps (6ES), has not been possible. To address this gap, the project developed a rapid relatively inexpensive overnight test based on mid-infrared spectroscopy that can predict the potentially mineralisable N (PMN) during the cropping season in NSW sugarcane soils. These rapid predictions compared favourably with the 14-day laboratory testing method.

To evaluate the potential benefits of PCU on nutrient use efficiency and sugarcane yield, four field trials were established in three NSW cane-growing catchments (Tweed, Richmond and Clarence). Each experiment examined the growth response of sugarcane to six different fertiliser application

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rates to give a crop response curve (0, 50, 100, 200, 300, 400 kg N/ha). All rates of fertiliser were applied as PCU or urea. All experiments were biometrically randomised in a complete block design with three replicates of each treatment. Across all experiments, cane yields showed no statistically significant differences between N supplied via urea or via PCU. However, all four field trials experienced well below-average rainfall in spring and early summer—conditions not conducive to major losses of N from the soil-plant system. A general trend for increasing yield with increasing N rate was observed at three of the four sites. The agronomic efficiency of fertiliser, an index of the yield benefit from applying fertiliser compared to a control, divided by the rate of fertiliser applied, ranged from 2.2% to 37.3%. For two of the four field sites, the highest agronomic efficiency of fertiliser occurred at the lowest rate of N fertiliser application. The low agronomic efficiency of fertiliser reflected the relatively flat N response curves detected with increasing N fertiliser rate. The data clearly demonstrate the ability of some of the NSW sugarcane soils to provide crops with adequate N nutrition (particularly when biomass growth is inhibited by low rainfall) with lower fertiliser N rates, and hence the need for growers to test their soil for both available soil N and PMN before applying N fertiliser.

A comprehensive dataset was obtained for the release pattern of plant-available N from two contrasting PCU products, as well as a better understanding of the N uptake pattern by sugarcane grown in NSW. Steps have been taken to ensure this quantitative information can be used in future models where seasonal climate forecasts could be used to predict ‘when’ PCU would show an advantage over urea, as well as ‘which’ PCU product would be most suited to the predicted specific climate/ rainfall scenario, soil PMN content and existing stores of plant available N. By incorporating a better estimate of PMN into the existing industry decision support tool (6ES), recommendations for N application rates could be refined, thereby ensuring both optimum yield as well as optimum fertiliser N application rate.

Abbreviations and glossary

6ES: The six easy steps. A decision support tool for the sugarcane industry.
(sugarresearch.com.au/wp-content/uploads/2017/02/IS13016-Best-practice-nutrient-management-Six-Easy-Steps.pdf)

EENF: enhanced efficiency nitrogen fertiliser

GNDVI: The Green Normalised Difference Vegetation Index (GNDVI) is a vegetation index for estimating photo synthetic activity and is a commonly used vegetation index to determine water and nitrogen uptake into the plant canopy. $GNDVI = (NIR - Green)/(NIR + Green)$

Mineral N: (the sum of nitrate-N and ammonium -N)

MIR: Mid-Infrared spectroscopy

N: nitrogen

N₂O: nitrous oxide- a greenhouse gas

N₂: dinitrogen

NH₄⁺: ammonium

NO₃⁻: nitrate

NDVI: Normalised Difference Vegetation Index

PCU: polymer coated urea

PCU90 : 90 day polymer coated urea (orange)

PCU270: 270 day polymer coated urea (blue)

PMN: potentially mineralisable N

TN: total N

TC: total C

TOC: total organic C

UAV: unmanned aerial vehicle

1 Project rationale

A review of fertiliser use in the sugarcane industry (Bell et al., 2015) recognised that N use efficiency, especially following high fertiliser application, tends to be poor. This project directly addressed this key finding for NSW sugarcane farming systems.

1.1 The key research objectives were:

- To assess stocks of plant available N in NSW sugarcane soils prior to planting or ratoon emergence and determine whether soil properties influence these stocks;
- To better understand the contribution of potentially mineralisable N (PMN) – that is the N derived from the breakdown of plant materials or soil organic C, on these existing soil N stocks;
- To evaluate the use of PCU in sugarcane farming systems to improve N use efficiency;
- To evaluate mid infrared spectroscopy as a potential new test for rapidly assessing soil PMN;
- To collate this information for improved N use efficiency and farm profitability.

1.2 The key project recommendations are:

- Existing soil N stocks, including nitrate NO_3^- and NH_4^+ in the 0-40cm layer, as well as PMN should be considered in making decisions on the most appropriate N fertiliser rate (ie, informing the 6ES);
- While no benefits to yield were observed across four biometrically designed field trials with the use of PCU versus urea application, it must be noted that the field trials all experienced particularly dry starts to the season, where loss pathways of N were low. The use of PCU (being a more expensive product than urea) should be considered when N loss pathways are deemed important- ie, average or higher than average rainfall is expected following N fertiliser application. This would require a modelling approach detailed location specific climate forecasting;
- Mid-infrared spectroscopy (MIR) provides a useful prediction for mineralisable N (especially long term mineralisable N) for NSW soils collected at sowing, which along with available mineral N can be used to refine fertiliser N recommendations for growers. Opportunities exist to offer this test as a service to the NSW sugarcane industry, allowing refined fertiliser N decisions.

1.3 Key messages to industry

- Careful consideration needs to be given in selecting EENFs, as their efficacy compared to the less expensive urea products did not justify their expense in the current testing seasons, which experienced very dry or drought conditions.
- Improved location specific seasonal climate forecasting is required, in conjunction with a modelling approach, to determine when EENFs would be of benefit, and which N release pattern from PCU would be optimal for the given season;
- Some soils can provide a significant quantity of plant available N from existing mineral N stores and PMN. The project team will work with Sunshine Sugar to further validate the potential of the MIR test for PMN, and how this could inform the 6ES.

2 Method and project locations

2.1: Determine deep soil N content/ potentially mineralisable N

Twenty-seven cane paddock sites representative of key regions in NSW were sampled in 2016 from across the Tweed, Richmond and Clarence catchments, with an additional 14 sites from the Tweed catchment added in 2019, to determine deep soil N content and PMN. All sites selected were post-harvest/pre-fertiliser application.

Soils were cored to 1 m depth on-row from three locations of the paddock using a hydraulic soil corer. The cores were sectioned into 20cm depth increments. The sectioned cores were analysed for mineral N (ie, nitrate + ammonium), total C & N, bulk density and laboratory based PMN. Data were used to determine the plant available N stocks in soil prior to the paddocks being fertilised for the given season. For each site, an additional 1 m core sample was taken on-row from the centre of the paddock and collected intact for assessment of root distribution.

2.2: Assessment of PMN

The 14-day PMN assessment was undertaken according to the methods described by Allen et al (2019). Sub-samples from the 0-20 and 20-40cm profiles of the deep soil cores taken at all 41 sites were incubated at field capacity and 30°C under aerobic conditions, and sampled at 0, 7 and 14 days. At each time, samples were analysed for mineral N (ammonium-N and nitrate-N) within NSW DPI's NATA accredited facility at Wollongbar. PMN was calculated as the difference between the mineral N before and after incubation. Using bulk density conversions from the field cores, the PMN was converted to "Available N" in kg/Ha.

The incubation method was extended from 14-day to 56-day with the inclusion of sampling times at 21 and 56 days to address a perceived underestimation of PMN from the 14-day method. An additional "long-term" incubation study aimed at determining the contribution of mineralisation to N availability (PMN) across the cropping cycle was also conducted with samples analysed at 300 and 456 days (10 and 16 months) using the methodology described by Allen et al (2019).

Soils from the 41 core sites sampled under 2.1 were analysed by MIR at the NSW DPI NATA approved facility. Data from these analyses were provided to the University of Queensland along with results of 56-day and long-term PMN incubations for modelling and correlation.

2.3: Field trial assessment of PCU

Four core field sites (see table below) were established across the three Northern NSW cane-growing catchments over two growing seasons: 2016/17 and 2018/19/20. The field trials established at each site used a randomised complete block design of 6 rates (0, 50, 100, 200, 300 and 400 kg N/Ha) with the source of N being either standard urea or PCU. Trials 1 and 2 established in 2016/17 used the

orange 90- day polymer coated urea (PCU90), while field trials 3 and 4 used a 50:50 blend of PCU-90 and 270- day release formulation (PCU270).

Each plot spanned three rows of cane. The outer two rows served as a buffer, while all sampling and measurement was conducted on the centre row. The length of the trial plots was adjusted to suit block allocation – ranging from 27-36m. The large agronomically relevant plot size enabled commercial harvesting of the sugarcane. Fertiliser was applied using a stool-splitter as per standard practice, calibrated in the field for each product and rate.

Field trials 1 and 2 were machine harvested as 1-year sugarcane using a weigh bin with 5kg accuracy. Field trials 3 and 4 were established as 2-year cane trials with a yield estimate conducted in 2019 using an SRA-supplied methodology for estimating 2-year yield from hand cut 9-month old cane. Harvest of the field sites occurred in July 2020, and data is presented in the report.

Nitrogen release curves from both PCU90 and PCU270 were generated from field trials 3 and 4. An unfertilised section of the trial block was set aside, and PCU90 and PCU270 matching the rate of 200 kg N/Ha were placed in nylon bags in the same zone that the stool splitter placed the N fertiliser. The nylon bags were removed from the field at regular intervals over a 12 month period, and PCU in the nylon bags collected and analysed for residual N content.

Performance of PCU and urea was evaluated through yield assessment, biomass N accumulation, Apparent NUE and Apparent Fertiliser Recovery. Additional monitoring of leaf N via SRA Third-Leaf field sampling (for plant N uptake) and UAV based multi spectral imaging informed crop performance over time.

2.4: Quality Assurance

All laboratory procedures, field trials and project management were undertaken through the team's ISO9001:2015 certification, which was externally audited twice within the project funding period. The ISO9001:2015 certification is based on a number of quality management principles including a strong client focus, and a process approach with a commitment to continual improvement. Laboratory analysis for mineral N, total C and other soil measurement were undertaken in a NATA accredited facility.

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Table of the locations

Research Site Type	Name	Location	Coordinates	Active Site Period	Experimental treatments
<i>Core field site</i>	Quirk Family- Commercial Farm	Stotts Creek, NSW	-28.28185, 153.50739	11/2016- 11/2017	Field trial assessing EENF (PCU) vs urea at 0, 50, 100, 200, 300, 400 units N each for each formulation of fertiliser. Plots a minimum of 33m in length, Random complete block design (n=3).
<i>Core field site</i>	Rodgers Family - Commercial Farm	Pimlico, NSW	-28.89123, 153.51904	12/2016- 06/2018	Field trial assessing EENF (PCU) vs urea at 0, 50, 100, 200, 300, 400 units N each for each formulation of fertiliser. Plots a minimum of 33m in length, Random complete block design (n=3).
<i>Core field site</i>	Pye Family- commercial farm	Coraki, NSW	-29.008100, 153.294945	11/2018- Field site active for final commercial harvest outside of project period	Field trial assessing EENF (PCU) vs urea at 0, 50, 100, 200, 300, 400 units N each for each formulation of fertiliser. Plots a minimum of 33m in length, Random complete block design (n=3).
<i>Core field site</i>	Munroe Family - Commercial Farm	Woodford Island, NSW	-29.525483, 153.110182	10/2018- Field site active for final commercial harvest outside of project period	Field trial assessing EENF (PCU) vs urea at 0, 50, 100, 200, 300, 400 units N each for each formulation of fertiliser. Plots a minimum of 33m in length, Random complete block design (n=3).
<i>Field N stocks assessment</i>	Maclean 1	“Clarence Catchment”	-29.52417, 153.12073	06/16-03/20	4 deep soil cores taken per field, 1 used for assessment of BD and root mass, 3 bulked for chemical assessment. Cores divided into 0-20cm, 20-40cm, 40-60cm, 60-80cm and 80-100cm layers. Soils used

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					throughout project for assessment of soil N stocks, PMN, calibration with MIR and other factors.
<i>Field N stocks assessment</i>	Maclean 2	“Clarence Catchment”	-29.52559, 153.11119	06/16-03/20	4 deep soil cores taken per field, 1 used for assessment of BD and root mass, 3 bulked for chemical assessment. Cores divided into 0-20cm, 20-40cm, 40-60cm, 60-80cm and 80-100cm layers. Soils used throughout project for assessment of soil N stocks, PMN, calibration with MIR and other factors.
<i>Field N stocks assessment</i>	Palmers Island 1	“Clarence Catchment”	-29.45663, 153.26624	06/16-03/20	4 deep soil cores taken per field, 1 used for assessment of BD and root mass, 3 bulked for chemical assessment. Cores divided into 0-20cm, 20-40cm, 40-60cm, 60-80cm and 80-100cm layers. Soils used throughout project for assessment of soil N stocks, PMN, calibration with MIR and other factors.
<i>Field N stocks assessment</i>	Palmers Island 2	“Clarence Catchment”	-29.45633, 153.25976	06/16-03/20	4 deep soil cores taken per field, 1 used for assessment of BD and root mass, 3 bulked for chemical assessment. Cores divided into 0-20cm, 20-40cm, 40-60cm, 60-80cm and 80-100cm layers. Soils used throughout project for assessment of soil N stocks, PMN, calibration with MIR and other factors.
<i>Field N stocks assessment</i>	Harwood 1	“Clarence Catchment”	-29.42276, 153.24615	06/16-03/20	4 deep soil cores taken per field, 1 used for assessment of BD and root mass, 3 bulked for chemical assessment. Cores divided into 0-20cm, 20-40cm, 40-60cm, 60-80cm and 80-100cm layers. Soils used throughout project for assessment of soil N stocks, PMN, calibration with MIR and other factors.

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<i>Field N stocks assessment</i>	Harwood 2	"Clarence Catchment"	-29.42115, 153.24786	06/16-03/20	4 deep soil cores taken per field, 1 used for assessment of BD and root mass, 3 bulked for chemical assessment. Cores divided into 0-20cm, 20-40cm, 40-60cm, 60-80cm and 80-100cm layers. Soils used throughout project for assessment of soil N stocks, PMN, calibration with MIR and other factors.
<i>Field N stocks assessment</i>	Palmers Channel 1	"Clarence Catchment"	-29.46841, 153.27304	06/16-03/20	4 deep soil cores taken per field, 1 used for assessment of BD and root mass, 3 bulked for chemical assessment. Cores divided into 0-20cm, 20-40cm, 40-60cm, 60-80cm and 80-100cm layers. Soils used throughout project for assessment of soil N stocks, PMN, calibration with MIR and other factors.
<i>Field N stocks assessment</i>	Palmers Channel 2	"Clarence Catchment"	-29.48088, 153.28129	06/16-03/20	4 deep soil cores taken per field, 1 used for assessment of BD and root mass, 3 bulked for chemical assessment. Cores divided into 0-20cm, 20-40cm, 40-60cm, 60-80cm and 80-100cm layers. Soils used throughout project for assessment of soil N stocks, PMN, calibration with MIR and other factors.
<i>Field N stocks assessment</i>	Pimlico 1	"Richmond Catchment"	-28.89122, 153.52121	06/16-03/20	4 deep soil cores taken per field, 1 used for assessment of BD and root mass, 3 bulked for chemical assessment. Cores divided into 0-20cm, 20-40cm, 40-60cm, 60-80cm and 80-100cm layers. Soils used throughout project for assessment of soil N stocks, PMN, calibration with MIR and other factors.
<i>Field N stocks assessment</i>	Pimlico 2	"Richmond Catchment"	-28.89312, 153.49715	06/16-03/20	4 deep soil cores taken per field, 1 used for assessment of BD and root mass, 3 bulked for chemical assessment. Cores divided into 0-20cm, 20-40cm, 40-60cm, 60-80cm and 80-100cm layers. Soils used

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					throughout project for assessment of soil N stocks, PMN, calibration with MIR and other factors.
<i>Field N stocks assessment</i>	Pimlico 3	“Richmond Catchment”	-28.9099, 153.48656	06/16-03/20	4 deep soil cores taken per field, 1 used for assessment of BD and root mass, 3 bulked for chemical assessment. Cores divided into 0-20cm, 20-40cm, 40-60cm, 60-80cm and 80-100cm layers. Soils used throughout project for assessment of soil N stocks, PMN, calibration with MIR and other factors.
<i>Field N stocks assessment</i>	Ballina N-Trial site	“Richmond Catchment”	-28.89123, 153.51904	06/16-03/20	4 deep soil cores taken per field, 1 used for assessment of BD and root mass, 3 bulked for chemical assessment. Cores divided into 0-20cm, 20-40cm, 40-60cm, 60-80cm and 80-100cm layers. Soils used throughout project for assessment of soil N stocks, PMN, calibration with MIR and other factors.
<i>Field N stocks assessment</i>	Coraki 1	“Richmond Catchment”	-29.01496, 153.30189	06/16-03/20	4 deep soil cores taken per field, 1 used for assessment of BD and root mass, 3 bulked for chemical assessment. Cores divided into 0-20cm, 20-40cm, 40-60cm, 60-80cm and 80-100cm layers. Soils used throughout project for assessment of soil N stocks, PMN, calibration with MIR and other factors.
<i>Field N stocks assessment</i>	Coraki 2	“Richmond Catchment”	-29.00669, 153.29093	06/16-03/20	4 deep soil cores taken per field, 1 used for assessment of BD and root mass, 3 bulked for chemical assessment. Cores divided into 0-20cm, 20-40cm, 40-60cm, 60-80cm and 80-100cm layers. Soils used throughout project for assessment of soil N stocks, PMN, calibration with MIR and other factors.

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<i>Field N stocks assessment</i>	Empire Vale 1	“Richmond Catchment”	-28.92178, 153.53275	06/16-03/20	4 deep soil cores taken per field, 1 used for assessment of BD and root mass, 3 bulked for chemical assessment. Cores divided into 0-20cm, 20-40cm, 40-60cm, 60-80cm and 80-100cm layers. Soils used throughout project for assessment of soil N stocks, PMN, calibration with MIR and other factors.
<i>Field N stocks assessment</i>	Empire Vale 2	“Richmond Catchment”	-28.91872, 153.53044	06/16-03/20	4 deep soil cores taken per field, 1 used for assessment of BD and root mass, 3 bulked for chemical assessment. Cores divided into 0-20cm, 20-40cm, 40-60cm, 60-80cm and 80-100cm layers. Soils used throughout project for assessment of soil N stocks, PMN, calibration with MIR and other factors.
<i>Field N stocks assessment</i>	South Ballina 1	“Richmond Catchment”	-28.88113, 153.52955	06/16-03/20	4 deep soil cores taken per field, 1 used for assessment of BD and root mass, 3 bulked for chemical assessment. Cores divided into 0-20cm, 20-40cm, 40-60cm, 60-80cm and 80-100cm layers. Soils used throughout project for assessment of soil N stocks, PMN, calibration with MIR and other factors.
<i>Field N stocks assessment</i>	South Ballina 2	“Richmond Catchment”	-28.88203, 153.53852	06/16-03/20	4 deep soil cores taken per field, 1 used for assessment of BD and root mass, 3 bulked for chemical assessment. Cores divided into 0-20cm, 20-40cm, 40-60cm, 60-80cm and 80-100cm layers. Soils used throughout project for assessment of soil N stocks, PMN, calibration with MIR and other factors.
<i>Field N stocks assessment</i>	Tatham 1	“Richmond Catchment”	-28.91912, 153.23892	06/16-03/20	4 deep soil cores taken per field, 1 used for assessment of BD and root mass, 3 bulked for chemical assessment. Cores divided into 0-20cm, 20-40cm, 40-60cm, 60-80cm and 80-100cm layers. Soils used

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					throughout project for assessment of soil N stocks, PMN, calibration with MIR and other factors.
<i>Field N stocks assessment</i>	Tatham 2	“Richmond Catchment”	-28.93017, 153.24054	06/16-03/20	4 deep soil cores taken per field, 1 used for assessment of BD and root mass, 3 bulked for chemical assessment. Cores divided into 0-20cm, 20-40cm, 40-60cm, 60-80cm and 80-100cm layers. Soils used throughout project for assessment of soil N stocks, PMN, calibration with MIR and other factors.
<i>Field N stocks assessment</i>	Tatham 3	“Richmond Catchment”	-28.94392, 153.24234	06/16-03/20	4 deep soil cores taken per field, 1 used for assessment of BD and root mass, 3 bulked for chemical assessment. Cores divided into 0-20cm, 20-40cm, 40-60cm, 60-80cm and 80-100cm layers. Soils used throughout project for assessment of soil N stocks, PMN, calibration with MIR and other factors.
<i>Field N stocks assessment</i>	Teven 1	“Richmond Catchment”	-28.84262, 153.49591	06/16-03/20	4 deep soil cores taken per field, 1 used for assessment of BD and root mass, 3 bulked for chemical assessment. Cores divided into 0-20cm, 20-40cm, 40-60cm, 60-80cm and 80-100cm layers. Soils used throughout project for assessment of soil N stocks, PMN, calibration with MIR and other factors.
<i>Field N stocks assessment</i>	Teven 2	“Richmond Catchment”	-28.83956, 153.49689	06/16-03/20	4 deep soil cores taken per field, 1 used for assessment of BD and root mass, 3 bulked for chemical assessment. Cores divided into 0-20cm, 20-40cm, 40-60cm, 60-80cm and 80-100cm layers. Soils used throughout project for assessment of soil N stocks, PMN, calibration with MIR and other factors.

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<i>Field N stocks assessment</i>	Woodburn	“Richmond Catchment”	-29.08937, 153.32968	06/16-03/20	4 deep soil cores taken per field, 1 used for assessment of BD and root mass, 3 bulked for chemical assessment. Cores divided into 0-20cm, 20-40cm, 40-60cm, 60-80cm and 80-100cm layers. Soils used throughout project for assessment of soil N stocks, PMN, calibration with MIR and other factors.
<i>Field N stocks assessment</i>	Stotts Creek	“Tweed Catchment”	-28.28417, 153.50022	06/16-03/20	4 deep soil cores taken per field, 1 used for assessment of BD and root mass, 3 bulked for chemical assessment. Cores divided into 0-20cm, 20-40cm, 40-60cm, 60-80cm and 80-100cm layers. Soils used throughout project for assessment of soil N stocks, PMN, calibration with MIR and other factors.
<i>Field N stocks assessment</i>	Tygalgah	“Tweed Catchment”	-28.28852, 153.42681	06/16-03/20	4 deep soil cores taken per field, 1 used for assessment of BD and root mass, 3 bulked for chemical assessment. Cores divided into 0-20cm, 20-40cm, 40-60cm, 60-80cm and 80-100cm layers. Soils used throughout project for assessment of soil N stocks, PMN, calibration with MIR and other factors.
<i>Field N stocks assessment</i>	Sunshine Commercial Farm	“Tweed Catchment”	-28.33726, 153.41036	06/16-03/20	4 deep soil cores taken per field, 1 used for assessment of BD and root mass, 3 bulked for chemical assessment. Cores divided into 0-20cm, 20-40cm, 40-60cm, 60-80cm and 80-100cm layers. Soils used throughout project for assessment of soil N stocks, PMN, calibration with MIR and other factors.
<i>Field N stocks assessment</i>	Eviron Peats 3 (farm 8254) Block 206	“Tweed Catchment”	-28.308326, 153.456325	10/19-04/20	3 cores taken per field from 0-20 and 20-40cm layer, and bulked for assessment of PMN to expand the calibration set for MIR.

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<i>Field N stocks assessment</i>	Eviron Peats 3 (farm 8254) Block 207	"Tweed Catchment"	-28.309082, 153.456175	10/19-04/20	3 cores taken per field from 0-20 and 20-40cm layer, and bulked for assessment of PMN to expand the calibration set for MIR.
<i>Field N stocks assessment</i>	Tumbulgum Clays 1 (farm 8213) Block 101	"Tweed Catchment"	-28.273063, 153.467871	10/19-04/20	3 cores taken per field from 0-20 and 20-40cm layer, and bulked for assessment of PMN to expand the calibration set for MIR.
<i>Field N stocks assessment</i>	Tumbulgum Clays 1 (farm 8213) Block 901	"Tweed Catchment"	-28.273261, 153.467023	10/19-04/20	3 cores taken per field from 0-20 and 20-40cm layer, and bulked for assessment of PMN to expand the calibration set for MIR.
<i>Field N stocks assessment</i>	Tumbulgum Clays 1 (farm 8213) Block 301	"Tweed Catchment"	-28.276134, 153.469730	10/19-04/20	3 cores taken per field from 0-20 and 20-40cm layer, and bulked for assessment of PMN to expand the calibration set for MIR.
<i>Field N stocks assessment</i>	Tygalgah Clay 1 (farm 8032) Block 102	"Tweed Catchment"	-28.314763, 153.423814	10/19-04/20	3 cores taken per field from 0-20 and 20-40cm layer, and bulked for assessment of PMN to expand the calibration set for MIR.
<i>Field N stocks assessment</i>	Tygalgah Clay 1 (farm 8032) Block 103	"Tweed Catchment"	-28.315622, 153.423149	10/19-04/20	3 cores taken per field from 0-20 and 20-40cm layer, and bulked for assessment of PMN to expand the calibration set for MIR.
<i>Field N stocks assessment</i>	Tygalgah Clay 1 (farm 8032) Block 115	"Tweed Catchment"	-28.316751, 153.421851	10/19-04/20	3 cores taken per field from 0-20 and 20-40cm layer, and bulked for assessment of PMN to expand the calibration set for MIR.
<i>Field N stocks assessment</i>	Tygalgah Clay 2 (farm 8130) Block 602	"Tweed Catchment"	-28.313087, 153.399620	10/19-04/20	3 cores taken per field from 0-20 and 20-40cm layer, and bulked for assessment of PMN to expand the calibration set for MIR.

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<i>Field N stocks assessment</i>	Tygalgah Clay 2 (farm 8130) Block 701	“Tweed Catchment”	-28.316232, 153.399666	10/19-04/20	3 cores taken per field from 0-20 and 20-40cm layer, and bulked for assessment of PMN to expand the calibration set for MIR.
<i>Field N stocks assessment</i>	Tygalgah Clay 2 (farm 8130) Block 702	“Tweed Catchment”	-28.316204, 153.400133	10/19-04/20	3 cores taken per field from 0-20 and 20-40cm layer, and bulked for assessment of PMN to expand the calibration set for MIR.
<i>Field N stocks assessment</i>	South Mbah Peats (farm 8086) Block 803	“Tweed Catchment”	-28.335517, 153.412204	10/19-04/20	3 cores taken per field from 0-20 and 20-40cm layer, and bulked for assessment of PMN to expand the calibration set for MIR.
<i>Field N stocks assessment</i>	South Mbah Peats (farm 8086) Block 902	“Tweed Catchment”	-28.337761, 153.412316	10/19-04/20	3 cores taken per field from 0-20 and 20-40cm layer, and bulked for assessment of PMN to expand the calibration set for MIR.
<i>Laboratory work</i>	Wollongbar Primary Industries Institute	“Richmond Catchment”		07/2016- 05/2020	Laboratory assessment in ISO17025 (NATA) labs for Mineral N, TN, TC. ISO17025:2015 certification of PMN, MIR, TOC, TON, HWEC, HWEN, biomass C.

Briefly describe the industry locations and/or regions where the research findings are applicable.

The project focused on the three key sugarcane growing regions in NSW, being the Tweed Catchment, Richmond Catchment and the Clarence Catchment. The Tweed Catchment hosted one core field site, as well as 17 additional sites for the assessment of PMN and existing N stocks, The Richmond Catchment hosted two core field trials and a further 15 sites for the assessment of PMN and existing N stocks, while the Clarence Catchment hosted one core field site and a further eight sites for the assessment of PMN and N stocks. The NSW sugarcane industry annually harvests 14-16,000 ha of sugarcane (Australian Sugarmilling Council, 2020), with a total of around 25,000 ha under cultivation. The NSW sugar industry generates over \$200 million of direct and indirect economic input to the region annually and supports an estimated 2,000 full-time equivalent (FTE) jobs (NSWSMC 2008).

3 Project Outcomes

This is a summation of the findings and recommendations detailed in your technical report.

Describe key results for each component of the project. Include graphs, tables and/or images where applicable.

The results of each research component must be summarised with key messages/ recommendations for the industry. This may include amendments or changes to current industry guidelines, DDS tools or methodology for determining nitrogen budgets.

3.1 PCU (an EENF) in NSW sugarcane field trials

Key results:

- The use of PCU (Field trials 1 and 2 used PCU90, Field trials 3 and 4 used a 50:50 blend of PCU90 and PCU270) did not influence yield compared to matched N- doses of urea.
- PCU 90 (90 day polymer coat) released 50% of the N in a field setting within 30 days, with the majority of the N released by 90 days. PCU 270 released 50% of the N within 90 days, and the majority was released by 270 days
- Increasing N doses generally resulted in increasing yield (except for Field trial 1 on the Tweed Valley – where yield was maximum at 200 units of fertiliser applied N).
- Yield response curves from several sites were flat, suggesting an adequate soil supply of N, or constraints that limit sugarcane production in the seasons that the field trials were conducted (ie, particularly dry spring and early summer) were greater than N limitations.
- Agronomic efficiency of N (yield of fertilised crop- yield control/ rate of fertiliser applied) ranged from 2.2- 37.3 %. Higher rates of fertiliser application tended to give lower agronomic efficiency of N.

Recommendations:

3.1.1 While the PCU products protected N from potential loss pathways by slowly releasing N, this did not influence yield in the four field trials. It should be noted that all four field trials had particularly dry starts to the seasons limiting N loss pathways. Therefore, under the conditions where the field trials were conducted (ie, dry Spring and Summer), the use of PCU cannot be recommended;

3.1.2 The slow release pattern of PCUs would be likely to minimise N loss pathways in wet seasons, particularly where N fertiliser is applied directly before heavy rain, therefore it is recommended that industry develop better climate forecasting and use a modelling approach to refine decisions on the seasons where EENFs are likely to have a benefit on lowering N loss pathways;

3.1.3 At some sites, lower doses of N fertiliser result in greater fertiliser N recovery in the crop, and improved apparent N use efficiency. However, at other sites, yields continued to increase with increasing N dose. It is therefore recommended to maintain current recommendations within the 6ES to maximise yield.

3.2 Soil supply of N: Opportunities to refine decision support tools

Key results:

- A detailed assessment of soil mineral N to 1 m (0-20, 20-40, 40-60, 60-80 and 80-100cm) from 27 sugarcane paddocks in 2016/17 revealed that a number of sites had considerable mineral N stores to depth. Nitrate stores were in all cases below a total of 50 kg N/ Ha, while ammonium stores were up to 250 kg N/ Ha. The high ammonium stores occurred on the Tweed Valley Hydrosols;
- A further assessment and refinement of the methodology has aggregated the data from the initial 27 sites, with a further assessment of 14 paddocks in the Tweed Valley. The additional assessment was limited to sampling from the 0-20 and 20-40cm soil layer. This has refined the mineral N stores to generally under 100 kg N/ Ha;
- PMN was conducted on the 0-20 and 20-40cm layer from all sites, and it was revealed that there was a large variability in 14-day PMN between soils. PMN ranged from 25 through to 225 kg N/ Ha;
- Summing mineral N and 14 day PMN, the soil was shown to provide between 50 and 400 kg N/ Ha, with the majority of sites providing between 75-175 kg N/ Ha.
- The 14-day PMN can significantly underrepresent the soil supply of mineralizable N, as assays on soils that were conducted to 456 days show between a 2-5 fold increase in PMN across this time period;
- MIR has provided a reasonable calibration to both 14-day and 300-day PMN, enabling an 'overnight' laboratory assessment of PMN. For example, a correlation of 0.81 (Pearson R² of 0.65) between a 300-day laboratory PMN measurement and the MIR prediction was obtained;
- The MIR calibration is suitable for NSW sugarcane soils.

Recommendations:

- 3.2.1 The 6ES could be further refined through soil testing for mineral N and PMN from the 0-40cm layer. This will provide an accurate assessment of the potential soil supply of N for the crop;
- 3.2.2 As a rapid test using MIR has been developed which reasonably 'predicts' 300 day PMN, the NSW sugarcane industry has been presented with a proposal to field validate 100 paddocks in a future season to determine whether the 300 day PMN test can be used to refine current decision support tools.

3.1 Project level achievements

Provide a description of project achievements against the final KPIs and outputs of the research project. As these final KPI have been worded to conclude the body of long-term investigation, please ensure the final findings are clearly articulated and linkage to impact upon current and future industry knowledge and practice is explained.

KPI no. and description	KPI Due Date	Relevant CRDC FRP Milestone Number/s.	Summary of final outcome of the reserach concluded by this KPI
KPI 6.5- Provide brief commentary regarding the drafting of a technical report for the use of EEFs at the sugar industry workshop (Output 4 (h))	31 May 2020	Milestone 8	<p>X Achieved</p> <p><input type="checkbox"/> Partially achieved</p> <p><input type="checkbox"/> Not achieveA Technical report is delivered that details results from the following key activities</p> <ul style="list-style-type: none"> • Four field trials assessing 6 rates of PCU (an EENF) vs 6 rates of urea in a replicated complete block design- testing yield, N uptake and apparent N-use efficiency, and development of N response curves. • Assessment of 27 paddocks in an initial assessment of deep N stores in NSW sugarcane soil • A further 14 cores from the Tweed Valley were taken, primarily to improve the correlation with MIR • A full correlation between MIR and PMN conducted to provide a rapid test for PMN for the NSW soils • UAV multi-spectral imaging correlated to leaf N content <p>Key Results presented in the technical report include:</p> <ul style="list-style-type: none"> • Generally flat N response curves from 4 sugarcane trials to increasing N dose, but noting that yield increases with increasing N • No difference between PCU or urea on yield (noting all 4 crops trials had very dry starts and well below average rainfall for the growing season) • In 2 of the 4 trials, PCU resulted in greater biomass uptake of N • PCU also resulted in slightly higher soil residual nitrate (0-40cm) at harvest • Soils provided between 50-350 units of N (sum mineral N + PMN), with recommendations to consider this within the 6ES. <p>Industry workshop</p> <ul style="list-style-type: none"> • More profit from N webinar presented.

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KPI no. and description	KPI Due Date	Relevant CRDC FRP Milestone Number/s.	Summary of final outcome of the reserach concluded by this KPI
			<p>Data and recommendations were presented to an industry workshop (webinar due to Covid19) in May 2020. The workshop session had 25 attendees, representing Sunshine Sugar advisors from the 3 regions in NSW, Sugar Research Australia staff, farmers and other researchers. Webinar link: https://www.dropbox.com/s/de9ic3k7h2ckkct/Lukas%20Van%20Zwieten%2012%20May%202020%2C%20NSW%20DPI_AgInfo%20Webinar%20NNSW.mp4?dl=0</p>
<p>KPI 7.4- Provide a brief and final account of the “Deep soil N” experiments and the definition of N response curves for farm scale N stocks (Output 6 (g) and Output 6 (h)).</p>	<p>31 May 2020</p>	<p>8</p>	<p>X Achieved <input type="checkbox"/> Partially achieved <input type="checkbox"/> Not achieved</p> <p>Output 6(g) was exceeded with the completion of four field sites which assessed a fertiliser response to PCU and urea, measuring yield and crop N uptake. An additional field site was established to obtain more robust data from field experiments with PCU, and in particular to further trial a blend of 90 day and 270 day PCU to better match N supply with crop demand. To complement these 2 field trials, a series of litter bags containing (separately) PCU90 and PCU270 were buried to match the conventional stool splitter application of urea (rate and depth) in an unfertilised section of both field trials “Coraki” and “Woodford Island.” N leached from the PCU beads was assessed across a 12 month period (by extraction of the beads from soil and measurement by TON analyser) with data used to compare N supply with crop N uptake. Leaching of N through soil was not assessed due to the extraordinarily dry conditions which were not conducive to downwards migration of N. This component was conducted with ¹⁴N PCU as it was impossible to procure ¹⁵N PCU. The ¹⁵N PCU was not needed to accurately complete this assessment.</p> <p>Key Results presented in the technical report include:</p> <ul style="list-style-type: none"> • Generally flat N response curves from 4 sugarcane trials to increasing N dose, but noting that yield increases with increasing N. There was no statistical differences between PCU and urea (at matching doses of N) • PCU90 released 50% of the urea under a field setting within 30 days, and the majority of the N was released by 90 days, supporting the manufacturer’s claims about the release pattern from this product. • PCU270 released 50% of the urea under a field setting within 90 days, and the majority of the N was released by 270 days. There was around 10-20% residual N remaining in the PCU270 at 270 days. Data and release curves supporting the manufactures claims about the release pattern from this product.

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KPI no. and description	KPI Due Date	Relevant CRDC FRP Milestone Number/s.	Summary of final outcome of the reserach concluded by this KPI
			<p>Output 6 (h) was delivered through the completion of N rate response curves (biometrically fitted), to 6 rates of N delivered via PCU and matching N delivered via urea. The supply of N from soil to the crop was calculated through the summation of soil mineral N reserves (to 1m) plus 0-40cm PMN. PMN assessments were conducted using the standard 7 and 14 day methodology, plus the extension of PMN across 56 and 300 days, to determine the potential provision of N across a sugarcane growing season. These PMN data (14, 56 and 300 day) were correlated to laboratory MIR, and a commercial testing service is currently under consideration. This cheap and rapid test will essentially be able to provide an estimate of the PMN across 300 days using an overnight laboratory assessment. This new test is currently in discussion with a commercial analytical provider, and further negotiation with Industry and the 6ES will occur.</p> <p>Key Results presented in the technical report include:</p> <ul style="list-style-type: none"> • Soil supply of N was calculated as the existing mineral N stocks in soil to 1 m (or to the maximum rooting depth up to 1m), plus the 14 day PMN. However, for practical field testing purposes, this was revised to a maximum depth of 40 cm. The range of soil supplied N for the crop from 41 sugarcane paddocks ranged from 50kg N/ Ha up to 400 kg N/ Ha. • The 14 day PMN may under represent the actual PMN released across the season, with soil N supply continuing through to (and exceeding) 300 days. • Because measuring PMN takes between 14-300 days, this time period exceeds the ability of the farmer to adjust fertilizer N doses according to the PMN contribution, therefore a rapid test based on MIR was developed. • Some surprising soil chemical data was obtained for the Hydrosols in the Tweed Catchment, where nitrate N was hardly detected, with the accumulation of ammonium N. The preservation of fertiliser N as ammonium N in these soil (to depth) has a similar effect as nitrification inhibitors (eg DMPP), preserving N as ammonium (cation) thus minimising N loss pathways. • A proposal has been provided to the NSW sugarcane industry where the MIR facility will be 'field' validated in the 2020 season.

3.2 Contribution to MPfN program objectives

Provide a description of how the project has contributed to the achievement of the relevant MPfN Program Objective/s.

The objective of the MPfN Program was to enhance NUE, improving profitability and sustainable use, through better understanding the influence of contributing factors. It will:

3.2.1 Generate a greater knowledge and understanding of the interplay of factors to optimise nitrogen (N) formulation, rate and timing across industries, farming regions and irrigated/ non-irrigated situations (Activity 5);

The key purpose of an EENF is to ensure a greater availability of N to the crop, through minimising N loss pathways (leaching of NO_3^- , volatilisation of NH_3 , loss as N_2O or N_2). To this end, PCU has been demonstrated in our study to slowly release N into the soil according to the formulation of PCU provided. For example, the project has established that 50% of the N in PCU90 is released within 30 days, with the majority of the remaining N released over 90 days. Similarly, 50% of the N in PCU270 is released within the first 3 months, with the majority of the remainder released over 270 days. This data collected from a replicated field study mimicking the use of PCU in sugarcane systems provides users (farmers, agronomists) with the confidence to better match the supply of fertiliser N with crop demand. Certainly, as the N fertiliser is protected within the polymer coat, it is protected from loss pathways including leaching or gaseous losses. However, when there are no significant N loss pathways present, the advantages of a PCU (or other EENFs that protect the N fertiliser from loss pathways), are nullified. This was the case in the four field trials conducted in NSW. Rainfall graphs linked to each field trial clearly show that after the application of fertiliser N (in Spring or early Summer), the rainfall was low. Thus, as there were no N loss pathways for the urea, there was no advantage from the application of PCU. The fact that we have established N release curves for the two PCUs would now enable the sugarcane industry to utilise a modelling approach (eg, Zhao, Verberg and Huth, 2017) to determine which years (incorporating climate forecasting) PCU would improve NUE. Further, the project has assessed leaf N content from Field Trials 3 and 4 throughout the growing season, data too that would be used to optimise these predictive models, through synchronising soil N supply with plant N demand.

Key Outcome: EENFs are unlikely to provide benefits to yield or NUE when major N loss pathways are not present in a given season. Other constraints (in our case limited supply of plant available water) limited crop production potential.

References

Zhao Z, Verburg K and Huth N (2017) Modelling sugarcane nitrogen uptake patterns to inform design of controlled release fertiliser for synchrony of N supply and demand. Field Crops Research

3.2.2 Generate a greater knowledge and understanding of the contribution (quantifying rate and timing) of mineralisation to a crop or pasture's nitrogen budget (Activity 6);

Baseline N application rates within the 6ES are adjusted within each region to take account of soil type. This is done by using an N mineralisation index based on soil organic C as determined using the method of Walkley and Black (1934). The use of an N mineralisation index for modifying N fertiliser guidelines for the Australian sugar industry was initially proposed by Schroeder and Wood (2001). As Walkley-Black organic C is the routine method used in commercial laboratories servicing the Australian sugar industry, it was deemed an appropriate surrogate measure for easily mineralisable N and a suitable basis for the N mineralisation index (Schroeder et al., 2005). A recent study on Qld sugarcane soils (Allen et al., 2019) has, however, shown that PMN is better related to hydrolysable NaOH organic N and soil respiration, both relatively time consuming tests to complete.

Our project has evaluated PMN using the standard 7 and 14 day PMN test as well as a modified procedure (Allen et al., 2019) enabling mineralisable N across 300 to 456 days to be assessed. A total of 41 soils from sugarcane fields in NSW were assessed using this methodology showing that between 25 and 225 kg N/Ha are mineralised (14 day PMN test). This variation in soil supplied N was large and was not consistent with the soil organic C content. More importantly, as assessment of 27 of these paddocks has shown that the PMN increases 2-5 fold in the 0-20 and 20-40cm soil layers over 56- 300 -436 days. The extended PMN test was conducted to estimate soil supply of N to sugarcane crops grown over 2 years in NSW. Using the 300- day laboratory assessment, this amounted to between 211 and 298 kg N/ Ha from soils in the Clarence catchment, 143 and 560 kg N/ Ha from soils in the Richmond catchment, and 190 and 234 kg N/ Ha from soils in the Tweed catchment. This demonstrates the significant contribution of longer-term PMN to sugarcane crop N nutrition. Indeed, the practice of green harvest and trash retention has recently been shown (Weng et al., 2020) on a NSW soil to result in more crop N being derived from both the breakdown of trash and also the soil organic C, than practices that don't have trash retention. At the same time, because the crop obtained N from both trash and SOC breakdown, it had significantly lower fertiliser N uptake (NUE) than soil where trash was not retained. This further highlights the need to understand and quantify PMN as an important source of soil (trash + SOC) derived N for crop production.

As PMN testing is a lengthy process and can't be undertaken practically (ie within a timeframe that is useful to farmer decisions on fertiliser N), refinements in predicting the PMN were required. While Allen et al. (2019) have shown that hydrolysable NaOH organic N and soil respiration could better estimate PMN, we applied MIR technology for this assessment. A reasonable correlation was achieved between predicted PMN over 300 days and laboratory obtained data from a detailed incubation study, providing the driver for us to seek to validate MIR for NSW soils and develop a commercial testing service. The advantage of this testing is that it is relatively inexpensive and can provide a rapid estimate of PMN across 14, 56 or 300 days. The 41 sites (x 2 depths) for the NSW soils have been calibrated against the Thermo MIR instrumentation at the Wollongbar Primary Industries Institute, which is a NATA accredited laboratory. It has been proposed that this new test could be validated by NSW DPI and a commercial service offered in 2021/22.

Key Outcome:

NSW sugarcane soils have been shown to supply relevant quantities of N for crop production, partly driven by the priming effect (stimulated breakdown of SOC) from trash retention. By having a more accurate estimate for PMN based on a rapid and inexpensive MIR test, the baseline N application rate as determined by the 6ES could be refined.

References:

- Allen DE, Bloesch PM, Orton TG, Schroeder BL, Skocaj DM, Wang W, Masters AB, Moody PM (2019) Nitrogen mineralisation in sugarcane soils in Queensland, Australia: I. evaluation of soil tests for predicting nitrogen mineralisation. *Soil Research* 57(7) 738-754
- Saunders DH, Ellis BS, Hall A (1957) Estimation of available nitrogen for advisory purposes in Southern Rhodesia. *Journal of Soil Science* 8: 301-312.
- Schroeder BL, Wood AW (2001) Assessment of Nitrogen mineralising potential of soils in two different landscapes in the Australian sugar industry – implications for N fertiliser management. *Proceedings of the Australian Society of Sugar Cane Technologists* 237, 281–288.
- 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.
- 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.
- Weng Z, Liu X, Eldridge S, Wang H, Rose T, Rose M, Rust J, Singh BP, Tavakkoli E, Tang C, Ou H, Van Zwieten L (2020) Priming of soil organic carbon induced by sugarcane residues and its biochar control the source of nitrogen for plant uptake: A dual ¹³C and ¹⁵N isotope three-source-partitioning study. *Soil Biology and Biochemistry*, doi.org/10.1016/j.soilbio.2020.107792

3.2.3 Develop greater knowledge and understanding of how enhanced efficiency fertiliser (EEF) formulations can better match a crop or pasture's specific N requirements (Activity 4).

While the four field trials did not show any benefits to sugarcane yield from the use of EENFs, a significant advancement in our understanding of the N release pattern of PCU in NSW sugarcane soil was obtained. The assessment of N release from PCU was undertaken using two products (PCU90 and PCU270) and at two field sites (Coraki in the Richmond catchment; Woodford Island in the Clarence catchment). The release patterns from the two locations were very similar, supporting the concept of PCU as an effective controlled release EENF. Supporting the release pattern of N from PCU at these two field sites, the project has also assessed monthly leaf N concentration (SRA 3rd leaf method). Combined, these data could be used to refine models (eg those developed by K. Verburg, CSIRO: eg, Zhao, Verberg and Huth, 2017) to predict crop N demand, and N loss pathways based on climate models and predicted weather/ rainfall. These models could then determine which seasons EENFs would be effective in optimising NUE, versus season (such as the four field sites) where there was no benefit in using PCU over urea.

Key Outcome:

Data on N release from PCU and leaf N concentration with an N rate trial (0,50, 100, 200, 300, 400 units N/Ha) have been collected and processed, and can be made available to future modelling activities for refinement of N-fertiliser decisions based on seasonal climate forecasting.

3.3 Demonstrable more profit from nitrogen

Demonstrate how the research outcomes will improve the productivity and/or profitability of the industry's primary producers. Include a quantitative case study/ example where possible.

The ultimate aim of the project was to provide farmers with knowledge and tools to accurately predict in-field N stocks that can be made available across both 1 and 2 year crops, and to improve recommendations for N fertiliser application and the use of EFNs to increase N fertiliser use efficiency. Improved N use efficiency has both direct economic benefits through greater yield or lower fertiliser N application, as well as environmental/ social outcomes through lower loss of N from the farming system. Data and outcomes from the project have 2 key pathways to adoption:

- 3.3.1 The project has demonstrated that some sugarcane soils can provide a significant quantity of plant available N across the season (ie PMN), but the prediction of PMN using current methods may not capture this longer -term release pattern. An MIR test has been developed which can rapidly estimate PMN (eg, 14, 56, 300 day PMN) which could be used by industry to inform the Six Easy Steps guidelines, thus refining N fertiliser recommendations for each paddock. Our data has shown that PMN (300 days) can vary from 143 to 560 kg/ha thus a 10% saving in applied N fertiliser from soils that can contribute a relevant quantity of N from PMN and existing mineral N stores will equate to a financial saving of \$30/ha. It was estimated that around ½ of the sites in our current study in NSW (extrapolating to be equivalent to 12,500 Ha in NSW) could potentially apply 10% less N fertiliser, thus equating to an annual saving in NSW of \$375,000. With more targeted N rates there should also be a potential CCS improvement (0.5 unit) or \$1.80/t of cane, (1.5 million tonnes of cane harvested in NSW 2019), this equates to up to a \$2.7M increase in profitability. The project has also addressed the imperatives outlined by Bell et al., (2015) by improving environmental outcomes and adding to the social license to farm.
- 3.3.2 Data on N release curves from PCU and N uptake by sugarcane across the season could be utilised by models that would use seasonal climate (weather and rainfall) data to refine when EFNs would provide benefits to NUE, as well as the optimal release pattern from the PCU (ie, 30, 90, 180, 270 day release pattern) and N dose (rate of application). While this information is relevant directly to NSW systems, the modelling would be relevant to the Qld sugarcane farming systems, involving a further 360,000 Ha of farmed land. More substantial refinement in N application could be achieved using this approach.

4 Collaboration

Describe the MAJOR collaborations established over the life of the project, how these collaborations have or will aid future innovation, and the likelihood that collaborations will continue beyond the duration of the project.

While this project had a limited scope, collaboration between the project partners (eg Southern Cross University, NSW DPI and Sunshine sugar), and indeed the farmers involved in field trials and field sampling were strengthened. Engagement included discussing field trial logistics, methodologies and results from the work. The project has already resulted in the commencement of a further field trial (funded by SRA) in the Tweed Valley on the role of fallows vs cover cropping on sugarcane yield and soil biological properties; including functions associated with C, N, P and S cycling, nematode communities and beneficial rhizosphere microbial association (ie VAM).

Team member Josh Rust has developed collaboration with Farmacist on EM38 mapping and interpretation of multispectral imaging. This resulted in Farmacist being commissioned to undertake mapping for Field Trials 3 and 4 from this current project, as well as mapping for other field sites outside of the current project. Discussions continue on the interpretation of mapping, and also further integration into field trial design.

Importantly, linkages were developed with scientists at the Qld Department of Environment and Science (eg, Dr Dianne Allen), who provided feedback on the methodologies for PMN. This collaboration resulted in a further project funding request (not successful), but linkages exist for future opportunities.

The project has taken steps to develop a collaboration with Dr Kirsten Verburg at CSIRO Agriculture and Food, who specialises in farming systems modelling. Dr Verburg has undertaken modelling using simulation analysis to quantify and explain the effects of climate, soil type and management on agronomic and environmental outcomes from using PCU in cropping systems (e.g. SRA Projects 2014/011, 2017/015). Importantly, seasonal variation (in particularly rainfall) was shown to significant control whether the PCU was effective, and modelling showed that in wet seasons, the use of PCU could lower both denitrification and deep drainage of N. Future collaboration opportunities identified include the utilisation of our data to verify models and potentially incorporate decision support based on improved seasonal climate forecasting.

5 Extension and adoption activities

5.1 Extension of the research to the end-user

Provide a well-considered statement or clear dot-points on how the extension activities conducted by, or supported by the research project, have/ will increase the adoption of project outcomes and outputs by primary producers and/or their advisors.

The project has been active in extending progress and results directly to Industry via three articles in Cane Connections, an Industry publication from SRA (2017, 2018 and 2020. These articles have described:

- The overall aims of the project, and the theory behind the assessment of controlled release fertilisers to minimise N loss pathways (estimated circulation = 1000).
- The utilisation of new technologies including multispectral imaging to enhance research on crop N uptake (estimated circulation = 1000).
- Results showing that in dry years, no benefits of PCU could be observed.
- PMN and existing stored N can be important contributors to crop nutrition. (estimated circulation = 1000).

Project results have also been extended more broadly to the Australian Fertiliser Industry, via:

- A presentation on April 23rd, 2020 as part of the More Profit from N (VC conference). (Estimate 50 attendees across the fertiliser industry and research).
- A presentation on September 6, 2019 “EENFs and accounting for soil supplied N in NSW Sugarcane” at the Australian Fertilizer Industry Conference (AFIC) 2019 field tour at Wollongbar Primary Industries Institute (75 Industry representatives).
- A farm walk at Trial Site 1 (Tweed catchment) on September 6, 2019 as part of the Australian Fertiliser Industry Conference (AFIC) where PMN and the role of cover cropping in PMN was highlighted (75 Industry representatives).

Importantly, final project data was presented at an Industry workshop/ webinar hosted by SRA on May 12, 2020 to around 25 key delegates in industry. This final presentation highlighted the results of the field trials and the assessment of existing N stocks that may better inform the 6ES.

Adoption outcomes from these extension activities include:

- A broader knowledge within both the fertiliser industry and more specifically the sugarcane industry of the fact that controlled release fertilisers will not necessarily provide benefits to NUE, yield or fertiliser nutrient recovery. Importantly, that to benefit from the EENFs, improved location specific seasonal climate modelling is needed and decisions on the use (ie PCU formulation) and N dose should be based on the outcomes of these models.
- Data on N release from PCU90 and PCU270 as well as crop N uptake (measured by leaf N content) is available to inform future models based on seasonal climate predictions.

- A new test that can more accurately represent PMN has been developed (specifically for NSW sugarcane soils), but results have been presented to the broader fertiliser industry, and similar principles and methodologies could be adopted across other industries. PMN was shown to be a major contributor to crop N nutrition.
- Adoption of MIR testing for PMN could be achieved through a commercial testing service, and a calibration set of soils (for PMN) is available for future purposes. Action has been taken to validate the MIR testing in the current season in collaboration with Sunshine Sugar, for the purpose of refining N recommendations with 6ES.

5.2 Recommendations to industry on adoption of the research outcomes.

Provide recommendations on how further adoption of the project outcomes could be achieved beyond the lifetime of this project- what needs to be done? Why is it needed? Who needs to do it? Who is the target audience?

5.2.1 **Context:** While the project concluded from four replicated field trials that controlled release N fertiliser provided no benefit to yield, NUE or fertiliser N recovery, robust field derived data was generated on the release patterns of N from PCU90 and PCU270, as well as the fertiliser N content of the 3rd leaf on monthly assessments. The project has taken steps to develop a collaboration on modelling using simulation analysis to quantify and explain the effects of climate, soil type and management on agronomic and environmental outcomes from using PCU in cropping systems. If seasonal conditions (in particularly rainfall) can be predicted, recommendations on PCU formulation, rate and timing could be delivered specifically for the seasons/years where N loss pathways are significant.

Recommendation: It is recommended that data generated by this project be used to verify models and decision support tools based on improved seasonal climate forecasting.

5.2.2 Context: The supply of N from the soil (sum of existing mineral N stores and PMN) varied significantly (range between ca. 100-560 kg N/ year), therefore having this information before implementing the 6ES could assist in refining recommendations on N application doses.

Recommendation: As a rapid and inexpensive test has been developed based on MIR to predict PMN, it is recommended that a pilot study be conducted via the guidance of Sunshine Sugar agricultural services where 100 paddocks in NSW are sampled and N recommendations are based on: a) existing 6ES protocols, and b) more informed 6ES (ie based on MIR prediction of PMN). The farmer could then have an option to do a split paddock based on both recommendations and determine differences in harvest. This pilot study would also help to inform the future viability of a commercial testing service for PMN.

6 Lessons learnt

Describe lessons learnt and key messages developed during the life of the project at the:

6.1 Research level

Robust data on field responses to PCU vs urea in NSW sugarcane farming systems have been generated. These data however show that there were no benefits to yield or agronomic N use efficiency between the EENF product and conventional urea. This lack of response is likely due to the (significantly) below average rainfall in spring and early summer experienced across the four field trials and two seasons. While the PCU released N according to the manufacturer's specifications, if N loss pathways due to the dry conditions were not present, then there was no expected benefit of the PCU. There are several steps that could be taken to avoid this occurrence in future work:

1. Seasonal forecasts can be utilised to determine whether a research field trial will proceed. This however would require significant flexibility with the funding body and milestone requirements. As an example, the project had 3 years where the spring and early summer were dry. Our experience would suggest that in these years, conventional urea application would perform equally as well as an EENF, as loss pathways were not present. However, it is the years with 'average' or 'above average' rainfall, where N loss pathways do exist. Future project allocations from industry for this work would need to have contracts established with the agreement that the project commences as soon a suitable testing season is predicted. Undertaking research under this 'response approach' would be impossible using current project funding models with fixed milestone dates.
2. To inform field evaluation of EENFs, a simulation analysis to quantify and explain the effects of climate, soil type and management on agronomic and environmental outcomes from using PCU in cropping systems could be conducted. These simulation analyses could show which years, and which EENF products are likely to provide benefit. However, while these simulation models are important for predicting responses, they should also be supported/ validated using field evaluation.
3. While field evaluations of new products such as EENFs are desirable, for the reasons outlined above, conditions in the field are not always suitable for evaluating these products. An alternative approach could be small plot field trials on research stations, where the simulation of rainfall and conditions conducive to N loss pathways, are possible. These experimental protocols are, however, expensive, and were well outside the scope of the budget for the current project.

6.2 Industry level

Similar lessons as to the above outlined in 6.1

6.3 Service Provider Level

More accurate seasonal forecasts would provide Sunshine Sugar extension staff with the ability to evaluate which years growers may benefit from the use of EENFs. Further, if this information were combined with simulation modelling, considering seasonal conditions and soil type, more accurate predictions for yield (hence requirement for N-fertiliser) could be provided. Data provided by the project could also be utilised by the Australian fertiliser industry for best decisions relating to EENFs, seasonal variability and the role of edaphic variables in determining N requirements.

6.4 Primary Producer Level

While the evaluation of PCU (an EENF) in the current project demonstrated no benefit over conventional urea application, there has been a lot of grower interest in understanding PMN and its relationship to soil health. For example, do healthy soils with lots of organic matter provide greater N nutrition compared to soils with depleted organic matter levels. There have also been a lot of questions over the role of trash retention and how this may affect soil N nutrition. Future projects assessing PMN and N nutrition should consider grower interest in this topic, to better understand the role of organic matter and organic matter fractions, and their influence on soil fertility.

7 Appendix - additional project information

7.1 Project material and intellectual property

Include a summary of all **journal publications & conference papers** and **all intellectual property created** or arising during the period covered by the project. You need to restate these here even if they have been entered into the MPfN M&E Data-base

7.1.1 Journal Papers published

7.1.2 Journal Papers in preparation and review

Van Zwieten L, Rose T, Rust J, Rose M, Morris S, Beattie R (2020) Potentially mineralizable N in NSW sugarcane farming systems contribute between 125-500 units N for crop production across the growing season. Soil Research (in preparation).

Van Zwieten L, Rust J, Morris S, Rose M, Verburg K, Beattie R, Rose T (2020) No benefit from controlled release N fertilisers across 4 sugarcane field trials- the role of seasonal climate forecasting. Soil Research (in preparation).

7.1.3 Conference Papers

Van Zwieten L, Rose T, Rust J, Rose M, Allen D, Driver F, Beattie R (2018) Improving nitrogen use efficiency in subtropical sugarcane through better utilisation of soil N and EENFs. Proceedings of the National Soils Conference Canberra, ACT, Australia, 18-23 November 2018, pp74-75.

7.1.4 Intellectual property

Calibration set of 82 soils (41 sites x 2 depths) for NSW DPI's Thermo MIR. Currently calibrated against multi-time PMN, and Total organic C. The calibration set has been archived for future purposes.

7.2 Equipment and assets

List of all equipment or assets created or acquired during the period covered by the project.

More Profit from Nitrogen Program

Item purchased	Date of purchase	Purchase price (GST exclusive)
<i>nil</i>		

7.3 Media and communications material

- **2020 Cane Connections Winter Edition.** The role of PCU and accounting for soil supplied N in NSW Sugarcane. (in press)
- May 12, 2020: **Sugar Research Australia** “Ag systems webinar and workshop” <https://sugarresearch.com.au/sra-information/events/ag-info-webinar/>
- Sept 6, 2019: 2019 **Australian Fertiliser Industry Conference/** MPfN Program Partner Forum Field Excursion. Enhanced Efficiency Fertilisers. Presented by Lukas Van Zwieten
- June 25, 2018 **Central West Farming Systems Magazine.** Nitrogen Use Efficiency research benefits from not so futuristic technologies. Written by Lukas Van Zwieten, Josh Rust and Marguerite White
- **2018 Cane Connections Winter Edition** Nitrogen use efficiency research benefits from eyes in the sky Written by Lukas Van Zwieten, Josh Rust and Marguerite White
- Jan 10, 2018 **The Land** “Managing fertiliser efficiency in sugar cane” by Jamie Brown
- **2017 Cane Connections Winter Edition** “Collaborative research to maximise profit from nitrogen”

7.4 Resource outputs for industry

Include a summary of all **fact sheets, guidelines or decision support tools** developed for the industry during the period covered by the project. You need to restate these here even if they have been entered into the MPfN M&E Data-base

Title	Author	Date finalised	Host platform for ongoing use
<i>NA Improved nitrogen use efficiency through accounting for deep soil and mineralisable N supply, and deployment of enhanced efficiency fertilisers (EEF) to better match crop N demand</i>	Lukas Van Zwieten	2017	NSW DPI Fact Sheet

8 Appendix – Project technical report



More Profit from Nitrogen (RRDP1717)

Improved nitrogen use efficiency through accounting for deep soil and mineralizable N supply & deployment of EEF to better match crop N demand

Final Technical Report

Addressing Outputs– 4 (h) 6 (e), 6(f), 6(g) and 6(h)).

This technical report forms part of the Final Report-

Rust J, Van Zwieten L, Rose T, Rose M, Morris S and Beattie R (2020) Improved nitrogen use efficiency through accounting for deep soil and mineralisable N supply & deployment of EEF to better match crop N demand. More Profit from Nitrogen Final report, May 30, 2020.

Acknowledgements

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More information

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www.dpi.nsw.gov.au

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Disclaimer: The information contained in this publication is based on knowledge and understanding at the time of writing (February 2021). However, because of advances in knowledge, users are reminded of the need to ensure that information upon which they rely is up to date and to check currency of the information with the appropriate officer of the Department of Primary Industries or the user's independent adviser.

1. Introduction

Nitrogen use efficiency in sugarcane is generally low, due to losses via denitrification, leaching and surface runoff (Bell, 2014). While being a financial consideration for farmers, N loss can also impact on water quality and can contribute to Australia's greenhouse gas inventory. Increasing evidence is emerging that enhanced efficiency nitrogen (N) fertilisers (EENFs) can reduce nitrous oxide (N₂O) emissions from soils, but recent published meta-analyses suggest only limited benefit for productivity (Rose et al., 2018). Common EENFs include urea with urease or nitrification inhibitors (Chalk et al. 2015) and slow release fertilisers. Recent field studies by Rose et al. (2017) have shown limited mitigation of N₂O emissions with nitrification inhibitors in a warm wet subtropical environment, and work has suggested a greater emphasis should be placed on synchronising N supply with crop N demand. While lowering the N dose to the crop can often result in improved N use efficiency, it can also result in lower crop yields, and lower soil N stocks. Thus, this work aims to better understand existing N stocks available in soil and to better match crop N demand with N availability using a slow release formulation based on polymer coated urea.

2. The objective of the Rural R&D for Profit program is to realise productivity and profitability improvements for primary producers, through:

- generating knowledge, technologies, products or processes that benefit primary producers;
- strengthening pathways to extend the results of rural R&D, including understanding the barriers to adoption; and
- establishing and fostering industry and research collaborations that form the basis for ongoing innovation and growth of Australian agriculture.

3. The objective of the MPfN Program is to enhance NUE, improving profitability and sustainable use, through better understanding the influence of contributing factors. It will:

- Generate a greater knowledge and understanding of the interplay of factors to optimise nitrogen (N) formulation, rate and timing across industries, farming regions and irrigated/ non-irrigated situations (Activity 5);
- Generate a greater knowledge and understanding of the contribution (quantifying rate and timing) of mineralisation to a crop or pasture's nitrogen budget (Activity 6); and
- Develop greater knowledge and understanding of how enhanced efficiency fertiliser (EEF) formulations can better match a crop or pasture's specific N requirements (Activity 4).

4.0: Output 6(e) - 'Deep soil N': conduct sampling and analysis of sugarcane paddocks in NSW to determine deep soil N content/mineralizable N (supply of N by soil)

4.1. Aim:

To determine deep soil N content/ mineralizable N (supply of N by soil) for the purposes of refining N rate recommendations in Northern NSW cane growing catchments.

4.2. Methodology:

Twenty seven cane paddock sites identified with Sunshine Sugar as representative of key regions in NSW were sampled in 2016 from across the Tweed, Richmond and Clarence catchments as a part of output 6(e)-'Deep soil N': conduct sampling and analysis of up to 30 cane paddocks in Queensland and NSW to determine deep soil N content/ Potentially Mineralizable N (PMN). All sites selected were post-harvest/pre-fertilizer application.

At each site, three one-metre cores were extracted on-row from three locations labelled A, B & C (9 cores in total) along a transect of the paddock using a hydraulic soil corer. The cores were sectioned into 20cm depth increments and pooled for each depth at each of the three paddock locations.

In order to more accurately measure mineral N reserves, a 9 g subsample of soil from each pooled increment at location A, B & C was immediately added to pre-labelled 50mL centrifuge tubes containing 30 mL Potassium Chloride (KCl) in the field. Soil/KCl solutions were kept cool and returned to the lab where they were placed on a shaker for 1 hour, centrifuged at 3000 x g for 10 minutes and filtered through 0.45-micron syringe-filter. The extracts were submitted to a NATA accredited facility for ammonium and nitrate analysis. Calculations for mineral N content were based on the freeze-dried weight of soil analysed, and mass of soil in each layer considering the bulk density of each soil layer.



Figure 1: One metre soil core extraction using trailer-mounted hydraulic soil corer

The sectioned cores were analysed for Total C & N by Dumas, bulk density characterisation and mineralization assays and were utilised in determining the existing plant available N stock in soil prior to either planting or ratoon emergence. Plant available N was based on the sum of nitrate-N, ammonium-N and 14-day PMN, with data presented for both rooting depth for each site (Figure 2), and the 0-40cm soil profile (Figure 3).

For each site, an additional 1m core sample was taken on-row from the centre of the paddock and collected intact for profiling and root distribution assessment.

In 2019/20, an additional 14 sites in the Tweed catchment were sampled as these were under-represented in the original sampling round. The additional sites were essential for the calibration of mid-infrared spectroscopy for the Tweed catchment soils.

4.3. Results

Soil chemistry analysis for 41 sites is presented in Appendix A.

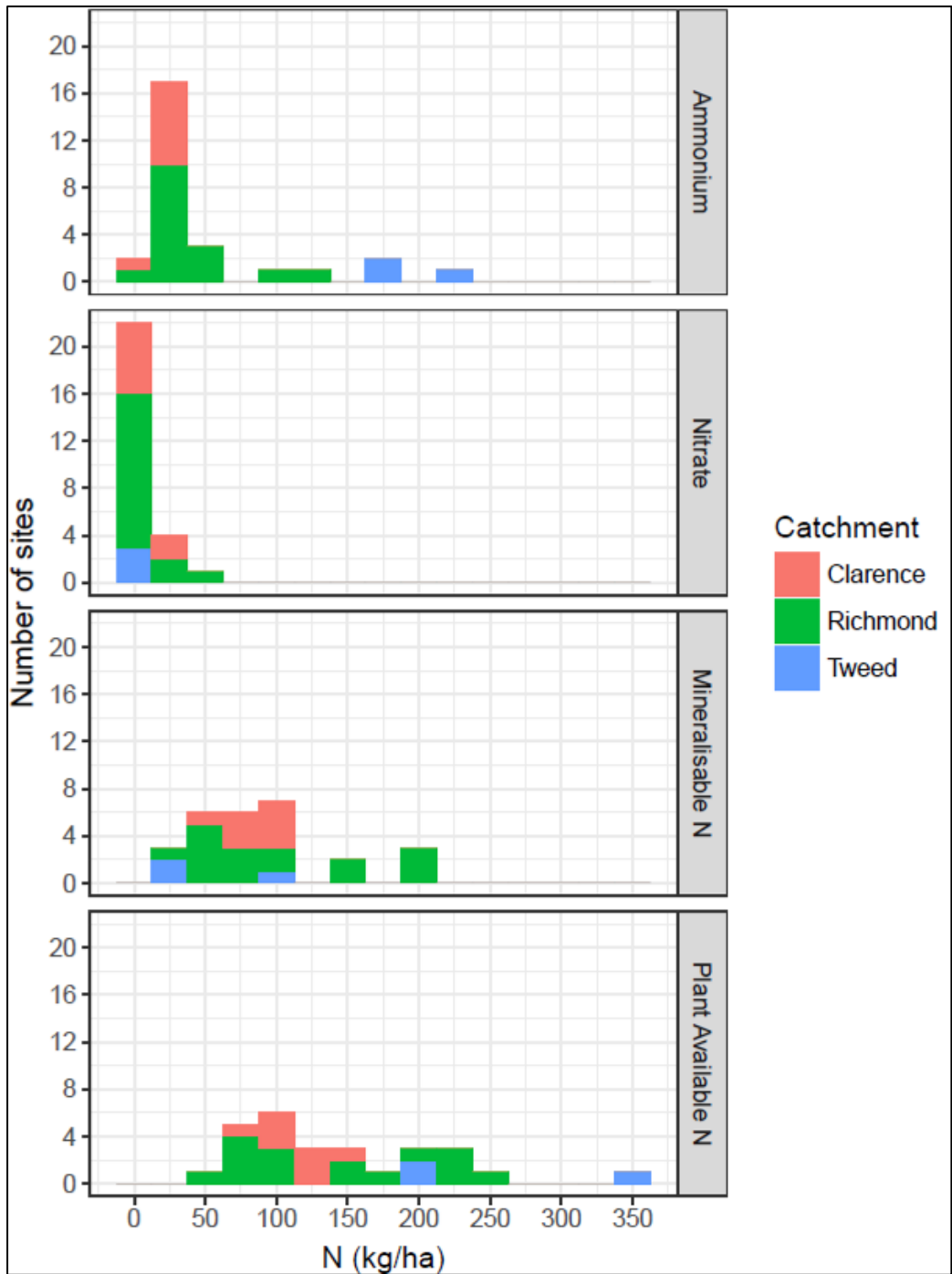


Figure 2: Distribution of deep soil N (1m) in the 2016/17 27 site analysis. Mineralizable N, and total plant available N across the sampling sites. Note: Soil N adjusted for soil BD and soil depth adjusted for rooting depth (ie, presence of sugarcane roots).

One site on the Tweed valley had 350 kg N/Ha available for crop uptake prior to planting. Most commonly, however, the sites ranged from 75 kg N/Ha to 225 kg N/Ha. All three Tweed valley sites had greater N availability, driven principally by the accumulation of ammonium to depth (see appendix Table A1). Interestingly, despite the Tweed field sites having generally a higher C content of soil, the mineralizable N was low. Most sites had either low or negligible nitrate content indicating either limited nitrification, or the presence of loss pathways for nitrate (denitrification and /or leaching).

In 2019 the project team undertook sampling of 14 additional sites from the Tweed catchment to strengthen the existing dataset. While the same methodology as the first 27 sites was followed, due to sampling constraints these sites were sampled only to 40 cm depth and therefore sectioned into 0-20 cm and 20-40 cm.

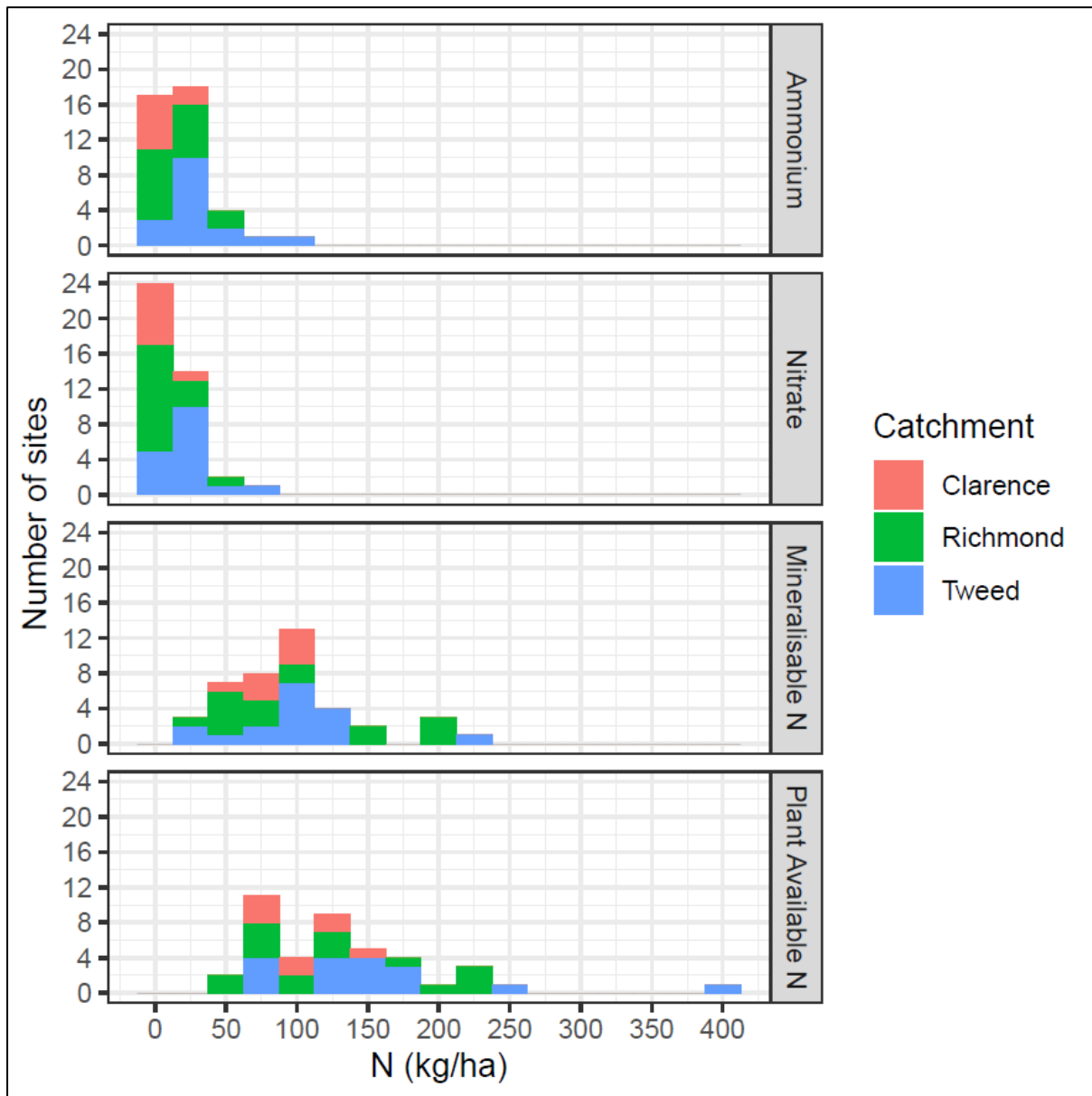


Figure 3: Distribution of deep soil N (40cm) from 41 sites in NSW. Mineralizable N, and total plant available N across 3 catchments including 14 additional Tweed sites sampled 2019. Note: Soil N adjusted for soil BD.

The extended data set has revealed total plant available N in the 0-40 cm layer across 41 sites to vary from around 50 kg N/Ha to 400 kg N/Ha. Most sites had negligible nitrate, while the 14-day PMN contributed important quantities of plant available N. Work presented below will show that PMN is underestimated using the 14-day PMN assay, and in fact may be a far more important source of crop nutrition than currently factored.

5: Output 6 (f) - 'Deep soil N': conduct incubations to estimate mineralizable N

5.1 Aim:

To provide an index of plant-available soil N to enable refinement of N fertiliser decisions through the 6ES.

5.2.1 14-Day Incubation Methodology:

A 2-week aerobic incubation method for determination of "Potentially Mineralizable-N" was supplied by Qld Department of Science, IT and Innovation, and adapted from Bremner (1965). Sub-samples from the 0-20 and 20-40 cm profiles of the deep nitrogen cores taken at all 41 sites were incubated at field capacity and 30°C under aerobic conditions, and sampled at 0, 7 and 14 days, respectively. The amounts of mineral-N formed at different times were measured by 2M KCl extraction followed by automated colorimetric determination. Mineralizable-N was calculated as the difference between the mineral-N before and after incubation. Using bulk density conversions from the field cores, the mineralizable N was converted to kg-N/Ha. (See summary distribution data from 6e and 6 f in Figures 2 & 3.)

5.2.2 14-Day Incubation Results:

Preliminary in-field mineral N and 14-day potentially mineralizable N (PMN) for the Clarence, Richmond and Tweed Catchment sampling sites (0-20 and 20-40 cm depths) are summarized in Tables 1 – 3. By combining these figures and adjusting for bulk density (BD) at each site, Available N (N available to the plant) was calculated and expressed as kg N/Ha.

Table 1: Clarence Catchment Available N

Clarence catchment				(BD adjusted) Available N (kg/Ha)
Site #	Depth (cm)	In Field Mineral N (mg/kg)	14-day PMN (mg/kg)	
1	0-20	6.90	7.30	25.9
	20-40	3.24	12.25	38.4
2	0-20	8.83	14.00	51.6
	20-40	3.23	8.55	32.5
3	0-20	4.70	17.60	37.7
	20-40	2.66	9.15	33.3
4	0-20	6.20	21.00	56.2
	20-40	1.25	3.20	12.6
5	0-20	5.38	11.70	26.6
	20-40	2.47	15.65	40.8
6	0-20	3.02	21.60	39.4
	20-40	2.61	16.35	43.9
7	0-20	12.47	28.90	61.2
	20-40	2.14	10.75	25.5
8	0-20	4.37	24.00	35.3
	20-40	3.46	13.20	35.2

Table summation: Pre-existing plant available N stocks of between 25.9 and 61.2 units N/ Ha were found in the 0-20 cm profile in some soils from the Clarence catchment and 12.6 to 43.9 units N/ha in the 20-40 cm profile.

Table 1: Richmond Catchment Available N

Richmond catchment				(BD adjusted) Available N (kg/Ha)
Site #	Depth (cm)	In Field Mineral N (mg/kg)	14-day PMN (mg/kg)	
9	0-20	7.96	15.25	34.9
	20-40	5.22	12.75	44.4
10	0-20	6.63	12.10	30.2
	20-40	2.67	7.60	23.1
11	0-20	21.53	25.00	71.4
	20-40	6.33	10.20	40.2
12	0-20	10.04	12.30	34.1
	20-40	11.43	17.95	65.6
13	0-20	19.87	33.00	108.7
	20-40	8.93	10.00	43.8
14	0-20	10.47	33.00	88.8
	20-40	3.95	24.15	64.1
15	0-20	3.70	14.21	26.8
	20-40	2.90	7.72	19.4
16	0-20	3.13	10.76	16.8
	20-40	1.97	13.34	24.7
17	0-20	4.35	22.62	34.3
	20-40	3.54	14.40	33.4
18	0-20	3.62	11.00	21.9
	20-40	1.89	8.85	27.4
19	0-20	2.29	24.50	65.7
	20-40	1.72	30.90	82.8
20	0-20	2.34	8.75	22.3
	20-40	1.65	13.55	39.7
21	0-20	2.81	25.50	56.3
	20-40	1.69	21.85	56.5
22	0-20	12.31	2.85	30.2
	20-40	2.78	7.10	21.1
23	0-20	3.99	11.15	23.1
	20-40	3.80	11.90	28.0
24	0-20	6.30	19.50	56.3
	20-40	3.77	27.55	75.6

Pre-existing available N at sites sampled from the Richmond Catchment ranged from 16 units N/ Ha up to 108 units N/ha in the 0-20 cm profile and from 19 to 83 units N/ha in the 20-40cm profile.

Table 2: Tweed Catchment Available N

Tweed catchment				(BD adjusted) Available N (kg/Ha)
Site #	Depth (cm)	In Field Mineral N (mg/kg)	14-day PMN (mg/kg)	
25	0-20	25.49	12.30	63.3
	20-40	17.38	9.04	57.2
26	0-20	20.40	14.00	57.0
	20-40	21.44	6.05	53.3
27	0-20	30.87	34.00	53.6
	20-40	23.03	19.05	51.9
28	0-20	8.30	11.58	30.0
	20-40	5.52	6.59	25.6
29	0-20	51.07	14.37	106
	20-40	13.90	5.58	38.2
30	0-20	15.53	17.91	66.8
	20-40	5.20	17.53	52.8
31	0-20	12.10	12.75	45.7
	20-40	5.63	21.92	65.3
32	0-20	11.70	11.73	50.6
	20-40	3.80	9.34	36.4
33	0-20	12.47	13.12	49.3
	20-40	5.63	17.93	55.0
34	0-20	11.70	13.75	48.2
	20-40	5.53	12.07	44.7
35	0-20	12.23	18.27	59.7
	20-40	6.53	19.42	64.9
36	0-20	10.17	16.65	49.6
	20-40	5.43	19.85	57.7
37	0-20	8.50	19.13	42.1
	20-40	5.00	18.15	57.1
38	0-20	9.13	15.65	41.3
	20-40	5.03	28.33	76.1
39	0-20	6.50	12.53	21.2
	20-40	6.77	23.12	39.2
40	0-20	121.0	18.67	162
	20-40	17.40	24.03	60.3
41	0-20	17.03	14.00	39.0
	20-40	9.07	16.94	42.8

In the Tweed Catchments, pre-existing Available N was found to range from 21.2 to 162 units N/Ha in the 0-20 cm profile and ranged from 25 to 76 units N/Ha at 20-40 cm.

5.3 56-Day incubations Rationale & Methodology:

It was noted that during the 2-week aerobic incubation method for PMN determination that while ammonium levels appeared to peak at T=7 to 14 days, nitrate levels continued to rise. This observation suggested that the 14-day method may underestimate available N stocks. The incubation was thus expanded to 56 days for all 41 sites. The new method followed the previous protocol but included additional sampling times T = 28 and 56 days.

5.3.1 56-Day Incubation Results:

PMN (mg/kg) as calculated by the difference between preliminary in-field mineral N and mineral N after incubation at each sample time was plotted for each site and grouped by sampling depth and catchment (Figures 2-7).

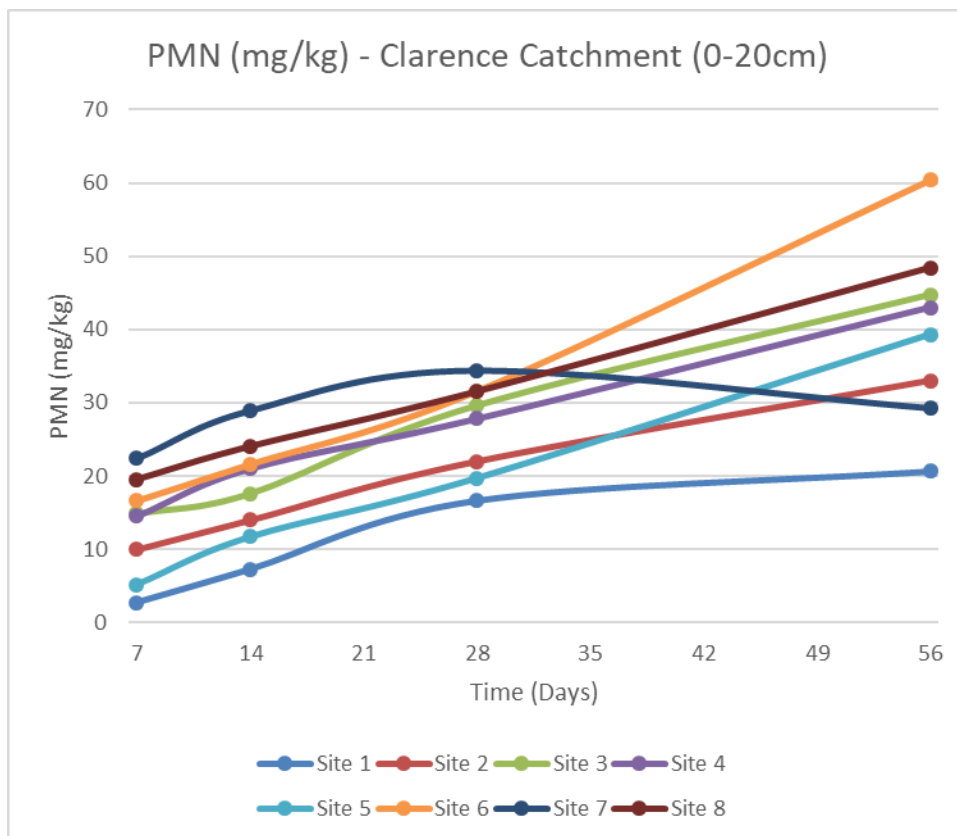


Figure 4: Potentially mineralizable N - Clarence Catchment 0-20cm

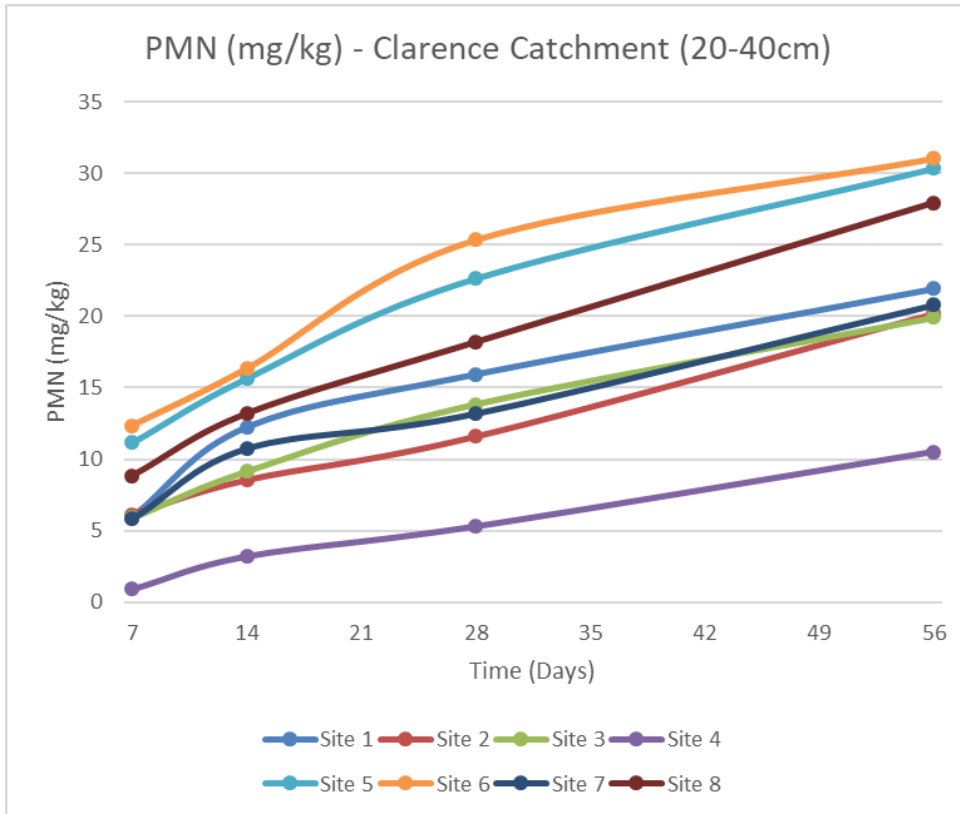


Figure 5: Potentially mineralizable N - Clarence Catchment 20-40cm

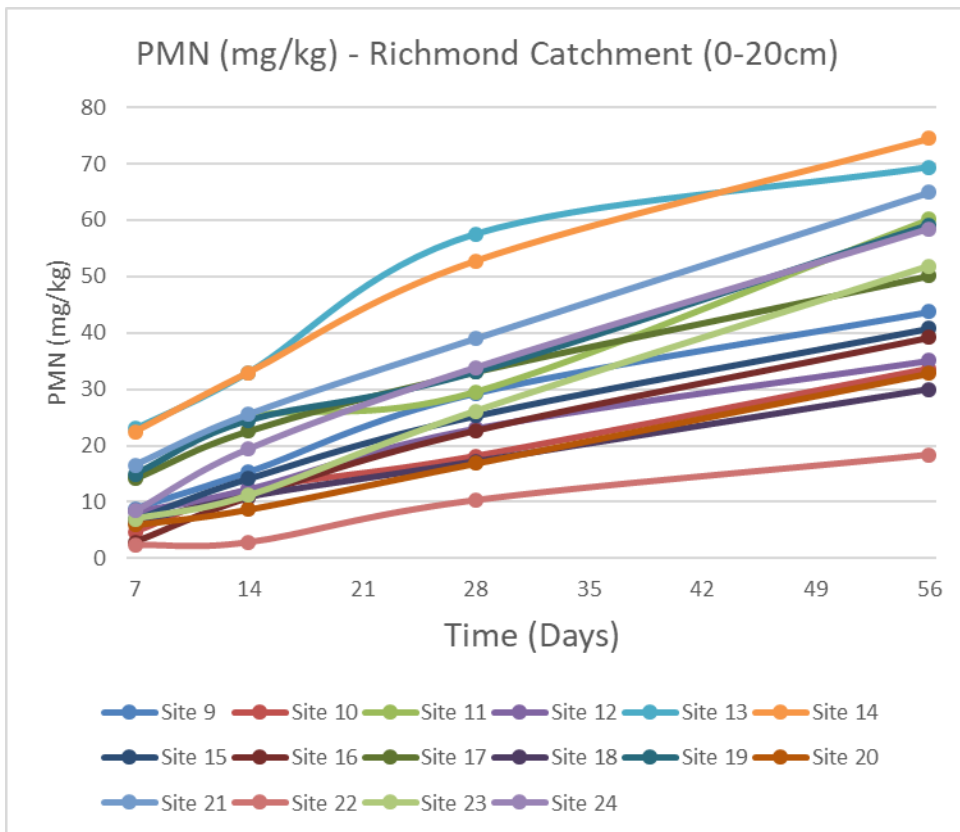


Figure 6: Potentially mineralizable N - Richmond Catchment 0-20cm

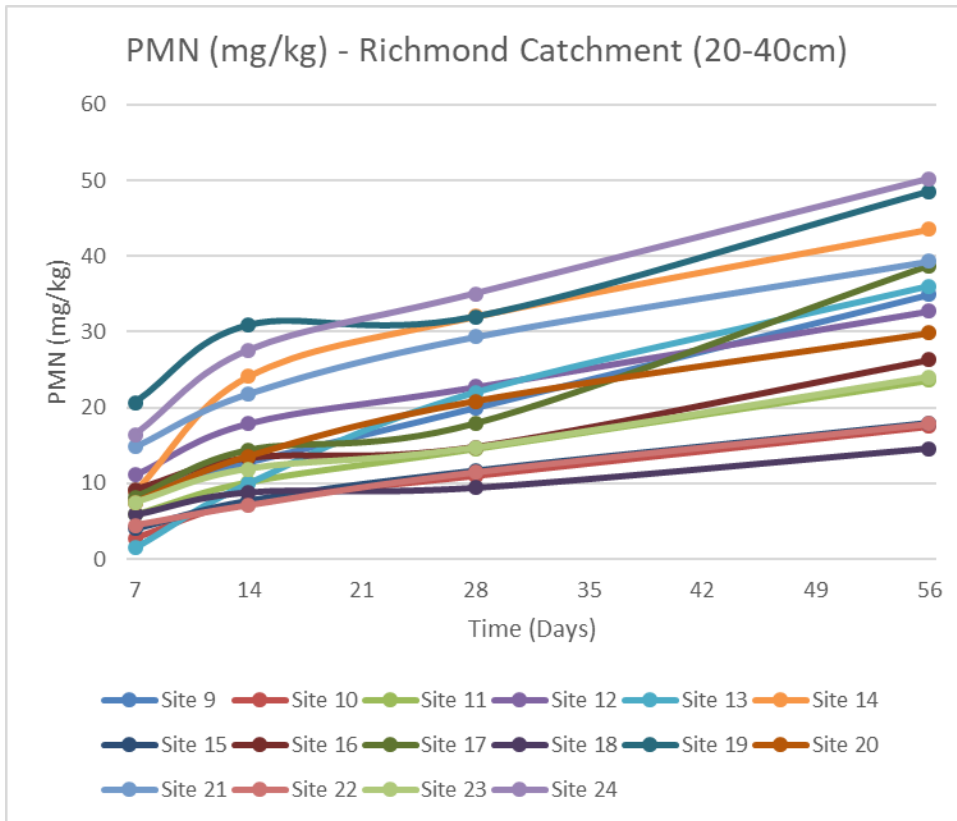


Figure 7: Potentially mineralizable N - Richmond Catchment 20-40cm

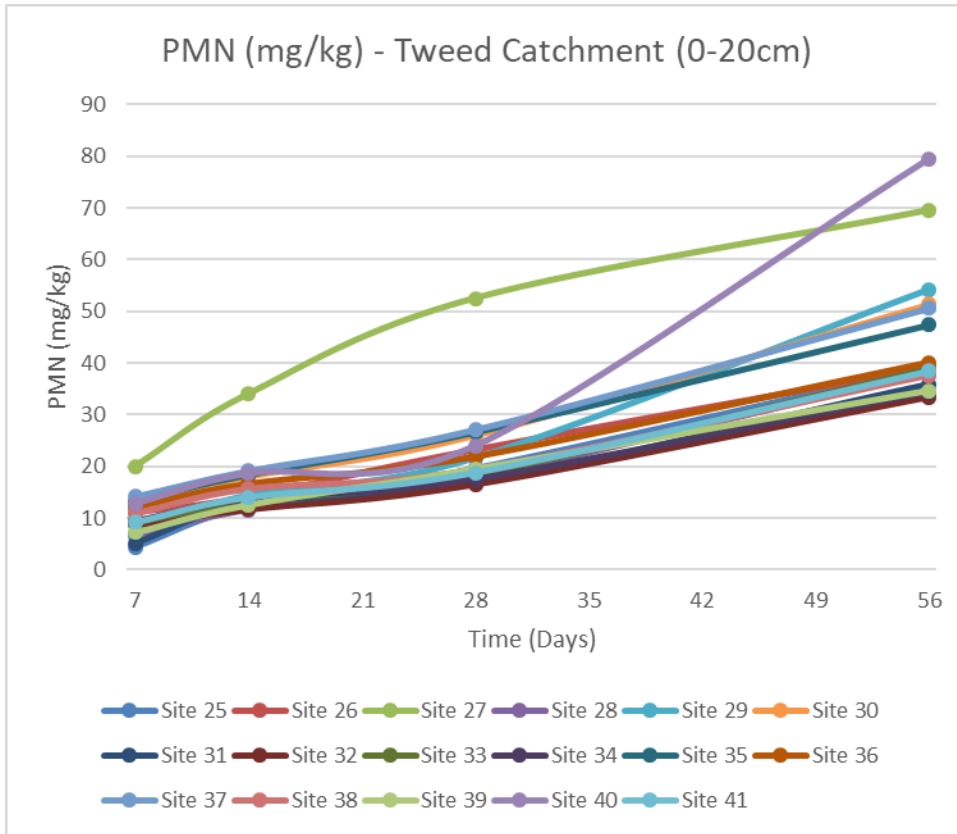


Figure 8: Potentially mineralizable N - Tweed Catchment 0-20cm

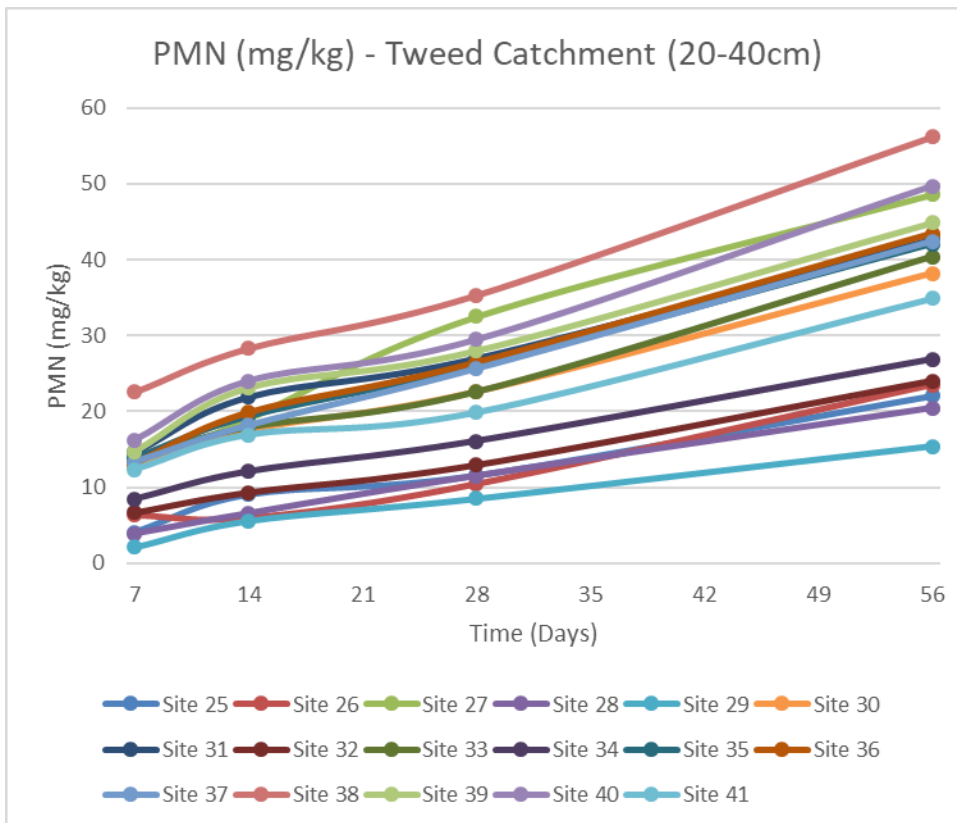


Figure 9: Potentially mineralizable N - Tweed Catchment 20-40cm

5.4 Assessing Long Term PMN from 27 field sites across 3 catchments:

5.4.1 Long Term Incubation Rationale and Methodology:

Soils in the 0-20 and 20-40 cm profiles from the initial 27 cores were included in a long-term incubation study aimed at determining the contribution of mineralisation to N availability (PMN) across the cropping cycle. The long-term incubation was based on a modified method (Allen et al., 2019- Qld Department of Environment and Science), with sampling times of 300 and 456 days (10 and 16 months).

5.4.2 Long Term /Incubation Results:

Results of the long term PMN incubations were grouped by catchment and depth and are summarized below.

Table 3: Clarence Catchment long term PMN (0-20cm)

Depth	0-20cm	Preliminary Mineral N		300 days PMN		436 days PMN	
Site	Catchment	mg/kg	Std error	mg/kg	Std error	mg/kg	Std error
1	Clarence	6.90	1.32	59.11	2.53	65.64	4.50
2	Clarence	8.83	0.09	80.60	1.98	94.36	3.25
3	Clarence	4.70	1.06	85.68	6.53	101.77	3.84
4	Clarence	6.20	1.65	84.63	1.79	102.29	5.22
5	Clarence	5.38	1.78	98.84	0.63	121.33	2.58
6	Clarence	3.02	0.61	98.66	4.63	121.95	5.12
7	Clarence	12.47	3.13	96.41	0.87	117.33	1.43
8	Clarence	4.37	0.19	92.27	2.50	110.38	0.41

Some sites in the Clarence Catchment had in excess of 100 mg N /kg available in the 0-20 cm profile following the 12-month incubation and up to 82 mg N/kg at depth (20-40 cm).

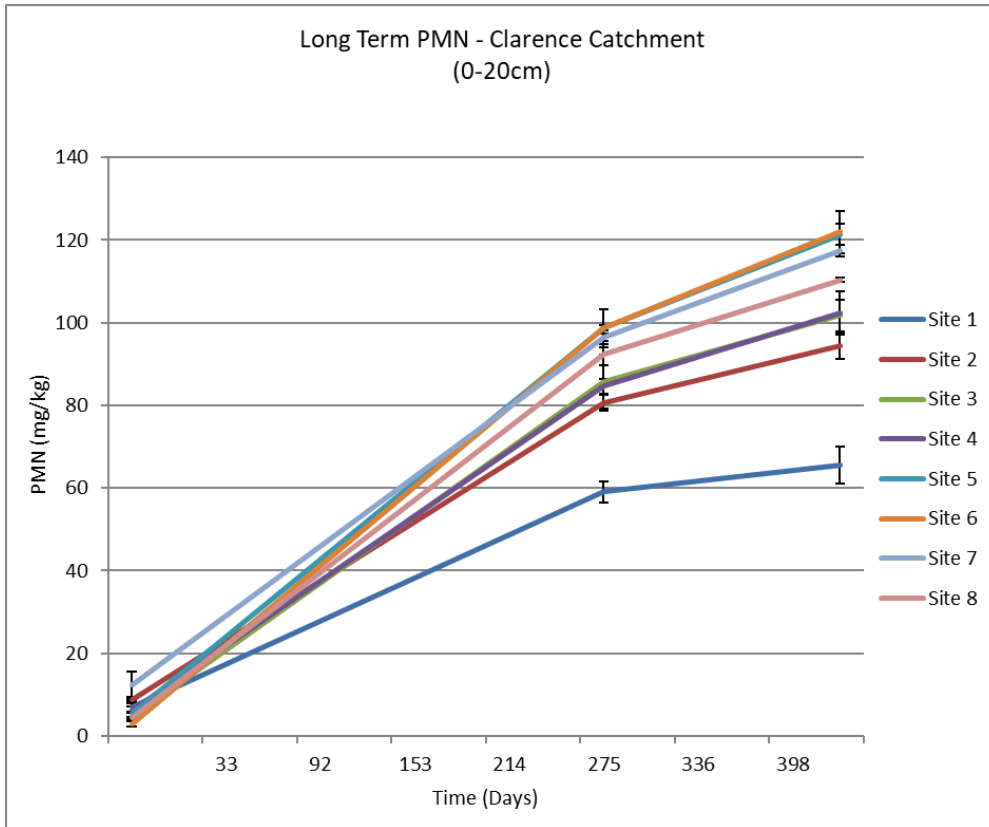


Figure 10: Long term PMN Clarence Catchment 0-20cm

Table 4: Long term PMN Clarence Catchment (20-40cm)

Depth	20-40cm	Preliminary Mineral N		300 days PMN		436 days PMN	
		Catchment	mg/kg	Std error	mg/kg	Std error	mg/kg
1	Clarence	3.24	0.25	41.90	0.37	46.44	2.96
2	Clarence	3.23	0.19	42.20	1.55	46.40	0.69
3	Clarence	2.49	0.18	42.08	2.23	45.83	1.04
4	Clarence	1.05	0.19	23.71	0.43	23.82	0.11
5	Clarence	2.47	0.49	54.49	0.94	68.42	3.09
6	Clarence	2.61	0.30	50.66	1.73	56.81	3.39
7	Clarence	1.99	0.36	43.79	0.88	48.70	0.55
8	Clarence	2.97	0.69	75.74	2.94	82.83	3.10

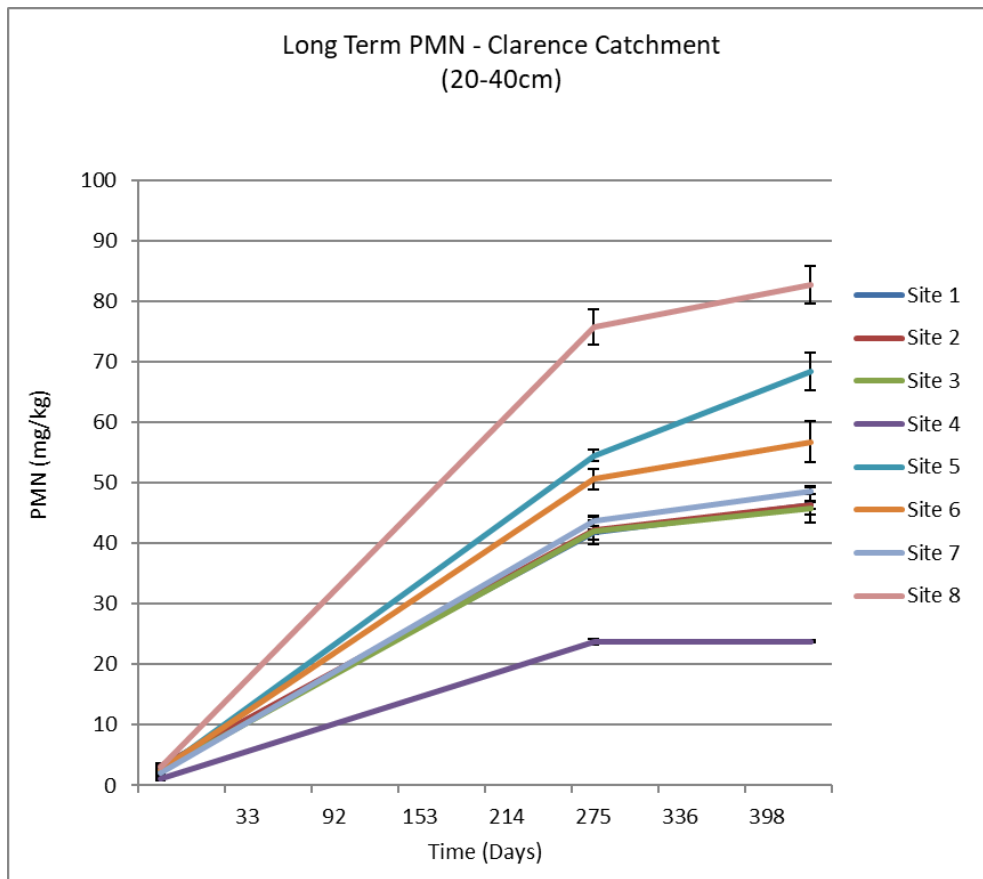


Figure 11: Long term PMN Clarence catchment 20-40cm

In the Richmond Catchment, N available from mineralisation in the 0-20 cm profile following the 12-month incubation ranged from 41 mg N/kg to 197.7 mg N/kg, and at depth (20-40 cm) 30.7 to 88.6 mg N/kg (Table 6 & 7).

Table 5: Long term PMN - Richmond Catchment (0-20cm)

Depth	0-20cm	Preliminary Mineral N		300 days PMN		436 days PMN	
		mg/kg	Std error	mg/kg	Std error	mg/kg	Std error
9	Richmond	7.96	0.49	108.32	1.82	116.79	6.08
10	Richmond	6.63	1.45	91.03	3.13	109.38	3.36
11	Richmond	21.53	4.34	106.89	2.25	128.40	1.40
12	Richmond	9.90	0.31	78.27	1.08	87.38	6.43
13	Richmond	19.87	3.07	184.09	3.30	197.70	16.40
14	Richmond	10.47	1.09	142.69	3.25	154.43	6.97
15	Richmond	3.70	0.42	87.28	2.58	96.79	1.82
16	Richmond	3.13	0.28	100.10	3.56	114.16	5.17
17	Richmond	4.35	0.76	103.81	3.42	109.97	2.83
18	Richmond	3.36	0.67	67.46	1.92	83.60	1.72
19	Richmond	2.29	0.09	119.81	3.49	126.61	3.48
20	Richmond	3.15	0.10	106.92	4.16	120.33	3.89
21	Richmond	2.81	0.22	114.12	4.73	138.93	2.45
22	Richmond	12.31	8.75	35.66	7.56	41.52	10.25
23	Richmond	3.99	0.36	104.70	6.94	97.32	18.75
24	Richmond	6.07	0.48	117.54	2.91	124.23	7.20

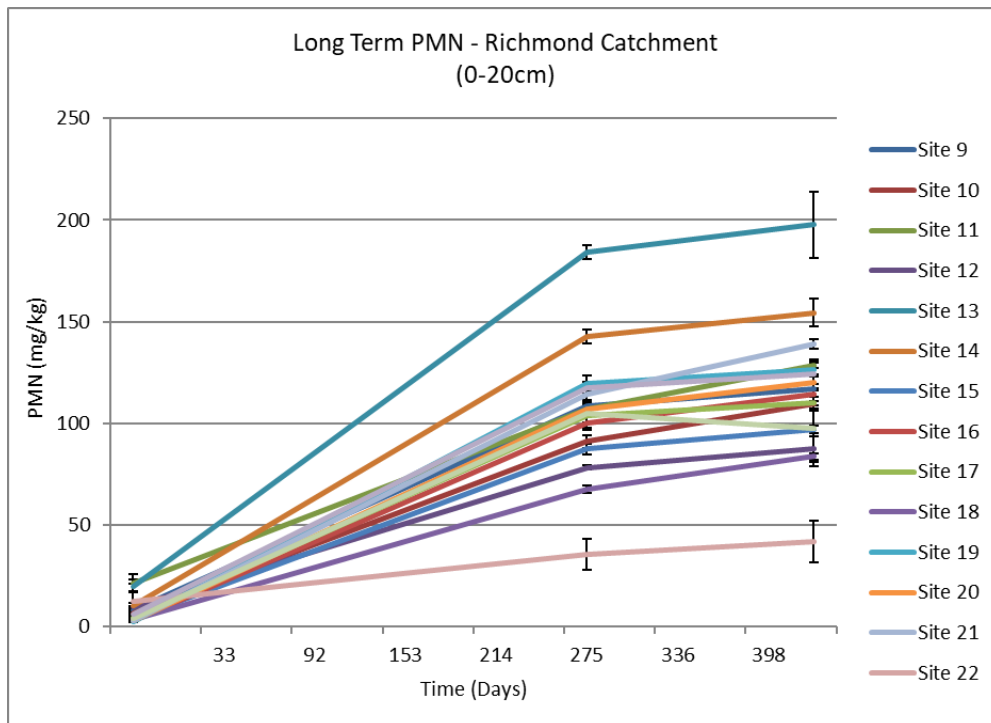


Figure 12: Richmond Catchment Long Term PMN (0-20cm)

Table 6: Long Term PMN Richmond Catchment (20-40cm)

Depth	20-40cm	Preliminary Mineral N		300 days PMN		436 days PMN	
		mg/kg	Std error	mg/kg	Std error	mg/kg	Std error
9	Richmond	5.22	0.30	48.87	2.55	58.66	1.42
10	Richmond	2.53	0.12	37.75	1.34	40.87	2.49
11	Richmond	6.33	1.72	43.91	1.02	56.96	1.39
12	Richmond	11.43	0.67	49.58	3.23	56.08	1.00
13	Richmond	8.93	0.98	78.56	6.82	78.97	7.92
14	Richmond	3.95	0.63	63.91	2.23	68.66	1.85
15	Richmond	2.90	0.50	38.57	1.06	44.35	1.35
16	Richmond	1.97	0.43	49.51	2.42	51.52	9.12
17	Richmond	3.46	0.23	49.14	0.30	60.46	0.94
18	Richmond	1.67	0.23	31.41	1.35	30.67	2.10
19	Richmond	1.72	0.22	65.45	1.53	79.67	2.42
20	Richmond	2.03	0.13	50.93	0.19	56.71	2.06
21	Richmond	1.69	0.34	70.53	0.74	78.72	1.94
22	Richmond	2.78	0.47	33.86	0.66	36.64	1.84
23	Richmond	3.25	0.73	47.99	3.21	49.02	2.76
24	Richmond	3.77	0.26	71.18	2.79	88.61	9.55

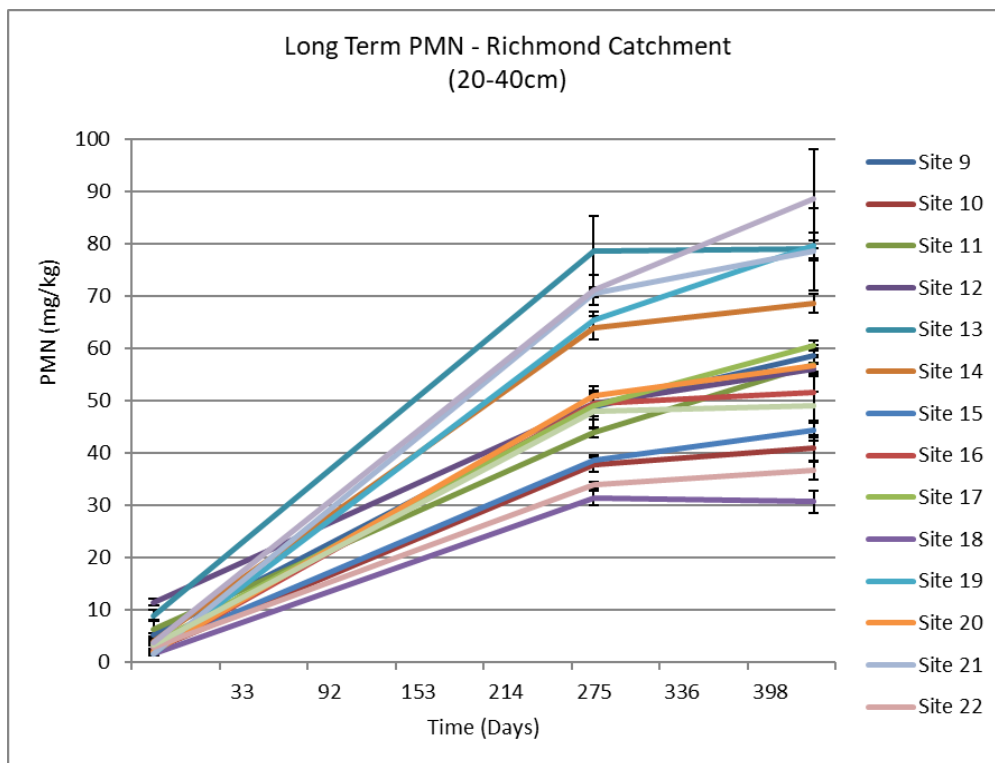


Figure 13: Richmond Catchment Long Term PMN (20-40cm)

The 3 sites sampled from the Tweed Catchment in the initial campaign had in excess of 100 mg N/kg available due to mineralisation in the 0-20 cm profile and >50 mg N/kg at depth (Table 8 & 9).

Table 7: Long Term PMN Tweed Catchment (0-20cm)

Depth	0-20cm	Preliminary Mineral N		300 days PMN		436 days PMN	
Site	Catchment	mg/kg	Std error	mg/kg	Std error	mg/kg	Std error
25	Tweed	25.14	3.41	75.75	9.97	102.68	6.21
26	Tweed	20.40	4.66	74.89	6.84	143.98	23.04
27	Tweed	21.44	3.77	131.57	1.80	146.87	22.71

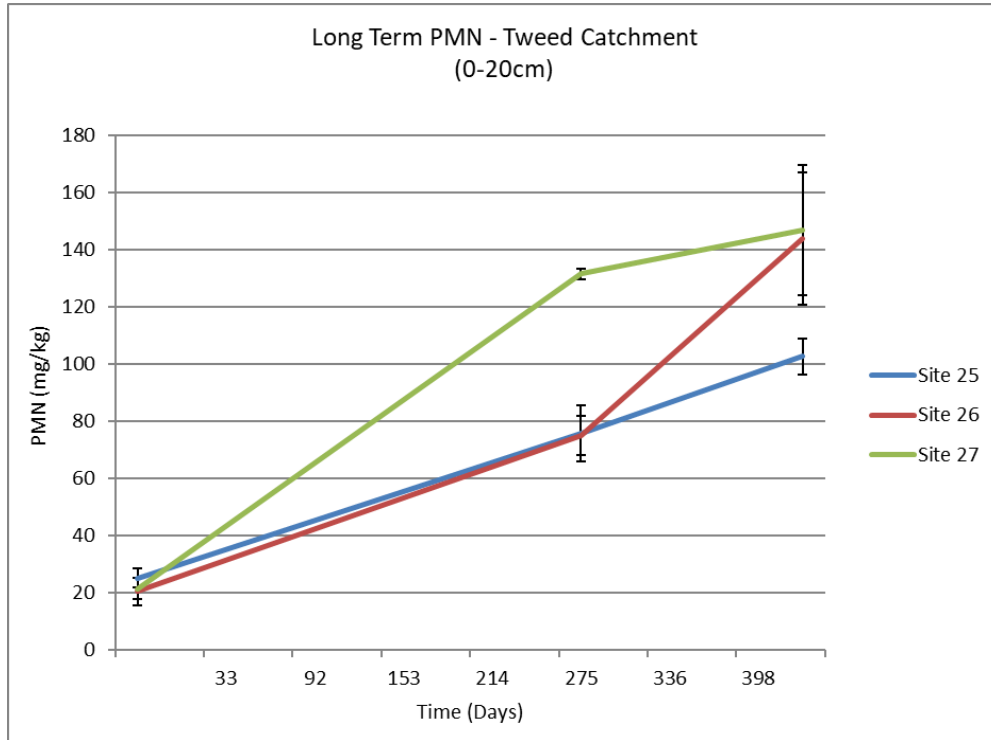


Figure 14: Tweed Catchment Long Term PMN (0-20cm)

Table 8: Long Term PMN Tweed Catchment (20-40cm)

Depth	20-40cm	Preliminary Mineral N		300 days PMN		436 days PMN	
Site	Catchment	mg/kg	Std error	mg/kg	Std error	mg/kg	Std error
25	Tweed	17.19	0.91	49.53	2.59	52.41	5.20
26	Tweed	30.87	4.75	47.22	0.89	56.68	2.05
27	Tweed	22.72	1.33	66.43	1.91	76.85	3.11

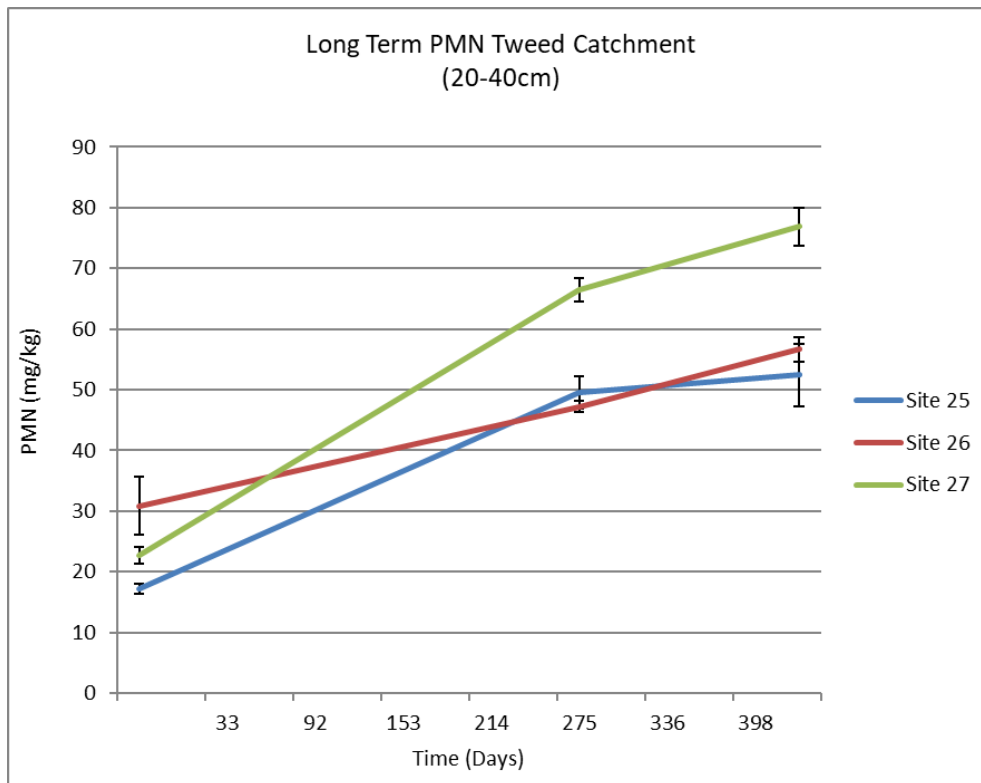


Figure 15: Tweed Catchment Long Term PMN (20-40cm)

Potentially Mineralizable N determined from the 56-day and long-term incubations for each site was calculated as kg N/Ha, combining the 0-20 and 20-40 cm layers into a single 0-40 cm value (Table 10) (calculated on a BD basis).

In the Clarence Catchment PMN in the 0-40cm profile ranged from 43.6 kg N/Ha to 72.5 kg N/Ha at T=14 days. At T=456 days PMN ranged from 235 kg N/Ha to 343 kg N/Ha. In the Richmond Catchment PMN 14 days ranged from 20.9 kg N/Ha to 139 kg N/Ha and PMN 456 days ranged from 161 kg N/Ha to 589 kg N/Ha. In the Tweed catchment PMN 14 ranged from 31.4 kg N/Ha to 90.7 kg N/Ha. Long term PMN incubations for 14 additional Tweed catchment sites are currently still underway, however in the 3 sites that have been completed the PMN 456 ranged from 216 to 349 kg N/Ha.

It should also be noted that the longer term-PMN data may also underestimate mineralisation, as high nitrate concentrations in soil tend to inhibit further nitrification. In a planted system where roots are actively growing, a large portion of this nitrate would be extracted from the soil. Therefore, under a field setting, greater PMN could occur.

Understanding the longer term PMN of a soil would enable refinement of fertiliser N additions, and in all likelihood, would allow for improved N response where the long term PMN was low. However, the current testing regime (ie 300 days) is impractical for making fertiliser decisions, thus a more timely assessment of 300-day PMN would be more acceptable. As such, the project has investigated MIR for the prediction of 300-day PMN (see below sections).

Table 9: Potentially mineralizable N (kg N/Ha) in the 0-40cm profile following selected incubation periods

Site	Catchment	GPS	PMN (kg N/Ha) 0-40cm			
			14 days	56 days	300 days	436 days
1	Clarence	-29.52417, 153.12073	43.6	92.0	211	235
2	Clarence	-29.52559, 153.11119	55.2	130	298	341
3	Clarence	-29.45663, 153.26624	55.5	132	263	301
4	Clarence	-29.45633, 153.25976	52.4	118	242	278
5	Clarence	-29.42276, 153.24615	53.4	129	276	343
6	Clarence	-29.42115, 153.24786	72.5	169	275	327
7	Clarence	-29.46841, 153.27304	64.0	84.4	229	270
8	Clarence	-29.48088, 153.28129	57.7	119	275	312
9	Richmond	-28.89122, 153.52121	54.4	152	283	320
10	Richmond	-28.89312, 153.49715	36.6	93.6	232	268
11	Richmond	-28.9099, 153.48656	63.1	150	271	335
12	Richmond	-28.89123, 153.51904	58.9	127	230	259
13	Richmond	-29.01496, 153.30189	91.0	226	560	589
14	Richmond	-29.00669, 153.29093	122	251	437	472
15	Richmond	-28.92178, 153.53275	35.4	94.1	201	226
16	Richmond	-28.91872, 153.53044	34.5	89.8	201	221
17	Richmond	-28.88113, 153.52955	55.6	136	224	252
18	Richmond	-28.88203, 153.53852	39.1	82.1	181	204
19	Richmond	-28.91912, 153.23892	139	268	460	513
20	Richmond	-28.93017, 153.24054	53.0	144	348	390
21	Richmond	-28.94392, 153.24234	103	224	396	465
22	Richmond	-28.84262, 153.49591	20.9	74.8	143	161
23	Richmond	-28.83956, 153.49689	38.3	122	246	236
24	Richmond	-29.08937, 153.32968	109	249	428	485
25	Tweed	-28.281789, 153.507495	40.2	113	234	286
26	Tweed	-28.28852, 153.42681	34.9	110	216	349
27	Tweed	-28.33726, 153.41036	51.5	117	191	216
28	Tweed	-28.308326, 153.456325	31.4	101	Results pending	
29	Tweed	-28.309082, 153.456175	34.2	118		
30	Tweed	-28.273063, 153.467871	76.5	191		
31	Tweed	-28.273261, 153.467023	75.4	167		
32	Tweed	-28.276134, 153.469730	51.3	139		
33	Tweed	-28.314763, 153.423814	66.8	168		
34	Tweed	-28.315622, 153.423149	56.7	133		
35	Tweed	-28.316751, 153.421851	84.3	198		
36	Tweed	-28.313087, 153.399620	76.1	173		
37	Tweed	-28.316232, 153.399666	73.9	182		
38	Tweed	-28.316204, 153.400133	90.7	191		
39	Tweed	-28.335517, 153.412204	44.3	97.4		
40	Tweed	-28.337761, 153.412316	56.7	165		
41	Tweed	-28.337969, 153.414000	45.4	106		

6.0 Field Trials – addressing Output 6 (g)

6.1 Aim:

Develop greater knowledge and understanding of how enhanced efficiency fertiliser (EEF), in this work being PCU, can better match crop-specific N requirements by developing N response curves and assessing apparent fertiliser N use efficiency.

6.2.1 Trial setup Methodology:

Four field sites were established across the 3 Northern NSW cane-growing catchments over 2 growing seasons: 2016/17 and 2018/19. The field trials established at each site were a randomized complete block design of 6 rates (including a nil-rate control) of each fertilizer (standard urea and Polymer Coated Urea (PCU)). Treatments were arrayed with 3 replicates giving a total of 33 plots including controls.

Each plot spanned 3 rows of cane. The outer 2 rows served as a buffer, whilst all sampling and measurement was conducted on the centre row. The length of the trial plots was adjusted to suit block allocation – ranging from 27- 36 m. The large agronomically relevant plot size enabled commercial harvesting of the sugarcane. The harvester employed used a weigh bin accuracy of +/- 5 kg, therefore accurate plot harvests were possible.

Amendments were applied using a stool-splitter as per standard practice, calibrated in the field for each product and rate.

6.2.2 Treatment matrix:

The treatment matrix on each field trial site was comprised as follows:

2 x Nitrogen Fertilizers: Urea and Polymer Coated Urea (PCU)

3 x reps

5 rates (units N/Ha): 50 100 200 300 400

+ 3 x control plots (nil N addition)

∴ 33 plots per farm

NB: Management for P and K application at each site followed standard farm practice.

On the field at each site, the trial plots were arranged as depicted in Figure 16.

Standard_50	Polymer_100	Polymer_300	Standard_100	Polymer_400	Polymer_200	Standard_200	Polymer_50	Nil_0	Standard_400	Standard_300
Polymer_300	Standard_400	Polymer_200	Nil_0	Standard_200	Standard_300	Polymer_100	Standard_100	Polymer_50	Standard_50	Polymer_400
Standard_200	Polymer_50	Standard_300	Polymer_400	Standard_400	Nil_0	Standard_50	Polymer_300	Standard_100	Polymer_200	Polymer_100

Figure 16: Randomized block design for each field trial site. Each plot spanned 3 rows of cane and ranged from 27-36 m in length based on the field constraints at each farm

6.2.3 Field Sites 2016/17:

Field site 1: Stotts Creek (Tweed Catchment), GPS: -28.281789, 153.507495



Figure 17: Stotts Creek field trial site - Tweed Catchment NSW

The Stotts Creek field trial was established 12th December 2016 and corresponded with Site 25 from Output 6(e). The cane variety at this site was KQ228 with a row spacing of 1.65 m.

Field site 2: Pimlico, Richmond Catchment, GPS: -28.89123, 153.51904



Figure 18: Pimlico Field trial site - Richmond Catchment NSW

The Pimlico field trial in the Richmond Catchment was established 19th December 2016 and corresponded with site 12 from Output 6(e). At this site the cane variety was Q193, dual row with 1.7 m centre spacing.

6.2.4 Field sites 2018/19:

Two additional field trials were established in 2018. The project team sought to obtain sites with lower initial soil N stocks to maximise differences between response curves comparing urea with EENF. The two sites were selected based on earlier deep soil coring in the Clarence Catchment and Richmond Catchment (Sites 2 and 14 respectively from Output 6(e)). These sites were third and second ratoon respectively, each with low residual mineral N in the soil profile (see Tables 1 and 2).

Field Site 3: Woodford Island (Clarence Catchment), GPS: -29.525483, 153.110182



Figure 19: Woodford Island Field trial site – Clarence Catchment NSW

The Woodford Island field trial in the Clarence Catchment was established 31st October 2018. At this site the cane variety was Q232, 3rd Ratoon – planted 2012 with 1.8 m row spacing.

Field Site 4: Coraki (Richmond Catchment), GPS: -29.008100, 153.294945.



Figure 20: Coraki field trial site – Richmond Catchment NSW

The Coraki field trial in the Richmond Catchment was established 6th November 2018. The cane variety was Q203, second ratoon, dual row with 1.8 m centres.

6.2.5 Modification to 2018 Field Trials:

As described in Van Zwieten et al (2018) (National Soils Conference Canberra), the 90-day polymer was exhausted of urea within 90 days. It was discussed with Kirsten Verburg (CSIRO) that maximum N demand for most sugarcane crops in NSW is around 150 days (February-March) following ratoon, therefore the 90-day polymer may have already released all urea into soil before maximum crop demand. This was also reflected in the yield data comparing urea with PCU at matched N doses, where, essentially, no differences in yield were recorded. To address this, a blend (50:50) of 90- and 270-day polymer urea was assessed in these 2 field sites. The blended product was applied at the same rates prescribed for the two earlier field sites and compared with standard urea.

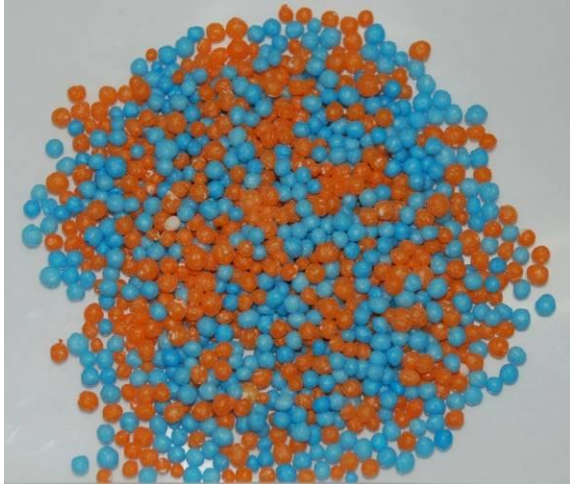


Figure 21: Blended PCU90 and PCU 270

Polymer coated urea was blended on a weight for weight basis and pre-bagged for transport to the field.

6.3 Field Trial Results:

6.3.1 Yield (Sites 1 & 2):

For yield assessment at Sites 1 and 2 the project team were able to secure usage of an SRA Cat Challenger with 5kg-accuracy weigh-bin. The Cat Challenger operated in conjunction with the commercial harvester tasked with harvesting the entire site. A member of the project team coordinated stop/start positions for each plot and the harvester and weigh-bin paused long enough to record bin weights and reset before moving on. The project team would like to acknowledge the patience and cooperation of the machinery operators involved.

Yields were calculated for each plot based on bin weights, and the plot length & row spacing specific to each site. These figures were converted to tons per hectare and averaged for each treatment.



Figure 22: SRA Cat Challenger experimental plot harvester

Site 1 Yield:

Site 1 was harvested on 12th October 2017 as one-year cane. The mean yield (T/Ha) for each treatment and standard error (SE) between replicates are presented in Table 11.

Table 10: Mean yield for each amendment – Site 1

Treatment	Yield (T/Ha)	SE
Nil_0	73.5	9.42
Polymer_50	87.5	8.10
Polymer_100	82.7	20.66
Polymer_200	96.4	12.23
Polymer_300	111.1	9.01
Polymer_400	93.1	20.46
Standard_50	90.0	12.50
Standard_100	98.6	12.82
Standard_200	123.1	12.87
Standard_300	92.8	18.43
Standard_400	98.9	10.34

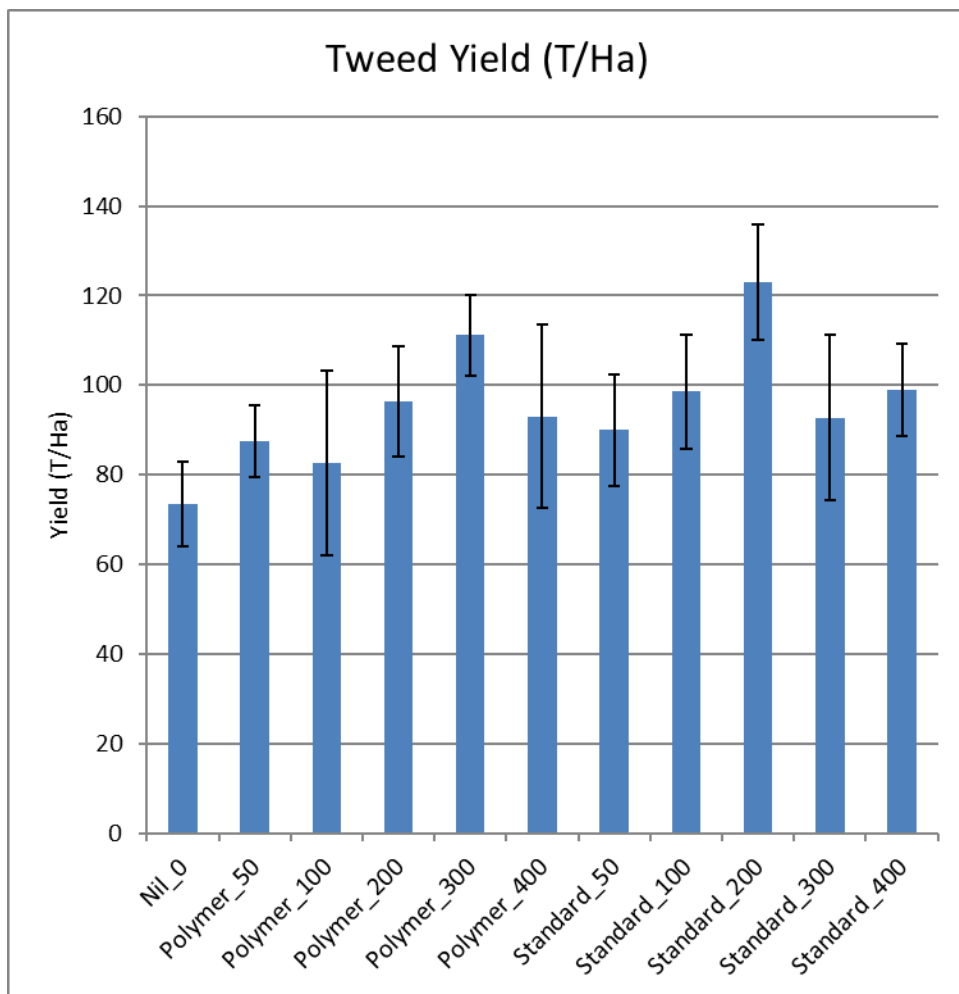


Figure 23: Yield (T sugarcane harvested (fresh weight) /Ha) Stotts Ck trial site.

The highest yielding amendment observed at Site 1 was standard urea at 200 units/Ha, however for all treatments there was considerable variability across the field.

Biometric analyses of the yield response at the Stott's creek site, factoring field variability, indicated that there was no evidence for a response to N product but there was a weak response to N rate averaged over the products as depicted in Figure 24. Consequently, the model is presented as a single curve. Note that the error band represents a 95% confidence interval around the predicted yield. The yield response to N fertiliser at this site was not strong, suggesting that the soil was able to provide an important contribution from PMN.

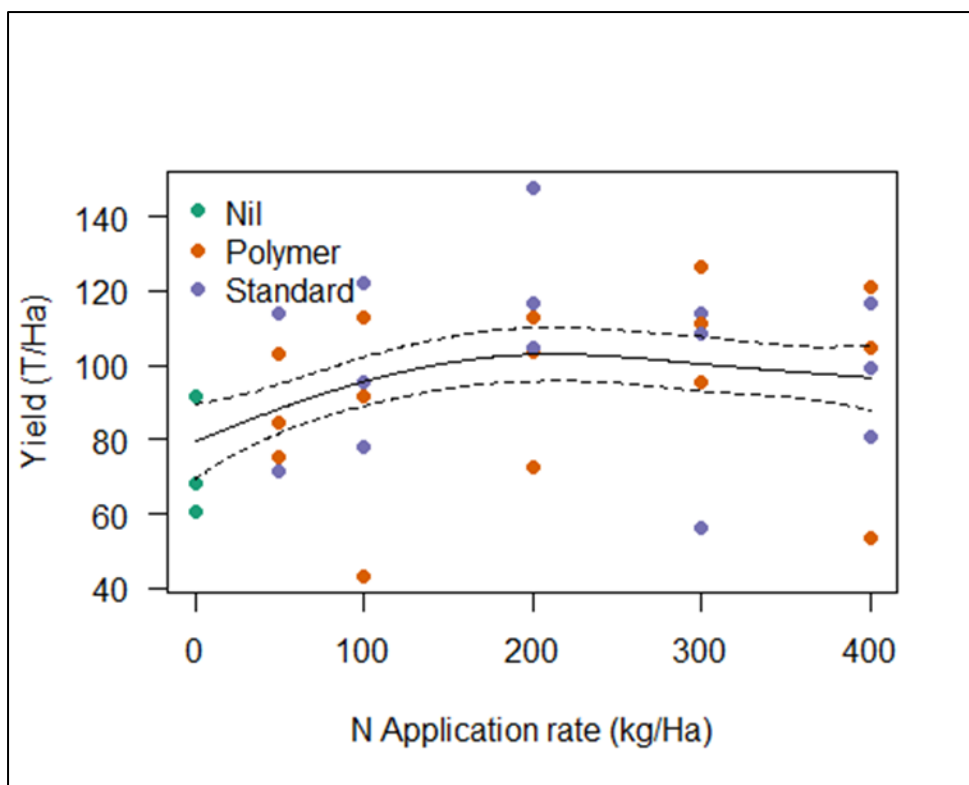


Figure 24: Yield (T/Ha) vs application rate Site 1

Table 12 summarizes the estimated yield and standard error at the design points based on the modelling in figure 24.

Table 11: Yield (T/Ha) vs application rate - Site 1

rate	Yield (T/Ha)	se
0	79.5	5.0
50	88.3	3.3
100	95.6	3.3
200	103.0	3.7
300	100.4	3.7
400	96.7	4.4

Statistical modelling indicated a maximum yield of 103 T/Ha at the 200 kg/ha fertilizer application rate for this site, compared to 79.5 T/Ha for the nil rate controls. Higher rates of N application resulted in modelled yields below the maximum; 100.4 T/Ha and 96.7 T/Ha for 300 and 400 kg N/Ha rates respectively.

Site 2 Yield:

Site 2 was harvested on 15th June 2018. Harvest was brought forward due to an accidental burn arising from a neighbouring cane block. The mean yield (T/Ha) for each treatment and standard error (SE) between replicates are presented in Table 13.

Table 12: Mean yield for each amendment – Site 2

Treatment	Yield (T/Ha)	SE
Nil_0	83.9	6.00
Polymer_50	107.2	11.42
Polymer_100	127.2	13.56
Polymer_200	139.2	2.38
Polymer_300	149.7	11.30
Polymer_400	157.3	9.84
Standard_50	125.4	14.52
Standard_100	114.8	5.95
Standard_200	134.1	11.13
Standard_300	160.6	7.59
Standard_400	153.7	12.63

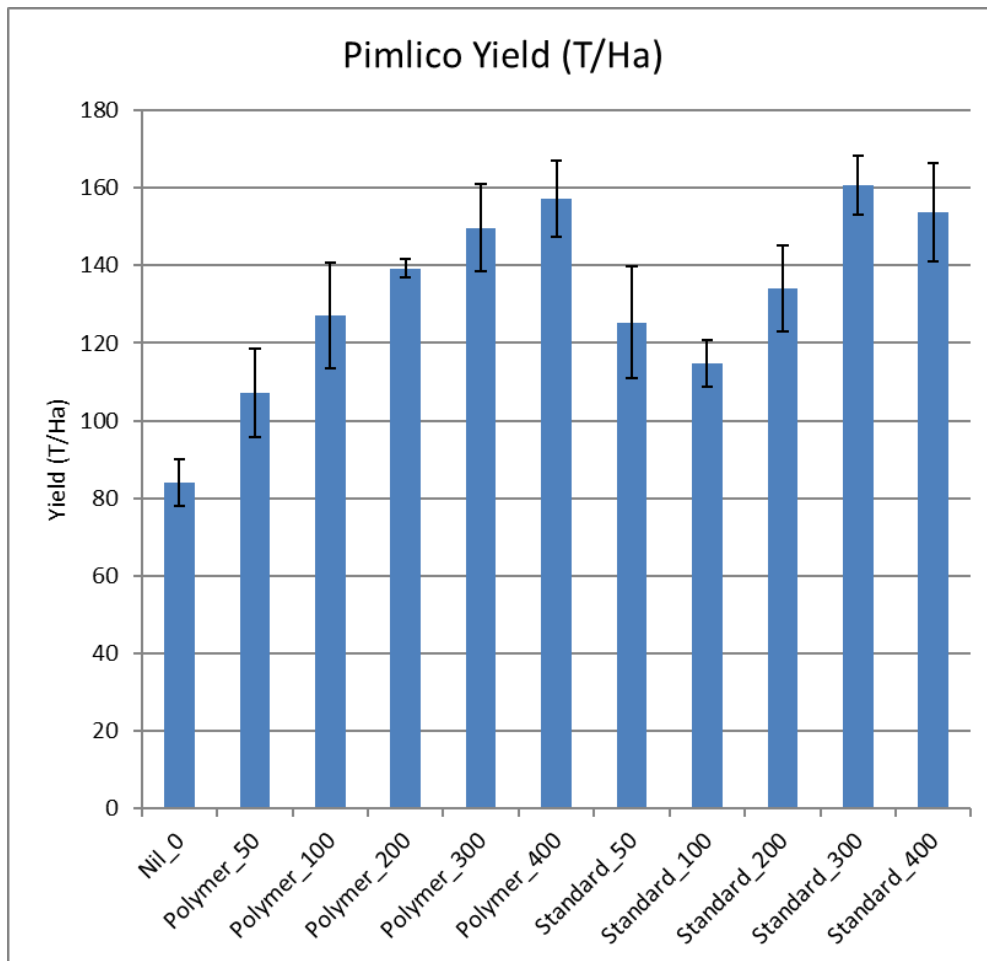


Figure 25: Yield (T sugarcane harvested (fresh weight) /Ha) Pimlico trial site

Biometric analyses of the yield response at the Pimlico site, accounting for field variability, indicated that there was not strong evidence for a response to N product but there was a weak response to N rate averaged over the products as depicted in Figure 26. Consequently, the model is presented as a single curve.

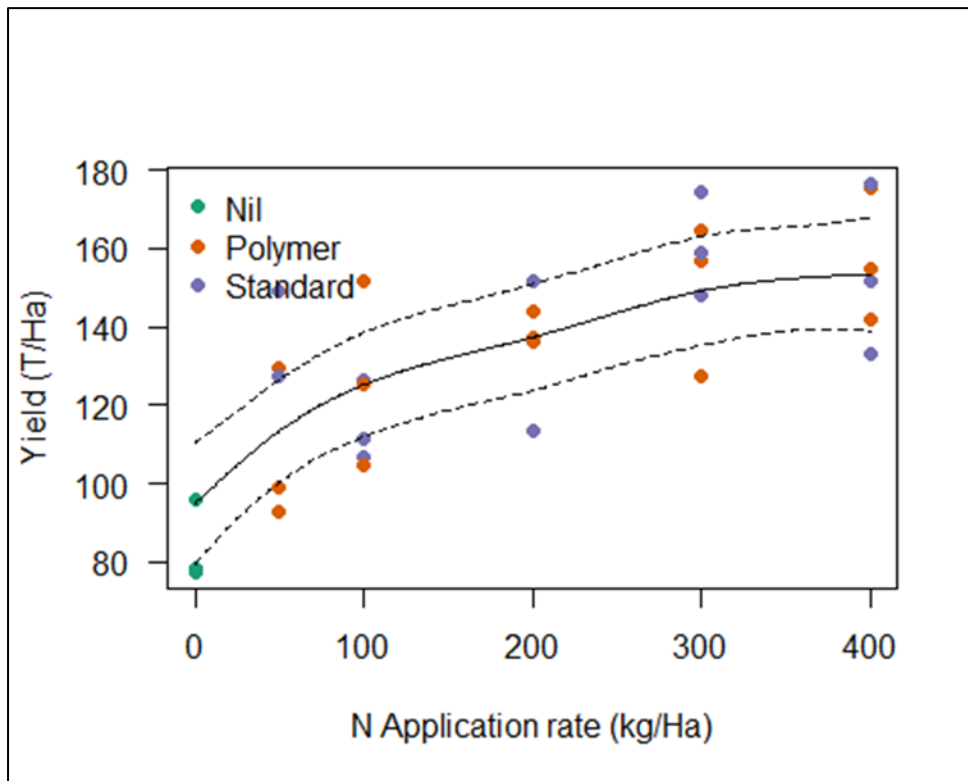


Figure 26: Yield response to application rate - Pimlico

The Pimlico data has shown a stronger yield response to N compared to field site 1, indicating the soil supply of PMN was likely to be lower.

Table 14 summarizes the estimated yield and standard error at the design points based on the modelling in figure 26.

Table 13: yield vs application rate - Pimlico

rate	Yield (T/Ha)	se
0	94.9	7.8
50	113.5	6.6
100	125.3	6.6
200	137.4	6.8
300	149.3	7.0
400	153.5	7.3

Statistical modelling indicated that at the Pimlico site yield response to fertilizer rate increased steadily with increasing fertilizer rate with no decline at higher rates. Modelled yield response ranged from 94.9 T/Ha in the control treatment to 153.5 T/Ha at 400 kg N/Ha applied.

6.3.2 Yield Estimates (Sites 3 & 4):

As sites 3 and 4 (2-year cane) were due to be harvested in late 2020, the project team adopted a methodology for estimating yield in 2-year-old cane that was provided by Rick Beattie of Sunshine Sugar. The total number of stalks in a pre-marked 20m subplot were counted, and then 40 stalks from within that subplot were harvested for analysis. The hand cut samples were weighed on-site using a flatbed balance mounted to the back of a vehicle. Harvest weight and number of stalks was converted to T/Ha to estimate yield. Previous studies have found a strong correlation between estimates at 9-month-old and actual 2-year yields ($r^2=0.8009$).



Figure 27: Yield estimate methodology in field

Yield estimate equation:

2-year yield estimates were calculated using the formula:

$$y = 0.6696x + 2.0971$$

Where: y = 9-month subsample harvest weight
 x = 2-year yield estimate

Site 3 Yield:

Unseasonably low rainfall slowed sugarcane growth considerably at Site 3. Woodford Island received 600.8 mm from October 2018 to December 2019 (Harwood Mill rain records) compared to the average of 1097.5mm for the same period (BOM climate averages Maclean NSW). Daily rainfall at Woodford Island is shown in figure 28.

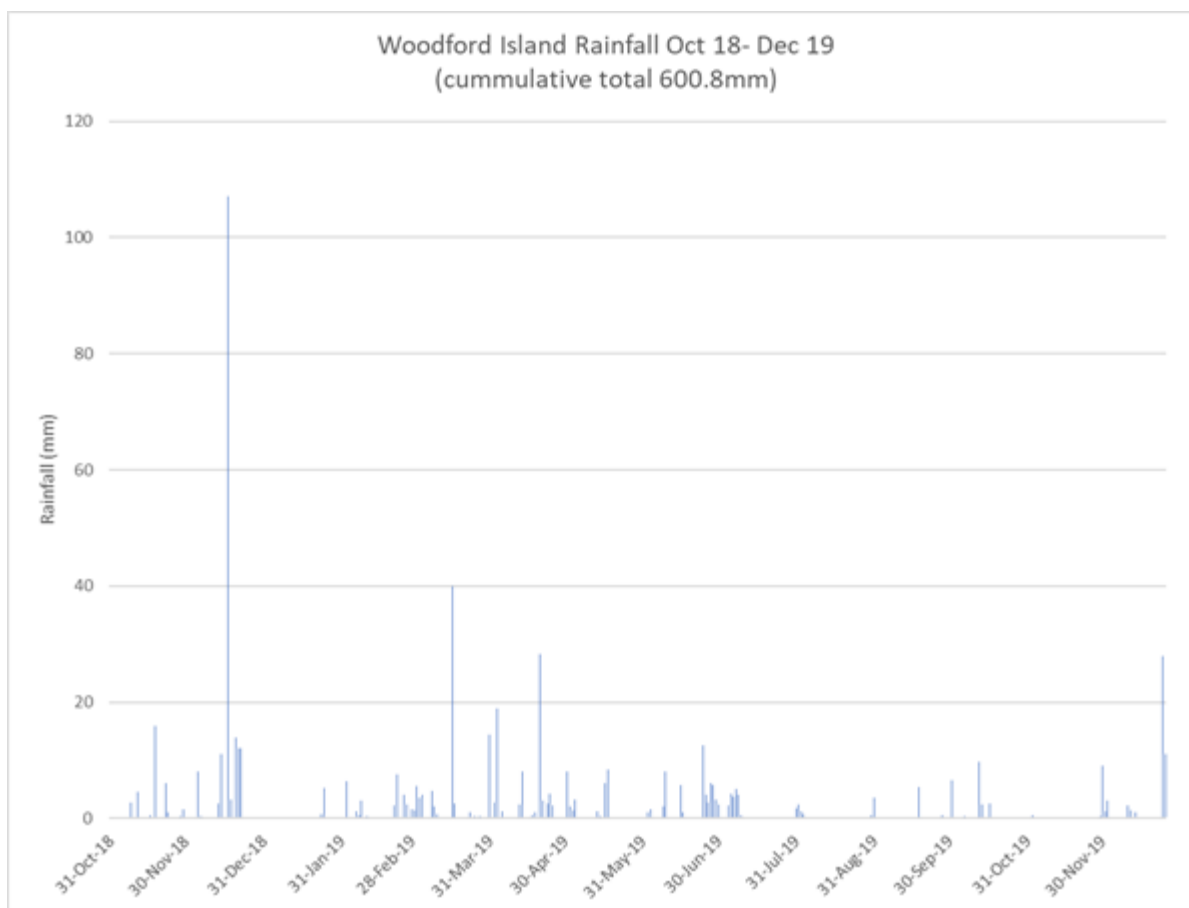


Figure 28: Significant rainfall deficit at Woodford Island, particularly during the summer months

Yield estimates for the Woodford Island site were undertaken on 25th July 2019. The mean yield at 9 months for each treatment at Woodford Island is presented in Table 15 along with 2-year yield estimates for 2020 based on the yield estimate equation described above. These predicted figures are well below the previous season average yield from this block which was 80 T/acre (197.6 T/Ha). Actual yield (Figure 29) of 2 -year cane was obtained in July, 2020 using the same high-resolution harvesting equipment as described for Sites 1 and 2.

Table 14: Woodford Island 2-year yield estimate

Treatment	Yield T/Ha	std error	2-year yield estimate (T/Ha)
Nil_0	43.4	8.67	61.7
Polymer_50	68.2	1.29	98.7
Polymer_100	83.9	4.73	122.2
Polymer_200	89.2	9.80	130.1
Polymer_300	83.5	2.47	121.6
Polymer_400	77.3	8.11	112.3
Standard_50	45.2	2.37	64.4
Standard_100	78.1	11.19	113.4
Standard_200	83.3	2.51	121.2
Standard_300	101.6	13.84	148.6
Standard_400	88.2	6.29	128.5

The assessment of 2-year yield (Fig 29) was fitted using a model to accommodate the potential for a quantitative rate response plus accounting for spatial variation in the field. The model revealed no separation between PCU and urea at given fertiliser rates. This is likely reflected by the environmental conditions during the experiment, where very low rainfall would have resulted in little opportunity for fertiliser N-loss. Maximum harvested yield was obtained between 200-300 units N/Ha.

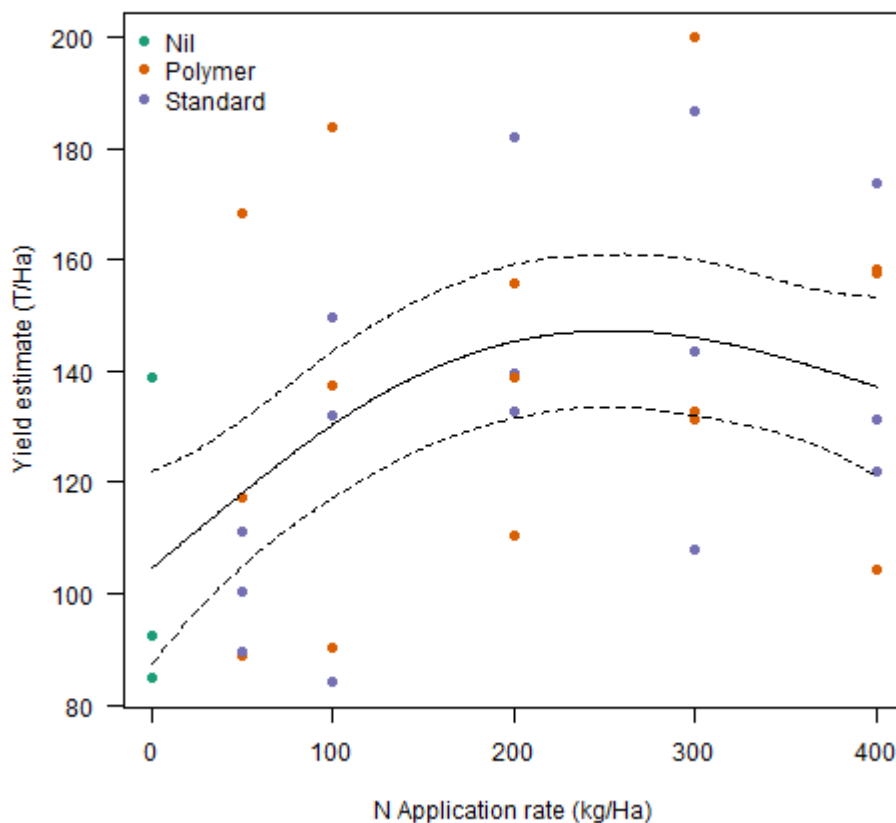


Figure 29: Woodford Island 2-year yield (July 2020)

Site 4 Yield:

As per Site 3, unseasonably low rainfall slowed sugarcane growth considerably at Site 4. Coraki received 767.3mm of rain to end of October 2019 compared to an average of 1484.8mm for the same period (BOM Coraki field station records).

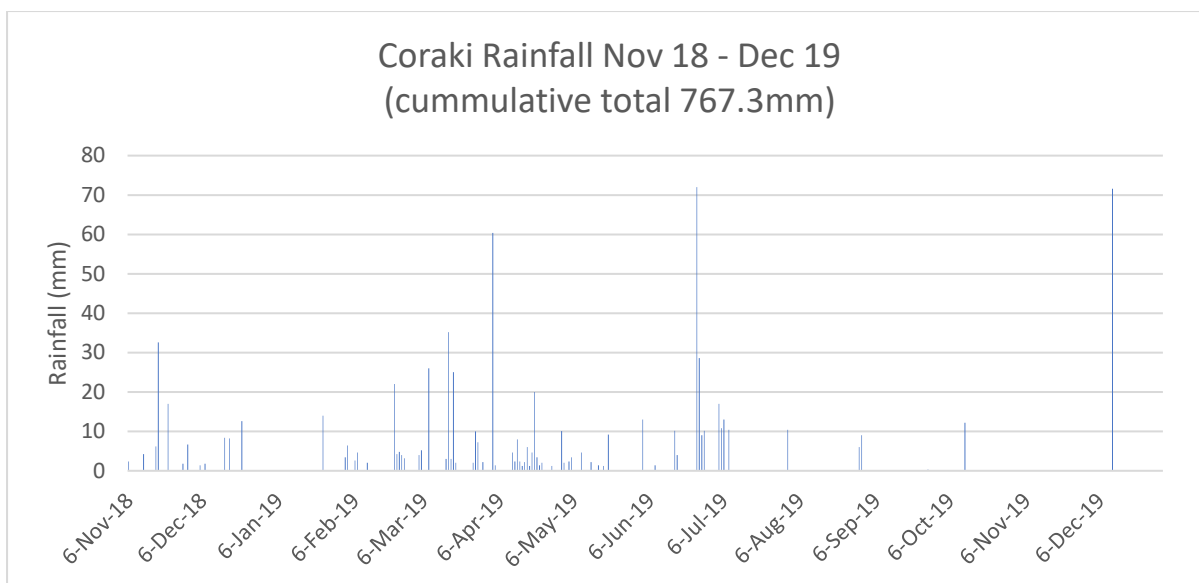


Figure 30: Rainfall over the growing season at Coraki was well below average

Yield estimates for the Coraki site were undertaken on 31st October 2019. The mean yield at 9 months for each treatment at Coraki is presented in Table 16 along with 2-year yield estimates for 2020 based on the yield estimate equation.

Table 15: Coraki 2-year yield estimate

Treatment	Yield T/Ha	std error	2-year yield estimate (T/Ha)
Nil_0	42.9	3.24	60.9
Polymer_50	44.7	4.41	63.6
Polymer_100	41.1	5.26	58.2
Polymer_200	47.7	9.08	68.1
Polymer_300	63.7	6.25	92.0
Polymer_400	52.3	5.23	74.9
Standard_50	43.4	4.19	61.7
Standard_100	46.1	2.12	65.7
Standard_200	55.4	3.18	79.6
Standard_300	47.6	5.94	68.0
Standard_400	48.0	5.89	68.5

As per Woodford Island, these figures are well below the previous season average yield from this block which was 75 T/acre (185.3 T/Ha). At the Coraki site yields for PCU and standard urea were similar for the 50-200 units N/Ha treatment range. The highest recorded yield however was in the PCU 300 units N/Ha treatment (92.0 T/Ha).

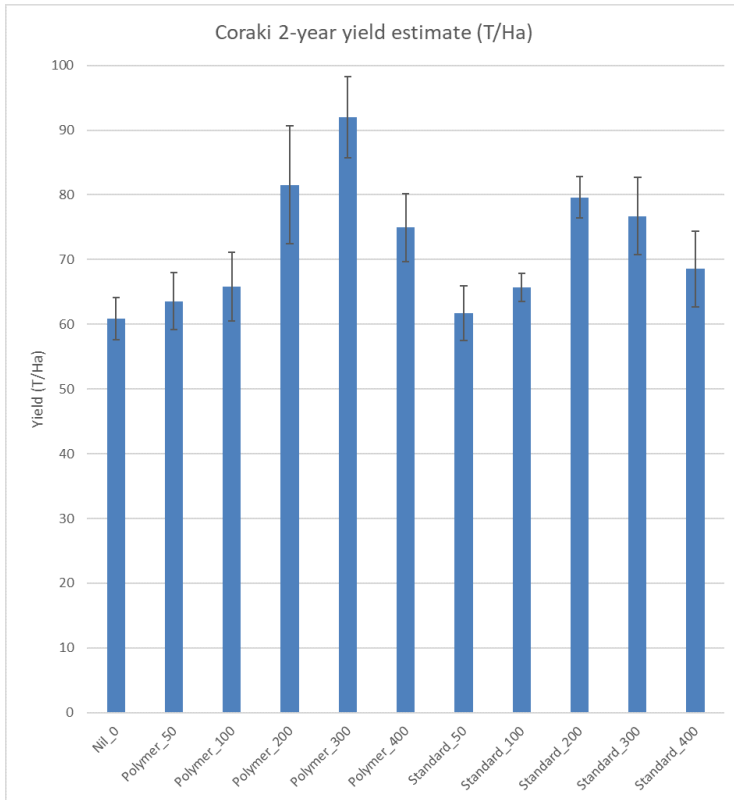


Figure 31: Coraki 2-year yield estimates

There were systematic lower yields over plots 8-11 in each replicate. Figure 34 shows field trend as measured by residuals (observed - predicted values) from the analysis.

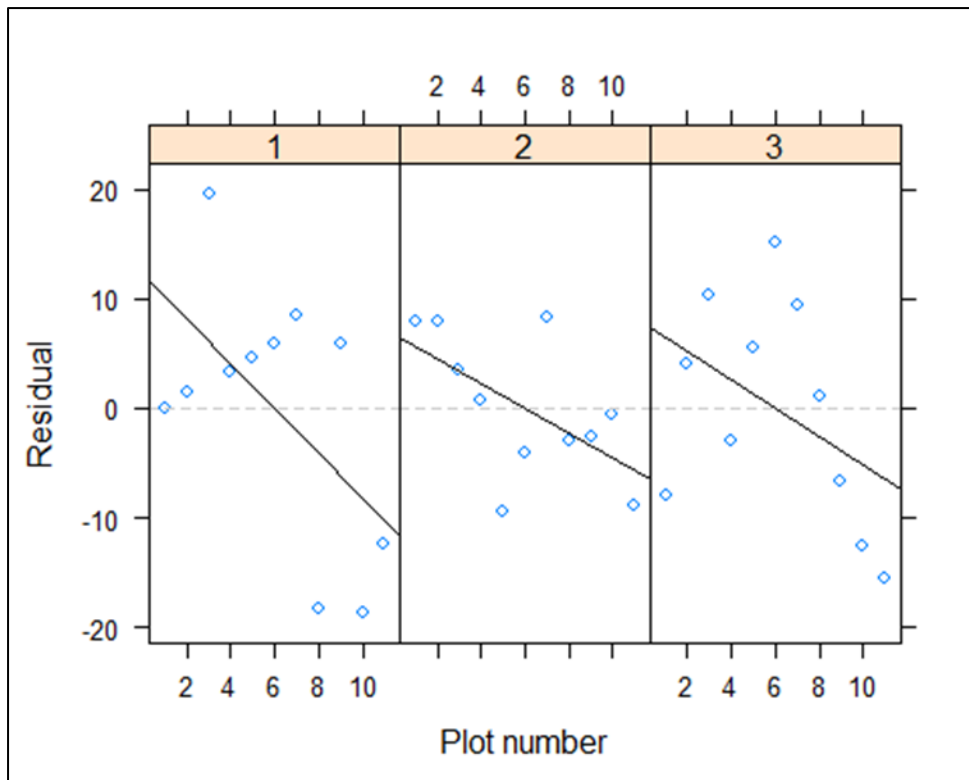


Figure 32: Field Trend at Coraki

A more complex model was fitted to accommodate the potential for a quantitative rate response plus accounting for spatial variation in the field (Figure 33). For yield, the final model indicated a positive gradient in response to application rate averaged over both sources i.e. there was not strong evidence for a response to N product but there was a response to N rate averaged over the products. Consequently, the model is presented as a single curve

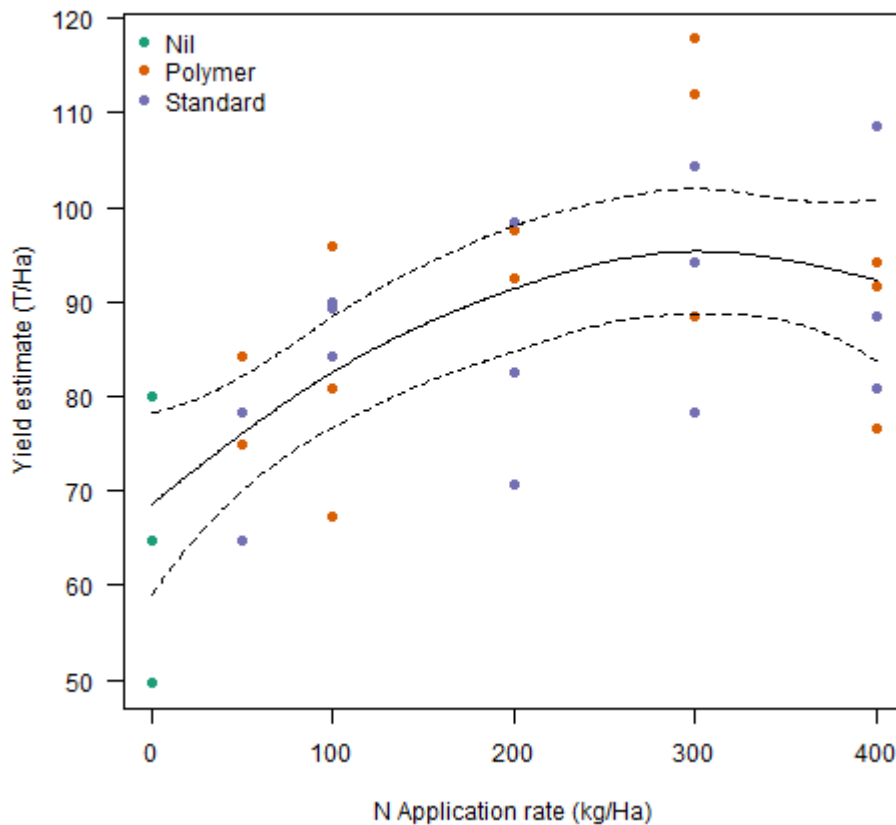


Figure 33: Predicted yield response to application rate - Coraki

A fertiliser N response was obtained up to 300 units N/Ha.

6.4 Biomass Nitrogen accumulation

6.4.1 Nitrogen Accumulation Methodology

From the cane harvested by hand at each site, ten representative stalks from each plot were subsampled for N content analysis. The leafy material was stripped from these and labelled “trash”, and the remainder of the stalks hitherto referred to as “stalk”. Following dry matter determination, the subsamples were finely ground and analysed for total N content in the stalk and trash. From these data, an estimate of plant N accumulation (T/Ha) was calculated for each treatment.

6.4.2 Nitrogen accumulation results:

Biomass N Site 1:

Table 16: Mean plant N accumulation – Stotts Creek

Treatment	Total Nitrogen (T/Ha)					
	Stalk	std err	Trash	std err	Whole Plant	std err
Nil_0	0.040	0.007	0.025	0.003	0.065	0.009
Polymer_50	0.058	0.008	0.023	0.003	0.081	0.010
Polymer_100	0.055	0.013	0.021	0.006	0.077	0.019
Polymer_200	0.062	0.010	0.029	0.003	0.091	0.013
Polymer_300	0.086	0.009	0.035	0.001	0.121	0.010
Polymer_400	0.074	0.011	0.030	0.006	0.104	0.017
Standard_50	0.046	0.003	0.022	0.004	0.068	0.006
Standard_100	0.059	0.007	0.024	0.004	0.083	0.011
Standard_200	0.069	0.004	0.029	0.003	0.098	0.004
Standard_300	0.070	0.014	0.030	0.003	0.100	0.016
Standard_400	0.073	0.012	0.021	0.007	0.093	0.007

Mean N accumulation in the cane crop at Stotts Creek ranged from 0.065 T/Ha (65 kg/Ha) in the control (nil) treatments to a maximum of 0.121 T/Ha (121 kg/Ha) observed with a fertiliser dose of PCU at 300 units N/Ha. The highest observed N uptake in the standard urea application was also at 300 units N/Ha. Biomass N accumulation in the 400 units N/Ha treatments for both products was 104 kg N/Ha for PCU and 93 kg N/Ha for standard urea.

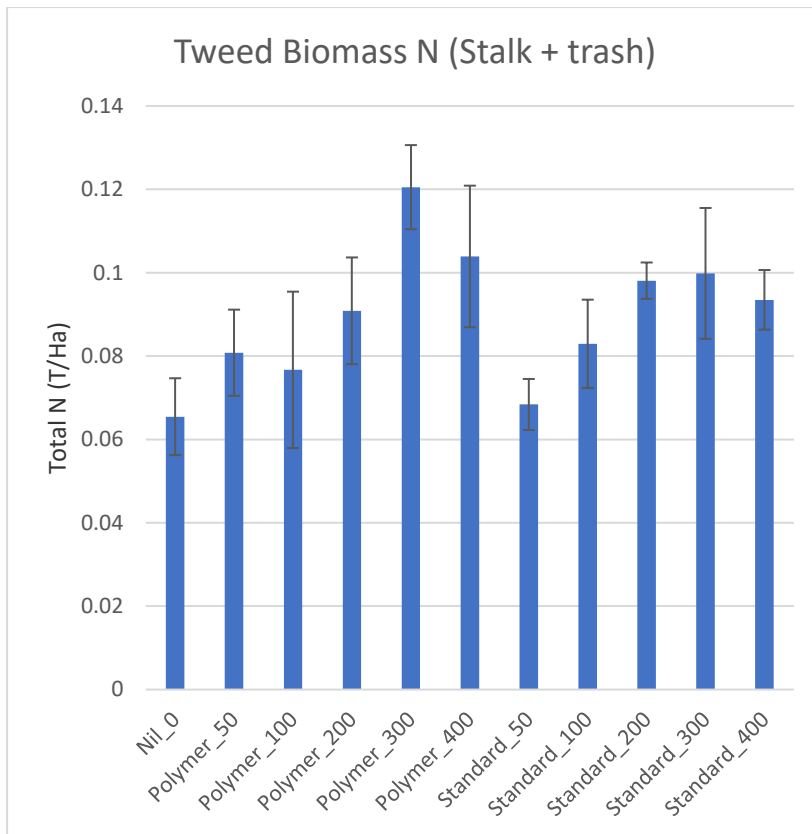


Figure 34: Plant biomass nitrogen (stalk + trash)

Biometric analysis accounting for spatial variability in-field indicated that there was a significant increase in crop N uptake (leaf + stalk) with increased application rate but no significant difference between PCU and standard urea products. Consequently, statistical modelling of biomass N accumulation based on rate of N supplied from either product resulted in a single curve for this site.

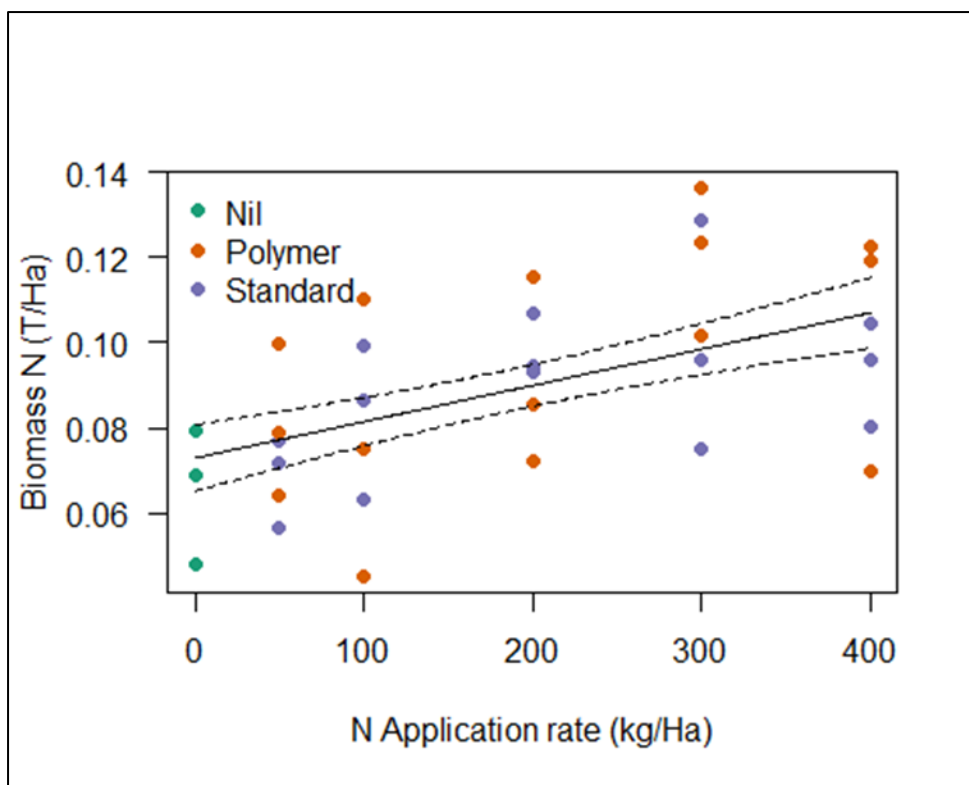


Figure 31: Biomass N accumulation (T/Ha) accounting for spatial variability – Stotts Creek site

Table 18 summarizes the estimated Biomass N accumulation (T/Ha) and standard error at the design points based on the modelling in Figure 35:

Table 18: Biomass N (T/Ha) vs application rate – Stotts Creek

rate	Biomass N	se
0	0.073	0.004
50	0.077	0.003
100	0.081	0.003
200	0.090	0.002
300	0.098	0.003
400	0.107	0.004

The model indicates Biomass N accumulation increased steadily with N application rate regardless of fertilizer type from 73 kg N/Ha in the control treatments to 107 kg N/Ha at the 400-unit rate.

Biomass N Site 2:

Table 19: Mean plant N accumulation - Pimlico

Treatment	Total Nitrogen (T/Ha)					
	Stalk	std err	Trash	std err	Whole Plant	std err
Nil_0	0.051	0.024	0.040	0.003	0.091	0.027
Polymer_50	0.056	0.013	0.036	0.005	0.092	0.018
Polymer_100	0.047	0.004	0.044	0.003	0.091	0.001
Polymer_200	0.071	0.004	0.047	0.001	0.118	0.003
Polymer_300	0.072	0.009	0.044	0.012	0.117	0.019
Polymer_400	0.117	0.012	0.054	0.004	0.171	0.016
Standard_50	0.042	0.004	0.040	0.005	0.082	0.002
Standard_100	0.041	0.006	0.038	0.001	0.079	0.005
Standard_200	0.090	0.004	0.048	0.003	0.138	0.004
Standard_300	0.102	0.017	0.054	0.002	0.156	0.016
Standard_400	0.062	0.019	0.040	0.006	0.103	0.023

At the Pimlico site, mean biomass N accumulation in the nil treatment was 0.091 T N/Ha. There was little difference in the observed N accumulation in the polymer 200- and 300-units N/Ha treatments (0.118 T/Ha and 0.117 T/Ha) but accumulation was highest at 400 units N/Ha PCU (171 kg N/ha). In the standard urea treatments, the highest N accumulation was 0.156 T N/Ha, observed at the fertiliser dose of 300 units N/Ha, with a decline at the 400 units N/Ha rate to 0.103 T N/Ha.

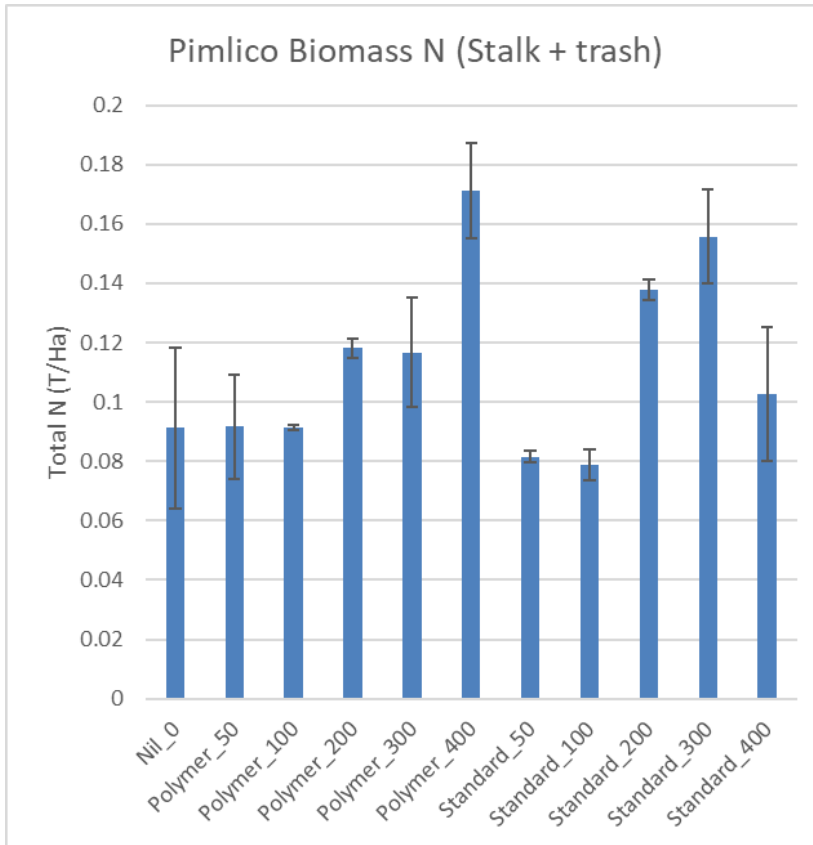


Figure 36: Plant biomass N (stalk + trash) - Pimlico

The quantitative rate plus spatial variability model indicated a statistically important gradient for biomass N to increase with application rate modified by the cubic spline for each product as shown in the following figure. Statistical modelling places Biomass N uptake from each fertilizer source on separate curves.

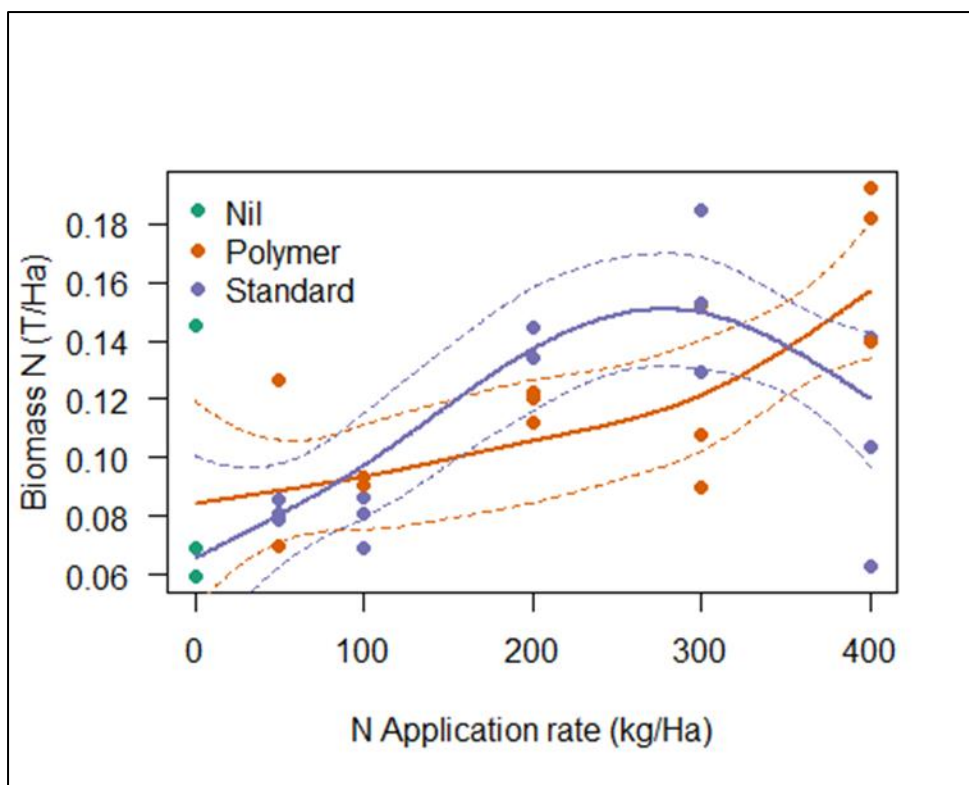


Figure 32: Biomass N accumulation accounting for spatial variability - Pimlico

Table 20 summarizes the estimated Biomass N accumulation (T/Ha) and standard error at the design points based on the modelling in Figure 37. The zero rate values presented in Table 20 are intercepts derived from the statistical model.

Table 20: Biomass N (T/Ha) vs treatment - Pimlico

source	rate	Biomass N	se
Polymer	0	0.084	0.018
Polymer	50	0.089	0.009
Polymer	100	0.093	0.009
Polymer	200	0.106	0.011
Polymer	300	0.121	0.010
Polymer	400	0.157	0.012
Standard	0	0.065	0.018
Standard	50	0.080	0.009
Standard	100	0.097	0.009
Standard	200	0.137	0.011
Standard	300	0.150	0.010
Standard	400	0.120	0.012

Statistical modelling of the data from this site shows that biomass N accumulation was increased steadily with increasing PCU fertilizer application from 0.089 T N/Ha at 50 units of N to 0.157 T N/Ha at 400 units of N as PCU. With Standard Urea application, the model

indicates a maximum Biomass N accumulation of 0.15 T N/Ha occurred at the 300-unit N rate. At 50 units of N, the Biomass N accumulation was 0.08 T N/Ha.

Biomass N Site 3:

Table 17: Mean plant N Accumulation - Woodford Island

Treatment	Total Nitrogen (T/Ha)					
	Stalk	std err	Trash	std err	Whole Plant	std err
Nil_0	0.023	0.005	0.032	0.009	0.055	0.015
Polymer_50	0.035	0.006	0.051	0.010	0.086	0.016
Polymer_100	0.038	0.007	0.054	0.002	0.092	0.005
Polymer_200	0.047	0.011	0.049	0.018	0.096	0.029
Polymer_300	0.057	0.003	0.065	0.005	0.122	0.005
Polymer_400	0.053	0.015	0.065	0.014	0.117	0.029
Standard_50	0.023	0.001	0.030	0.007	0.053	0.006
Standard_100	0.041	0.013	0.065	0.013	0.106	0.000
Standard_200	0.049	0.010	0.053	0.006	0.103	0.015
Standard_300	0.055	0.010	0.060	0.010	0.115	0.020
Standard_400	0.069	0.009	0.067	0.012	0.136	0.021

N accumulation in both the stalk and trash was considerably lower in the nil and standard 50 units/Ha treatments (Nil: 0.023 T/Ha and 0.032 T/H; Standard 50: 0.023 T/Ha and 0.030 T/Ha stalk and trash respectively). N accumulation increased with increasing N amendment in both standard and PCU but observed variability was high.

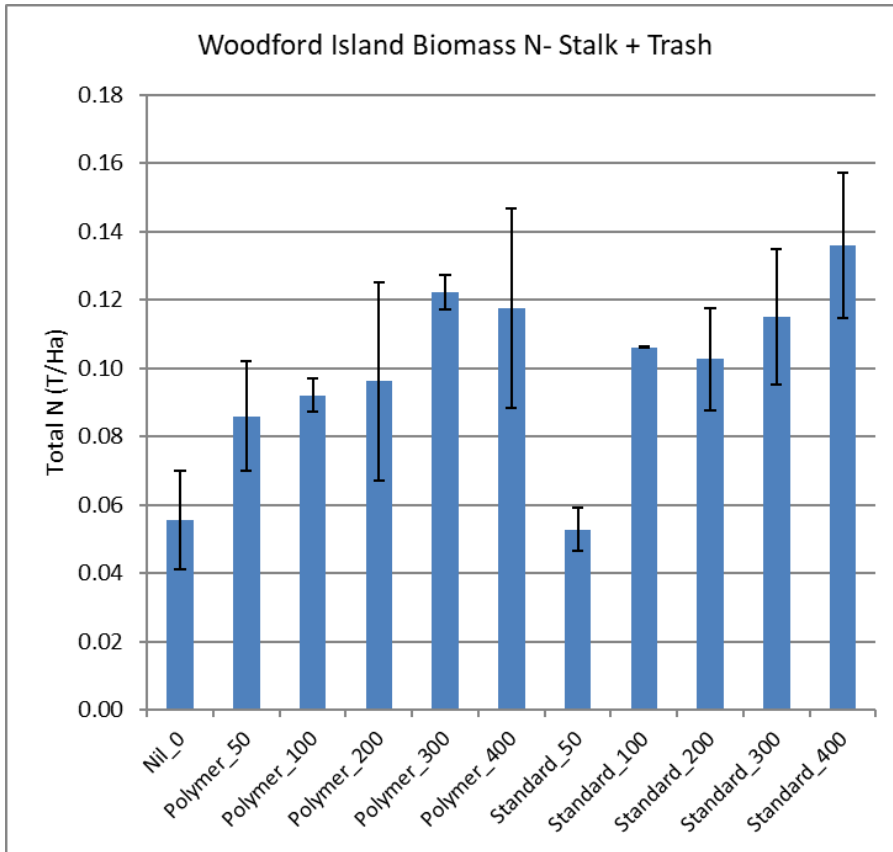


Figure 38: Plant biomass N (stalk + trash) - Woodford Island

Biometric analysis accounting for spatial variability in-field indicated that there was a significant increase in crop N uptake (leaf + stalk) with increased application rate but no significant difference between PCU and standard urea products. Consequently, statistical modelling of biomass N accumulation based on rate of N supplied from either product resulted in a single curve for this site.

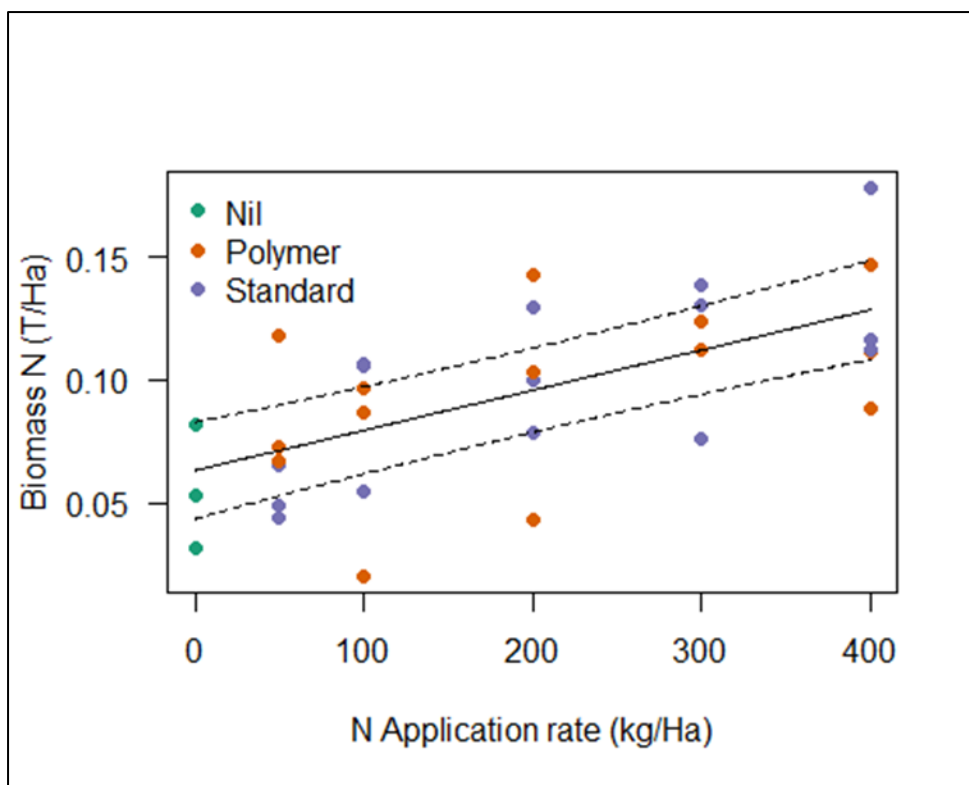


Figure 39: Biomass N accumulation accounting for spatial variability – Woodford Island

Table 22 summarizes the estimated yield and standard error at the design points based on the modelling in Figure 39.

Table 22: Biomass N (T/Ha) vs N application rate – Woodford Island

rate	Biomass N	se
0	0.063	0.010
50	0.071	0.009
100	0.080	0.009
200	0.096	0.009
300	0.112	0.009
400	0.128	0.010

The model indicates Biomass N accumulation increased steadily with N application rate regardless of fertilizer type from 63kg/Ha in the control treatments to 128 kg/Ha at the 400-unit rate.

Biomass N Site 4:

Table 23: Mean plant N accumulation - Coraki

Treatment	Total Nitrogen (T/Ha)				Whole Plant	std err
	Stalk	std err	Trash	std err		
Nil_0	0.030	0.005	0.026	0.002	0.056	0.008
Polymer_50	0.043	0.008	0.032	0.003	0.075	0.011
Polymer_100	0.038	0.004	0.029	0.004	0.067	0.008
Polymer_200	0.050	0.007	0.036	0.003	0.086	0.009
Polymer_300	0.071	0.009	0.040	0.005	0.111	0.014
Polymer_400	0.077	0.005	0.040	0.005	0.116	0.008
Standard_50	0.033	0.004	0.026	0.005	0.059	0.008
Standard_100	0.042	0.003	0.032	0.001	0.074	0.005
Standard_200	0.050	0.005	0.034	0.001	0.084	0.005
Standard_300	0.059	0.008	0.040	0.007	0.099	0.015
Standard_400	0.059	0.004	0.037	0.003	0.096	0.006

Biomass N accumulation in both the stalk and trash was considerably lower in the nil and standard 50 units/Ha treatments (Nil: 0.030 T/Ha and 0.026 T/Ha; Standard 50: 0.033 T/Ha and 0.026 T/Ha stalk and trash respectively). N accumulation increased with increasing N amendment in both standard and PCU but observed variability was high.

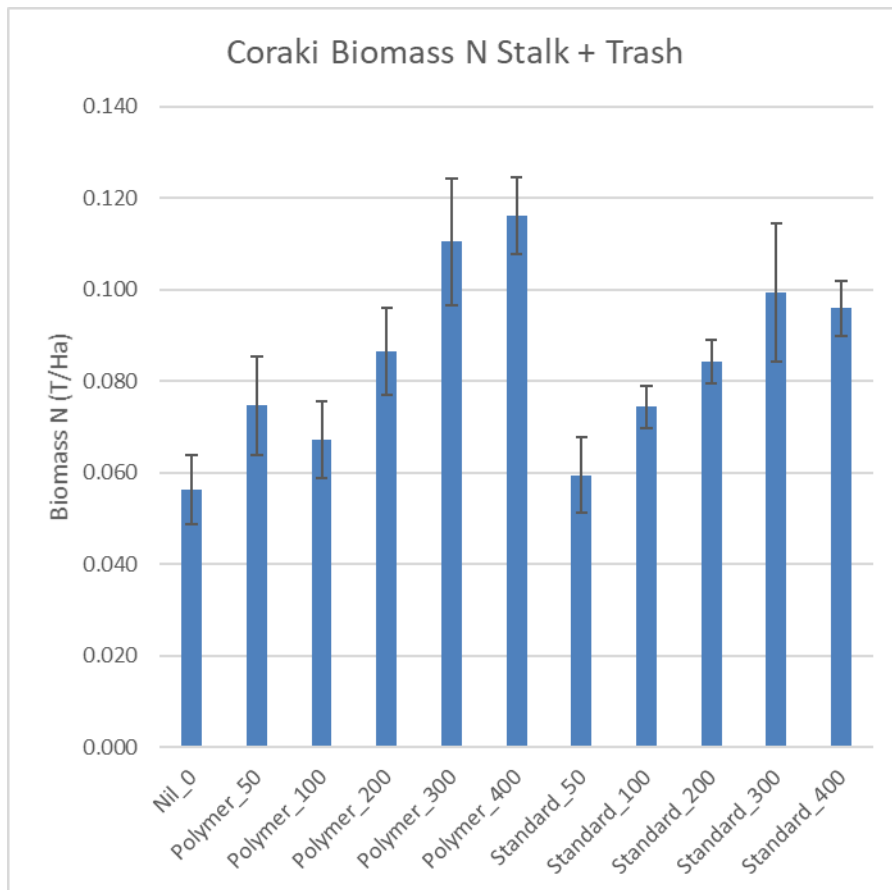


Figure 40: Biomass Nitrogen accumulation (Stalk + trash)

The quantitative rate plus spatial model indicated a statistically important gradient for biomass N to increase with application rate and this was increased under the PCU compared to the standard urea as shown in Figure 41. Statistical modelling places Biomass N uptake from each fertilizer source on separate curves.

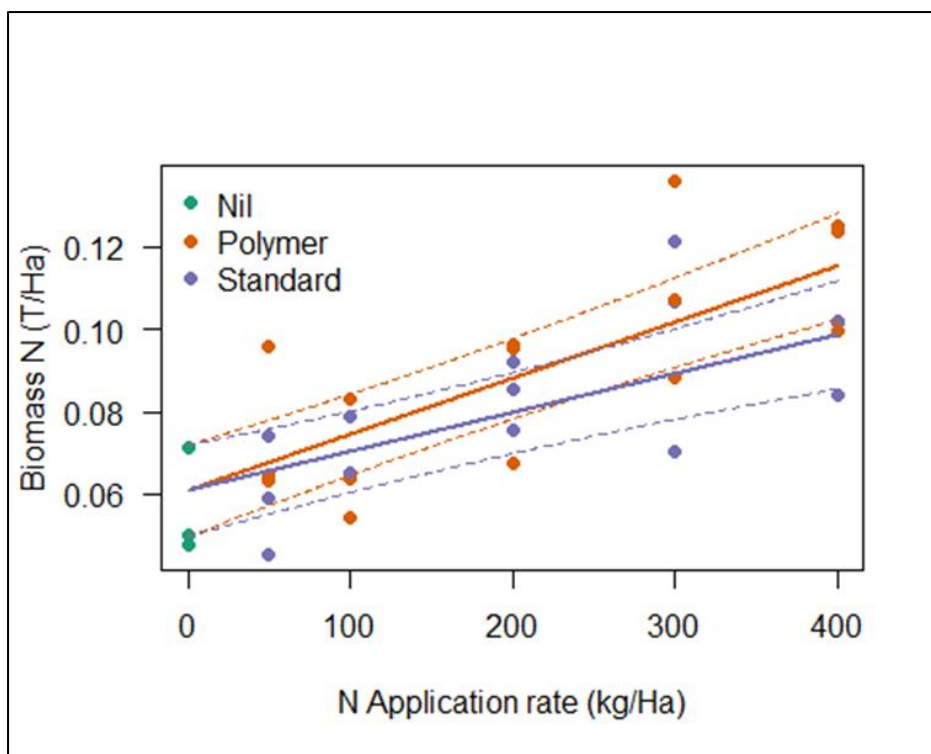


Figure 33: Biomass N accumulation accounting for spatial variability – Coraki

There was a small separation between total N uptake from standard urea, and N accumulated from PCU plots at 300- and 400-units N/ Ha. This did not however influence the yield of the sugarcane.

Table 24 summarizes the estimated yield and standard error at the design points based on the modelling in Figure 41.

Table 24: Biomass N (T/Ha) vs treatment – Coraki

source	rate	Biomass N	se
Polymer	0	0.061	0.006
Polymer	50	0.068	0.005
Polymer	100	0.074	0.005
Polymer	200	0.088	0.005
Polymer	300	0.102	0.005
Polymer	400	0.115	0.006
Standard	0	0.061	0.006
Standard	50	0.066	0.005
Standard	100	0.070	0.005
Standard	200	0.080	0.005
Standard	300	0.089	0.006
Standard	400	0.099	0.007

Statistical modelling of the data from this site Biomass N accumulation was highest with PCU fertilizer application. Biomass N increased steadily with increasing PCU fertilizer application from 68 kg N/Ha at 50 units of N to 115 kg N/Ha at 400 units. With Standard

Urea application, the model indicates Biomass N also increased steadily with application rate from 66 kg N/Ha at 50 units to 99 kg N/Ha at 400-unit rate.

6.5 Nitrogen Use Efficiency:

It has been suggested in a recent review of nitrogen use efficiency in sugarcane (Bell 2014) that there is considerable opportunity to reduce fertilizer N inputs through improved crop recovery of applied N and improved efficiency of use of that accumulated N to increase biomass production. This report adopts some of the terminology described in that review and attempts to quantify NUE by taking into account background soil N supply and crop recovery of applied N.

6.5.1 Agronomic Efficiency of Fertilizer

Agronomic Efficiency of Fertilizer ($\text{AgronEff}_{\text{Fert}}$) as described in Bell was calculated for each field site according to the formula:

$$\text{AgronEff}_{\text{Fert}} (\%) = ((YF - YC)/FN) * 100$$

Where YF = Yield of fertilized plot (T/Ha)

YC = Yield of control plot (T/Ha)

FN = Fertilizer N applied (kg/ha)

As there was no statistically significant difference in yield response to fertilizer type (Standard Urea vs PCU) at all sites, $\text{AgronEff}_{\text{Fert}}$ in the table below is presented for rate only, based on the modelling in section 6.4.

Table 18: Agronomic Efficiency of Fertilizer (%) at each trial site

Fertilizer rate (kg/Ha)	Stott's Creek		Pimlico		Woodford Island		Coraki	
	Yield (T/Ha)	$\text{AgronEff}_{\text{Fert}}$	Yield (T/Ha)	$\text{AgronEff}_{\text{Fert}}$	Yield (T/Ha)	$\text{AgronEff}_{\text{Fert}}$	Yield (T/Ha)	$\text{AgronEff}_{\text{Fert}}$
50	88.3	17.7	113.5	37.3	66.1	5.3	48.4	2.2
100	95.6	16.1	125.3	30.4	68.8	5.3	49.5	2.2
200	103	11.7	137.4	21.2	74.1	5.3	51.7	2.2
300	100.4	7.0	149.3	18.1	79.4	5.3	53.8	2.2
400	96.7	4.3	153.5	14.6	84.8	5.3	56.0	2.2

Agronomic Efficiency of Fertilizer ranged from 17.7% to 4.3% at the Stott's Creek site and from 37.3% to 14.6% at Pimlico, decreasing with increased fertilizer application. At the Woodford Island and Coraki sites (note, using 9 month data only), the $\text{AgronEff}_{\text{Fert}}$ for each fertilizer application rate was the same (5.3% and 2.2% respectively). It is suspected that these figures reflect the severe rainfall deficit experienced at both of these sites during the period of maximum growth rate and crop N demand, and subsequently reduced yields.

6.5.2 Fertilizer N Uptake Efficiency:

Fertilizer N Uptake Efficiency (NUpE_{Fert}) as described by Bell was calculated according to the following formula:

$$\text{NUpE}_{\text{Fert}} \text{ (kg/ha)} = (\text{NUF} - \text{NUC})/\text{FN}$$

Where NUF = Total N uptake in fertilized plot (kg/Ha)

NUC = Total N uptake in control plot (kg/Ha)

FN = Fertilizer N applied (kg/Ha).

Fertilizer N Uptake Efficiency calculated for each site based on the biometrical modelling in section 6.5 is presented in the following tables. Where modelling indicated no significant difference in Biomass N accumulation between standard and PCU urea, only the rate of N application (kg/Ha) is presented.

Table 19: Fertilizer N Uptake Efficiency - Stotts Creek Field Site

Stotts Creek		
Application Rate (kg/Ha)	Biomass N (kg/Ha)	NUpE _{Fert} (%)
50	77	8.5
100	81	8.5
200	90	8.5
300	98	8.5
400	107	8.5

At the Stott's Creek site, where Biomass N accumulation increased steadily with N application rate regardless of fertilizer type, NUpE_{Fert} was a constant at 8.5 %.

Table 20: Fertilizer N Uptake Efficiency - Pimlico Field Site

Pimlico			
Fertilizer	Rate (kg/Ha)	Biomass N (kg/Ha)	NUpE _{Fert} (%)
Standard urea	50	89	48
Standard urea	100	93	28
Standard urea	200	106	21
Standard urea	300	121	19
Standard urea	400	157	23
PCU	50	80	30
PCU	100	97	32
PCU	200	137	36
PCU	300	150	28
PCU	400	120	14

At the Pimlico site, where statistical modelling indicated a significant difference in Biomass N accumulation dependant on the form of fertilizer applied, $NUpE_{Fert}$ varied between treatments and was observed to vary with differing N application rate. With standard urea application, $NUpE_{Fert}$ was 48 % at the 50 kg N/Ha rate and was lowest at the 300 kg N/Ha rate (19 %). Conversely, with PCU application $NUpE_{Fert}$ was highest at the 200 kg N/Ha rate. The lowest $NUpE_{Fert}$ (14 %) across all treatments was observed in PCU at the 400 kg N/Ha application rate. These responses were markedly different to that observed at the other 3 sites and will require further investigation.

Table 28: Fertilizer N Uptake Efficiency - Woodford Island Field Site

Woodford Island		
Application Rate (kg/Ha)	Biomass N (kg/Ha)	$NUpE_{Fert}$ (%)
50	71	16.3
100	80	16.3
200	96	16.3
300	112	16.3
400	128	16.3

At the Woodford Island site, where Biomass N accumulation increased steadily with N application rate regardless of fertilizer type, $NUpE_{Fert}$ was a constant at 16.3%.

Table 29: Fertilizer N Uptake Efficiency - Coraki Field Site

Fertilizer	Coraki		
	Rate (kg/Ha)	Biomass N (kg/Ha)	$NUpE_{Fert}$ (%)
Standard urea	50	68	13.6
Standard urea	100	74	13.6
Standard urea	200	88	13.6
Standard urea	300	102	13.6
Standard urea	400	115	13.6
PCU	50	66	9.5
PCU	100	70	9.5
PCU	200	80	9.5
PCU	300	89	9.5
PCU	400	99	9.5

At the Coraki site where Biomass N accumulation increased steadily with N application rate for both standard and PCU but on statistically different curves, $NUpE_{Fert}$ was 13.6% and 9.5% respectively.

6.6 Monitoring Leaf N through field sampling and UAV multispectral analysis:

6.6.1 UAV Multi Spectral Image Acquisition and Processing Methodology:

Surveys using an Unmanned Aerial Vehicle (UAV) were conducted over each 2018/19 trial site on a fortnightly basis where possible, with corresponding monthly leaf sampling (according to SRA IS13014). The aim of the regular aerial surveys was to better monitor plant growth throughout the cropping cycle, and to attempt to quantify and correlate the imagery acquired with crop nitrogen uptake.

Imagery was acquired using a Micasense RedEdge 5-band multispectral camera mounted to a DJI M600™ hexacopter. The RedEdge camera simultaneously captures separate images in 5 discrete wavebands corresponding to Blue, Green, Red, Red Edge and Near Infrared (NIR) via a global shutter.

The multispectral imagery was corrected in real time for sun intensity and cloud cover variation via an on-board sensor and corrected radiometrically for sun angle and irradiance using pre-flight images of a calibrated reflectance panel. Survey flightpaths were pre-prepared using the DJI GSPRO™ app for iPad, and each subsequent fly-over followed the exact same route for the entire cropping cycle. The surveys were conducted from an altitude of 100m AGL with the multispectral camera aimed directly downward (NADIR) and this provided a ground sampling distance (GSD) of 2cm. Image overlap was set to 85%.

Several thousand discrete images acquired from each survey mission were “stitched” together using Pix4D-Mapper™ software and exported as a single georeferenced orthomosaic image file. The orthomosaic was then processed using the QGIS desktop geographic information system platform. A scaled plot map was overlaid upon the orthomosaic image derived from each survey, and reflectance values derived from several spectral algorithms extracted.

As the more traditionally used NDVI spectral index is susceptible to saturation at higher leaf area index (ie a thicker canopy – as occurs in large biomass crops such as sugarcane), the project team investigated an alternative spectral index that has shown a very strong correlation with laboratory analysis of leaf N content This was the Green Normalized Difference Vegetation Index (GNDVI), as determined by the algorithm:

$$\text{GNDVI} = (\text{NIR} - \text{Gr}) / (\text{NIR} + \text{Gr})$$

Where: NIR = reflectance in the near infrared waveband

Gr = reflectance in the green waveband

The GNDVI spectral index is related to the proportion of photosynthetically absorbed radiation in the crop canopy and is linearly correlated with Leaf Area Index (LAI) and biomass (Hunt et al. 2008). GNDVI is more sensitive to chlorophyll concentration than NDVI and is commonly used to determine water and nitrogen uptake into the crop canopy. GNDVI reflectance values range from 0 to 1.0.

A false colour gradient was applied to imagery reprocessed via spectral algorithm in order to highlight visually the variation in crop response across the trial area.



Figure 34: RGB orthomosaic image of Woodford Island trial site 100m altitude – T=160 days

From 100m altitude, areas of the trial block with lower N content are detectable using the standard visible (RGB) colour spectrum (Figure 42). This is highlighted in the GNDVI false colour image (Figure 43) with plot map overlaid. Plots with nil or lower N rates appear lighter in colour.

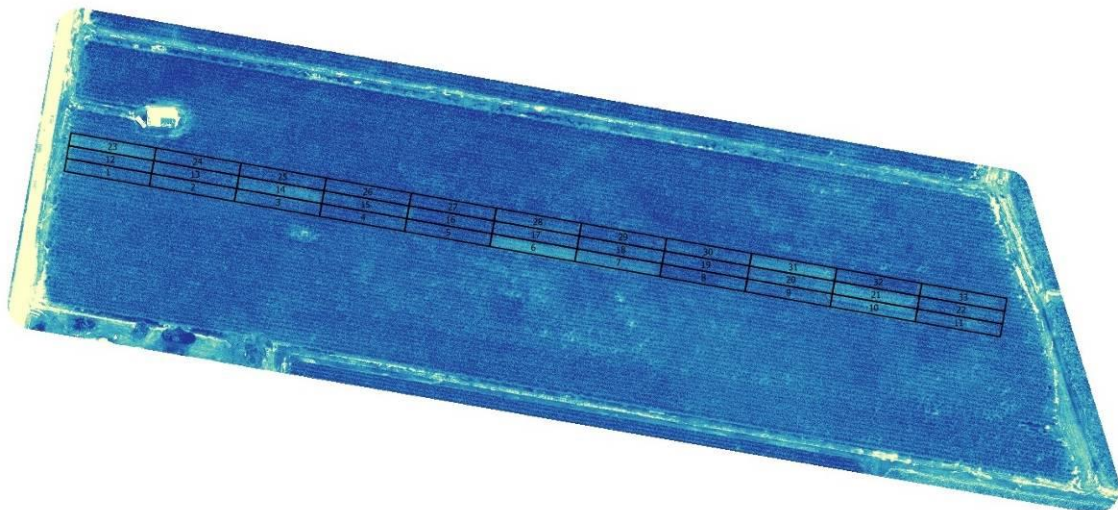


Figure 35: Reprocessed GNDVI false-colour image of Woodford Island field trial site at T=160 days highlighting treatment differences within the trial area.

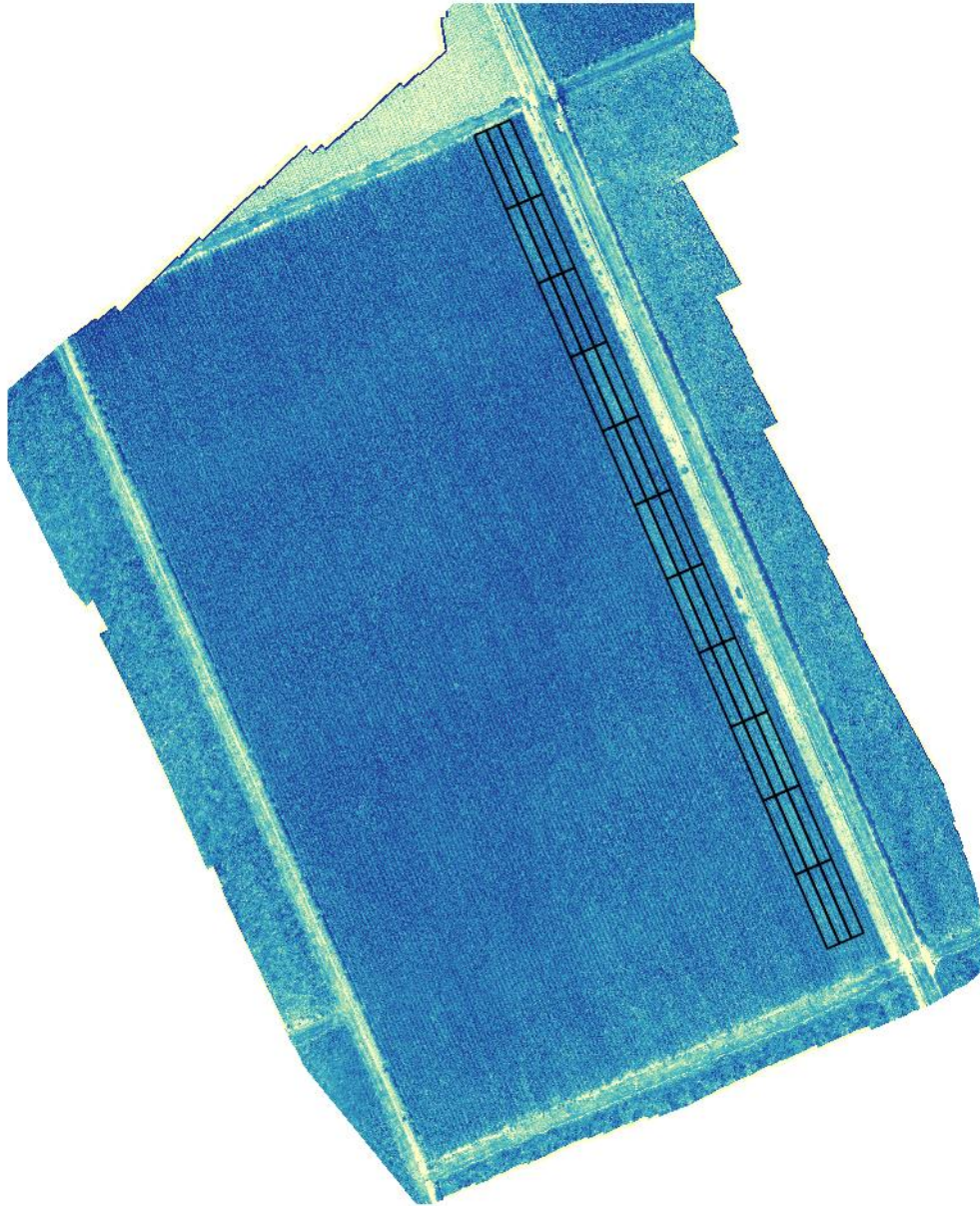


Figure 36: GNDVI false-colour image of Coraki field trial site at T=156 days

For the purpose of quantifying differences in reflectance from the crop canopy with minimal background interference (caused by regions of bare ground or the presence of shadow), identical smaller regions or “subplots” within each trial plot were defined using QGIS desktop software. These subplots were one metre wide and stretched the length of the trial plot within which they were created, centred over the middle row of cane. Reflectance values used in subsequent biometric analyses were extracted from the subplots only.

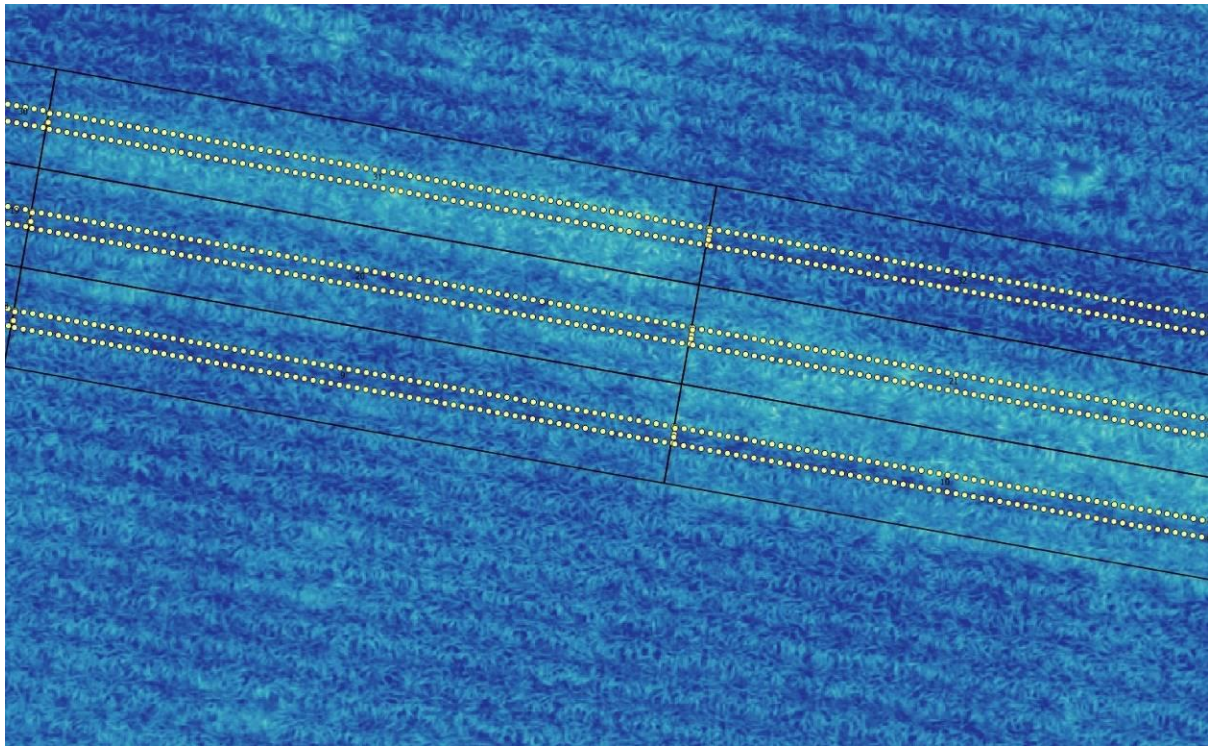


Figure 37: Close-up of GNDVI false colour image showing subplots selected for correlation analysis

6.6.2 Leaf sampling methodology

Leaf analysis provides a basis for growers to check on the adequacy of fertiliser recommendations by checking the nutrient status of the crop when it is between 3 and 7 months of age. This information is then used to identify if any remedial actions are required to correct any problems found within the season, or to provide guidance for adjusting fertiliser rates the following season. In the present study, regular sampling of leaf N was conducted to monitor the timing and uptake efficiency of fertilizer accumulation in the crop for each treatment.

Leaf sampling was conducted based on the Third Leaf methodology as described in SRA IS13014. 30 stalks of average height were selected at random from the centre row of each trial plot. The third leaf from the top of each stalk was collected, folded in half and cut to 100-200mm length from the fold. The 30 folded leaf sections were bundled and returned to the lab where they were dried and ground and submitted for total N analysis by Dumas Combustion.

6.6.3: Results - Leaf N and multispectral analyses

GNDVI and leaf N – Site 3

At the Woodford Island site, leaf samples and UAV images were acquired from each plot at intervals beginning from T=7 days after trial establishment through to T=253 days. Total N (%) for leaf samples in each treatment at Woodford Island at each sample time is summarized in Table 30.

Table 21: Total leaf N - Woodford Island

Woodford	Total Leaf N (%)							
Time (Days):	7	42	90	125	160	188	218	253
Nil_0	2.57	1.73	1.37	1.20	1.50	1.50	1.40	1.57
Polymer_50	2.63	2.07	1.57	1.40	1.86	1.90	1.70	1.90
Polymer_100	2.60	2.03	1.67	1.50	1.99	2.00	1.80	1.83
Polymer_200	2.70	2.23	1.67	1.63	2.00	2.00	1.77	2.00
Polymer_300	2.53	2.10	1.63	1.70	2.13	2.10	1.97	2.00
Polymer_400	2.63	2.17	1.87	1.80	2.20	2.13	1.97	2.03
Standard_50	2.57	2.10	1.50	1.40	1.71	1.70	1.50	1.47
Standard_100	2.67	2.30	1.63	1.60	2.01	1.90	1.80	1.83
Standard_200	2.70	2.33	1.73	1.67	2.18	2.07	1.87	1.97
Standard_300	2.70	2.30	1.83	1.73	2.11	2.07	1.90	1.97
Standard_400	2.67	2.43	1.80	1.73	2.14	2.23	2.00	1.83

Leaf N as a percentage was observed to decline steadily in all treatments from November through till April indicating that as the crop matured, nutrient concentrations decreased. Jarrell and Beverly (1981) reported that young plants usually contain higher nutrient concentrations, particularly N, P, and K, than do older plants, and this decrease in concentration with time is termed a dilution effect, caused by a faster rate of dry-matter accumulation when compared with nutrient uptake.

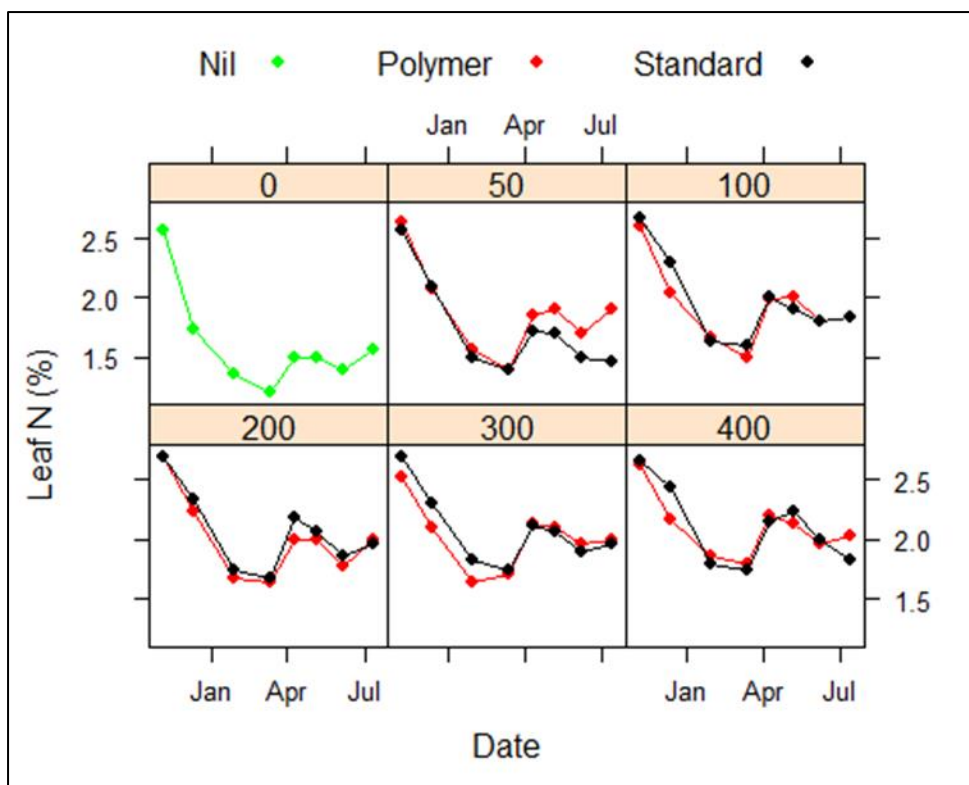


Figure 38: Leaf N% measured over time - Woodford Island

The apparent increase in leaf N% in late March/early April may have been a response to coinciding improved rainfall conditions following a deficit in the summer period (site rainfall is presented in Figure 28) leading to increased N uptake.

GNDVI reflectance values captured at Woodford Island for each survey time (days since trial establishment) are summarized in Table 31.

Table 31: Mean GNDVI reflectance values – Woodford Island

Time (Days):	GNDVI Reflectance									
	7	28	42	90	104	125	160	188	218	253
Nil_0	0.630	0.435	0.613	0.647	0.613	0.622	0.665	0.689	0.625	0.482
Polymer_50	0.613	0.422	0.643	0.672	0.643	0.667	0.713	0.728	0.653	0.520
Polymer_100	0.621	0.430	0.647	0.678	0.647	0.674	0.719	0.736	0.653	0.515
Polymer_200	0.613	0.422	0.647	0.675	0.647	0.668	0.720	0.736	0.649	0.497
Polymer_300	0.631	0.456	0.658	0.692	0.658	0.682	0.724	0.741	0.680	0.565
Polymer_400	0.613	0.416	0.658	0.693	0.658	0.684	0.729	0.743	0.649	0.504
Standard_50	0.611	0.413	0.603	0.628	0.603	0.622	0.673	0.695	0.638	0.502
Standard_100	0.624	0.451	0.649	0.690	0.649	0.677	0.717	0.732	0.646	0.501
Standard_200	0.613	0.423	0.663	0.686	0.663	0.693	0.730	0.743	0.654	0.506
Standard_300	0.630	0.463	0.661	0.695	0.661	0.684	0.725	0.740	0.672	0.545
Standard_400	0.637	0.474	0.658	0.694	0.658	0.686	0.733	0.739	0.658	0.519

GNDVI reflectance values increased steadily for all treatments up until T=188 days corresponding with the observed timing of peak N uptake in sugarcane (SRA Australian

Sugarcane Nutrition Manual 2018 edition, pp48). Reflectance values declined sharply beyond this point (Figure 49).

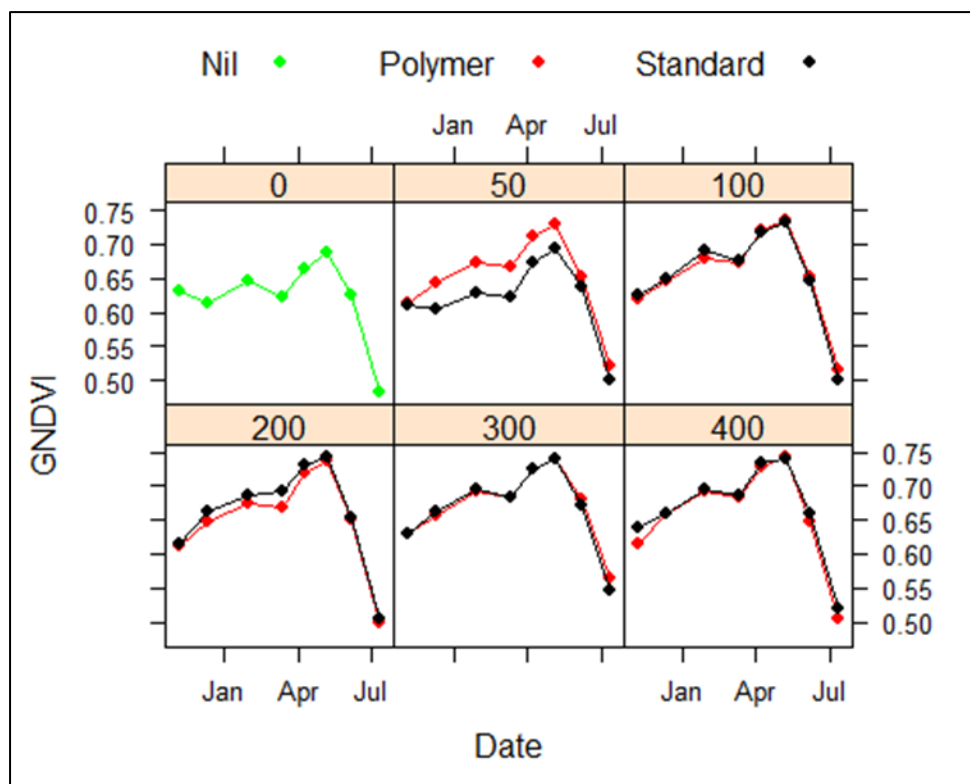


Figure 39: GNDVI reflectance measured over time - Woodford Island

GNDVI and leaf N – Site 4

At the Coraki site, UAV images were acquired from each plot at intervals beginning from T=0 days after trial establishment through to T=356 days. Leaf sampling commenced at T=14 days. Mean Total N (%) for leaf samples in each treatment at Coraki at each sample time is summarized in Table 32.

Table 22: Total Leaf N - Coraki

Coraki	Total Leaf N (%)									
	14	28	79	129	156	184	218	252	281	356
Time (Days):										
Nil_0	2.53	2.23	2.07	1.97	1.79	1.80	1.70	1.53	1.43	1.33
Polymer_50	2.57	2.37	2.00	1.87	1.95	1.87	1.83	1.67	1.53	1.30
Polymer_100	2.53	2.43	2.13	2.13	2.01	2.03	1.93	1.80	1.60	1.37
Polymer_200	2.63	2.57	2.17	2.17	2.13	2.13	2.17	2.00	1.73	1.43
Polymer_300	2.47	2.60	2.23	2.03	2.20	2.23	2.10	2.00	1.80	1.50
Polymer_400	2.70	2.60	2.20	2.20	2.18	2.20	2.27	2.10	1.87	1.63
Standard_50	2.60	2.63	2.13	2.00	1.91	1.83	1.77	1.63	1.47	1.30
Standard_100	2.67	2.57	2.20	1.93	1.95	2.03	1.87	1.73	1.63	1.33
Standard_200	2.60	2.67	2.10	2.07	2.14	2.10	2.03	1.93	1.70	1.40
Standard_300	2.73	2.67	2.37	2.03	2.21	2.13	2.13	1.97	1.80	1.47
Standard_400	2.73	2.67	2.17	2.30	2.16	2.03	2.13	1.93	1.83	1.47

Leaf N as a percentage declined consistently across all treatments throughout the sampling period at Coraki. Significantly reduced rainfall throughout the observation period may have led to an absence of periods of rapid growth in the crop, and hence the dilution effect as biomass slowly accumulated (described previously) presents as steady downward trend.

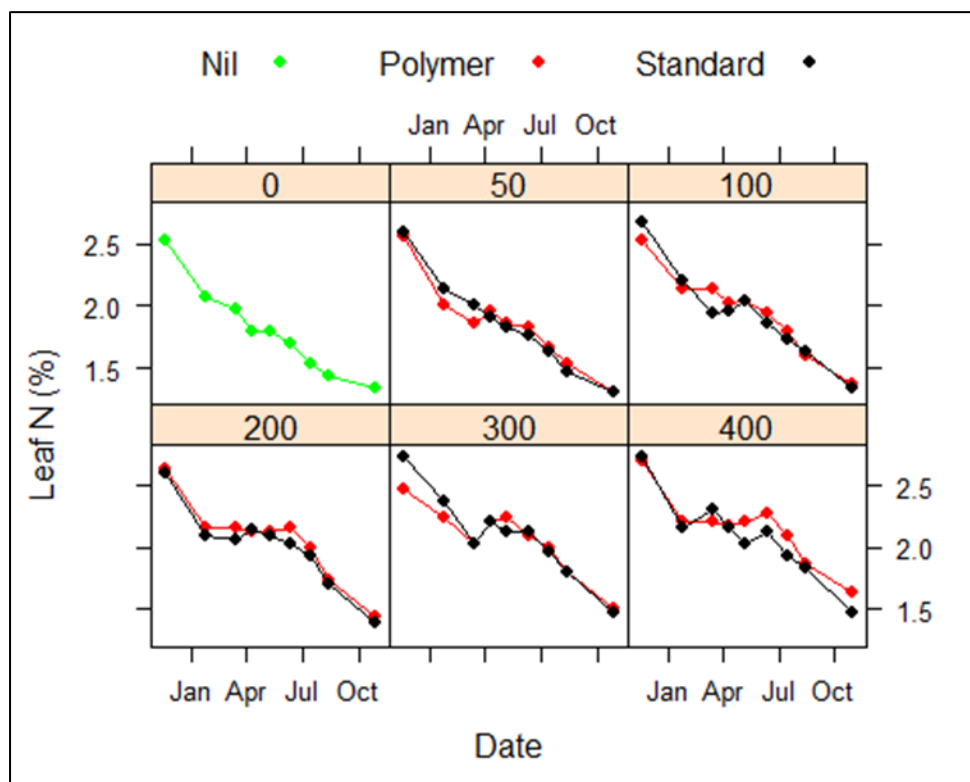


Figure 48: Leaf N% measured over time - Coraki

GNDVI reflectance values captured for each survey time (days since trial establishment) are summarized in Table 33.

Table 23: GNDVI Reflectance - Coraki

Time (Days):	GNDVI Reflectance											
	0	14	28	79	97	129	156	184	218	252	281	356
Nil_0	0.427	0.423	0.364	0.550	0.503	0.601	0.657	0.603	0.568	0.540	0.538	0.517
Polymer_50	0.423	0.421	0.359	0.570	0.513	0.606	0.676	0.627	0.592	0.560	0.555	0.528
Polymer_100	0.432	0.424	0.366	0.573	0.513	0.597	0.679	0.636	0.601	0.575	0.571	0.514
Polymer_200	0.424	0.422	0.362	0.584	0.526	0.622	0.697	0.662	0.623	0.605	0.603	0.541
Polymer_300	0.419	0.422	0.360	0.597	0.533	0.622	0.685	0.665	0.630	0.624	0.616	0.547
Polymer_400	0.425	0.421	0.369	0.585	0.534	0.621	0.693	0.663	0.620	0.605	0.610	0.549
Standard_50	0.414	0.416	0.357	0.572	0.521	0.597	0.665	0.620	0.585	0.559	0.552	0.509
Standard_100	0.424	0.423	0.359	0.586	0.535	0.605	0.682	0.637	0.601	0.565	0.563	0.544
Standard_200	0.422	0.427	0.373	0.602	0.543	0.612	0.684	0.653	0.627	0.606	0.601	0.525
Standard_300	0.427	0.429	0.370	0.581	0.534	0.627	0.689	0.656	0.613	0.600	0.602	0.534
Standard_400	0.426	0.430	0.372	0.588	0.525	0.628	0.691	0.658	0.621	0.610	0.606	0.541

GNDVI values peaked at 156 days after trial establishment. As observed at the Woodford Island site this corresponds approximately with the observed timing of peak N uptake in the crop.

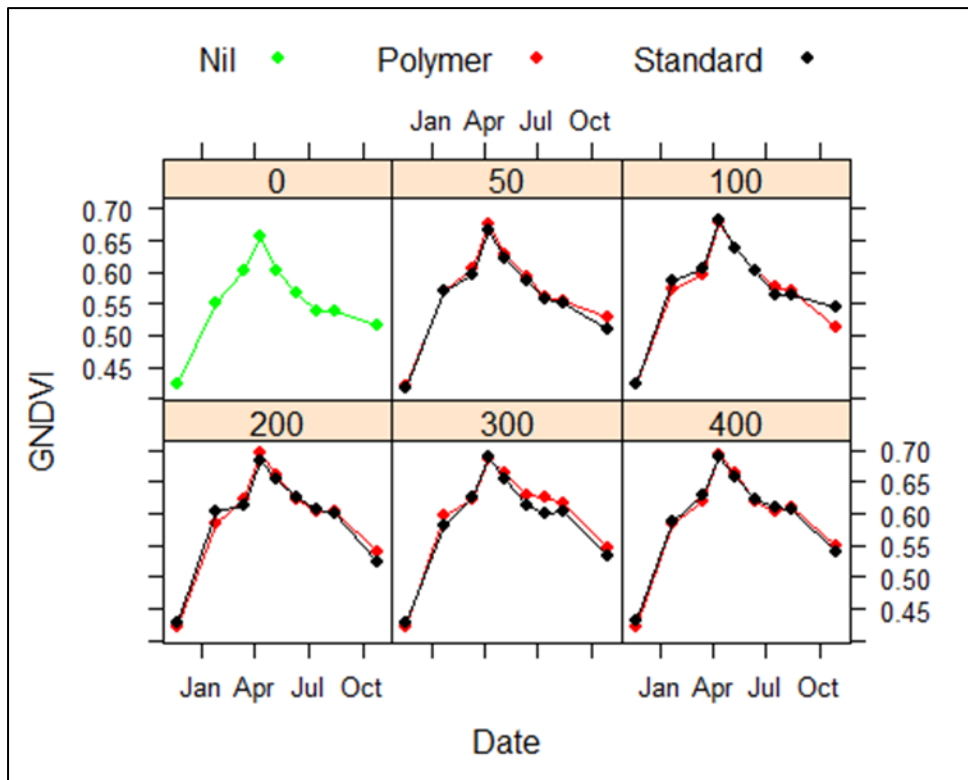


Figure 49: GNDVI measured over time - Coraki

6.6.4 Correlations between leaf N and GNDVI reflectance

The potential relationship between GNDVI reflectance and Leaf N (%) was investigated for each cropping stage captured by aerial survey at both sites 3 & 4.

Linear regression was used to estimate a straight-line relationship between mean leaf N and mean GNDVI for each source/rate within each measure date. Scatter plots of the estimates within each measure date were generated, within which line segments span 95% confidence intervals in each direction and the least squares estimated relationship is presented as a solid black line. The R^2 values are indicative for cane variety and climatic conditions in the given season and based on representative subplots as described in Section 6.7.1.

Site 3:

At Site 3 Correlations ranged from very weak ($R^2=2\%$) at T=7 days, to very strong ($R^2=92\%$) at T=160 days. The correlation scatterplot for each coinciding sampling date (Leaf N + GNDVI) along with the false colour orthomosaic image derived from that date is presented below.

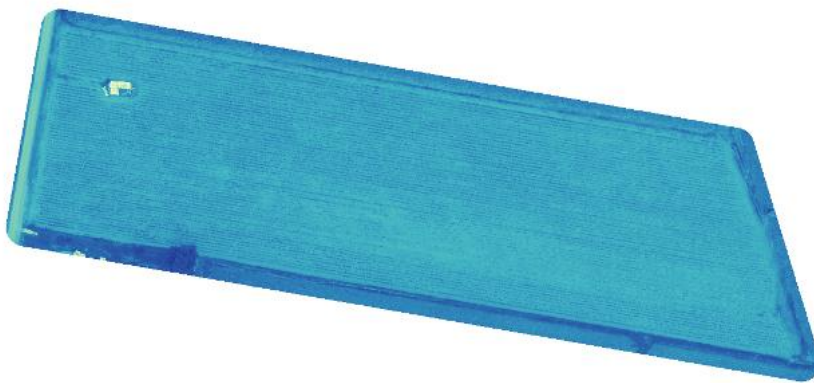
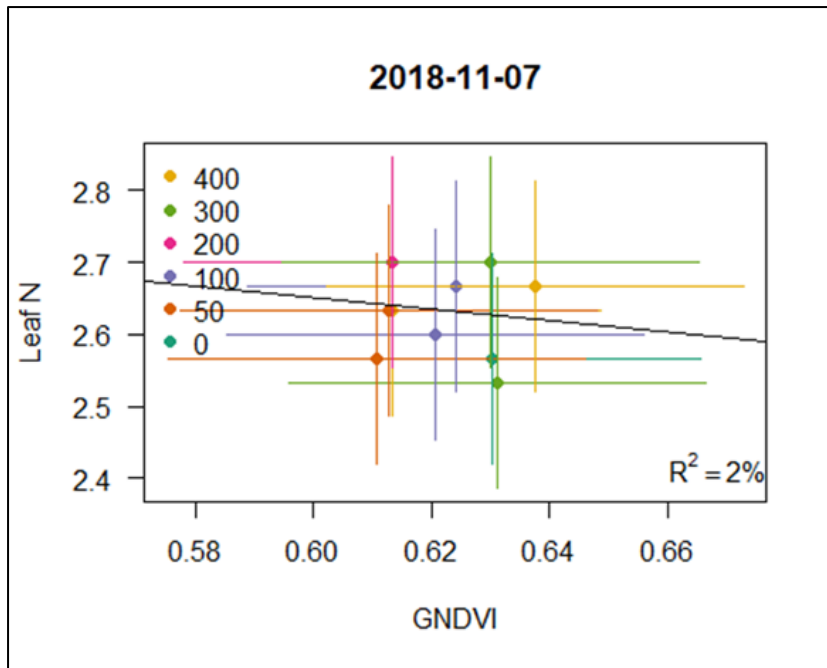


Figure 40: Leaf N vs GNDVI correlation + multispectral orthomosaic at T=7 days

At seven days post fertilizer application there is considerable variability in canopy cover and the correlation between reflectance and leaf N content is poor ($R^2=2\%$).

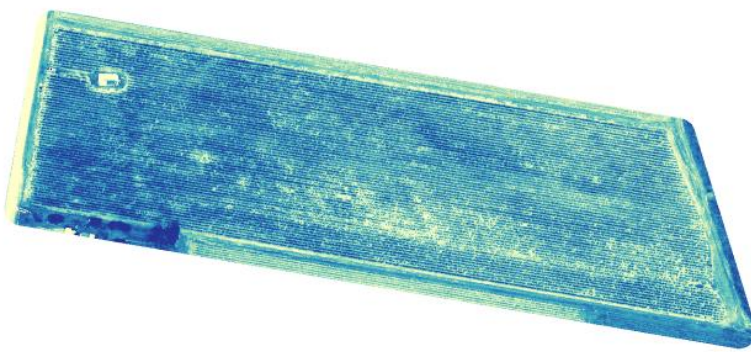
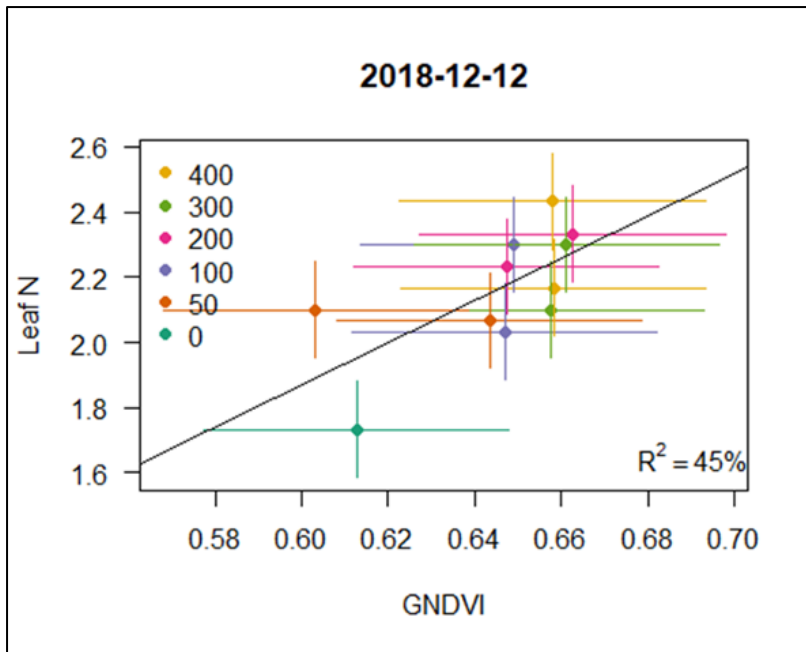


Figure 41: Leaf N GNDVI reflectance T= 42 days

At T=42 days ground cover had increased considerably, and the correlation had an R^2 of 45%. In the orthomosaic image, GNDVI imagery highlights inherent variability across the field.

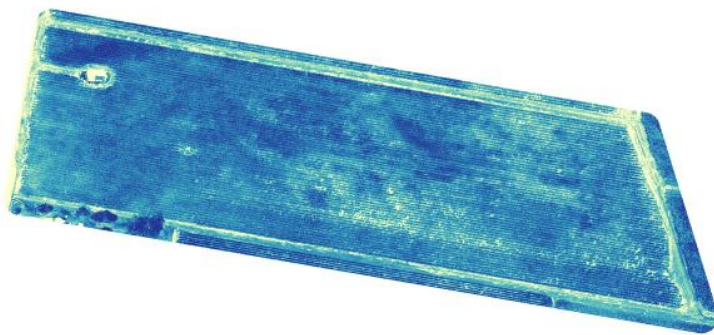
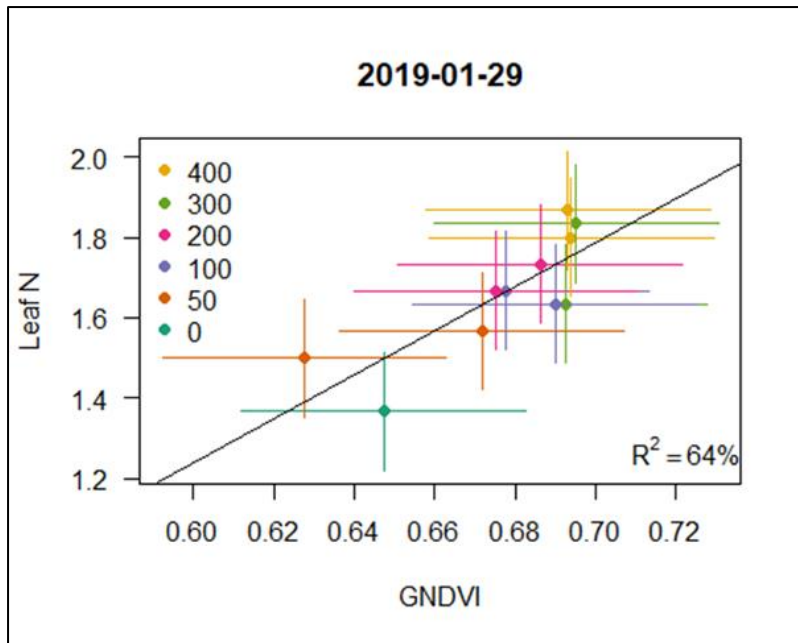


Figure 42: Leaf N vs GNDVI correlation + multispectral orthomosaic at T=90 days

At T=90 days the correlation had improved, with R^2 increased to 64%. Plots within the trial area (see Figure 52) receiving nil or lower doses of N begin to appear as lighter coloured rectangles.

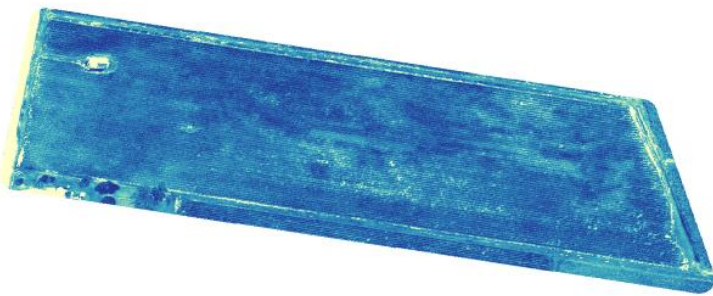
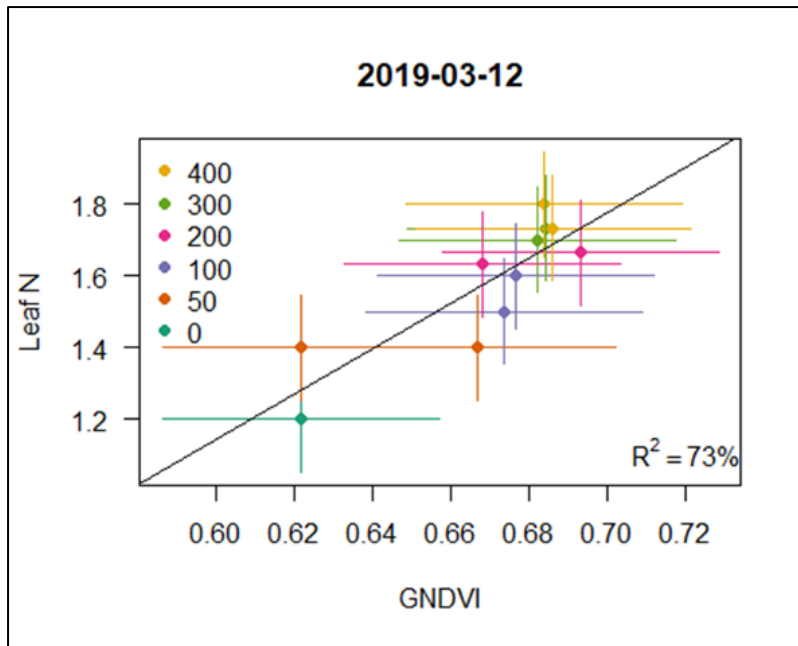


Figure 43: Leaf N vs GNDVI correlation + multispectral orthomosaic at T=125 days

At 125 days the correlation gave an R^2 value of 73%. Variability across the entire cane block was particularly evident as the crop approaches peak N demand.

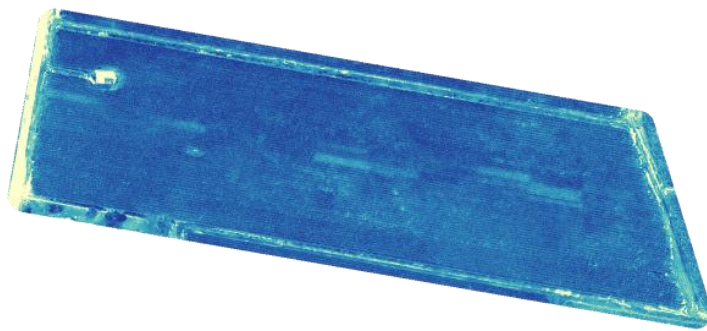
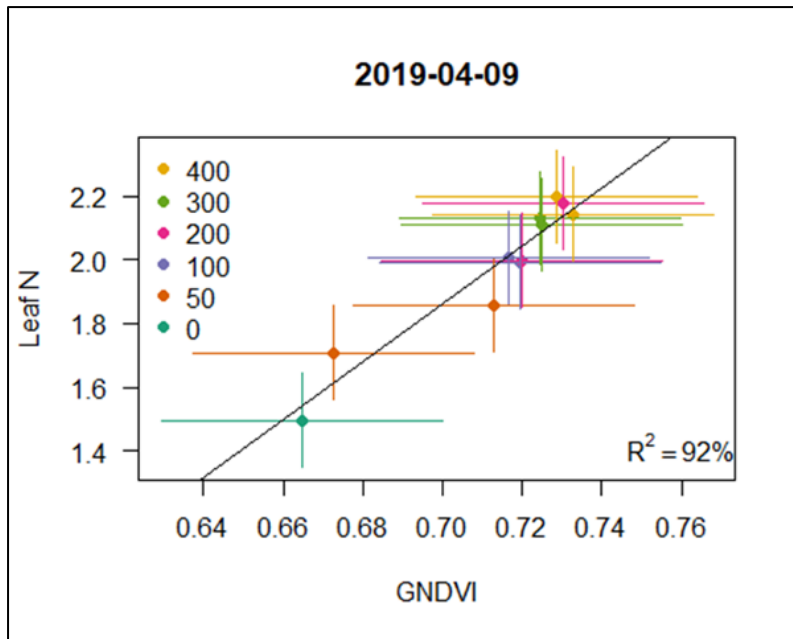


Figure 44: Leaf N vs GNDVI correlation + multispectral orthomosaic at T=160 days

At T=160 days the correlation between leaf N content and GNDVI reflectance was strongest with $R^2=92\%$. Low and nil N rate plots were particularly visible within the field trial area.

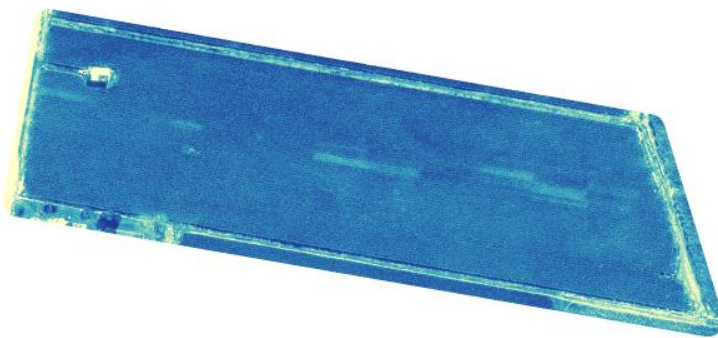
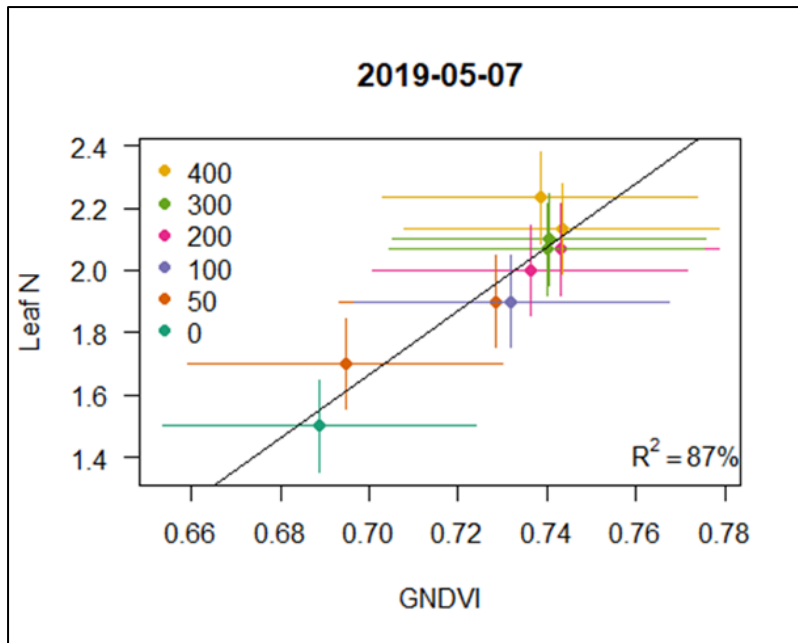


Figure 45: Leaf N vs GNDVI correlation + multispectral orthomosaic at T=188 days

188 days after fertilizer application the canopy appears most uniform across the block, and the nil and low N rate plots contrast starkly as pale rectangles within the field trial area. Correlation between leaf N and GNDVI reflectance was still strong with $R^2=87\%$.

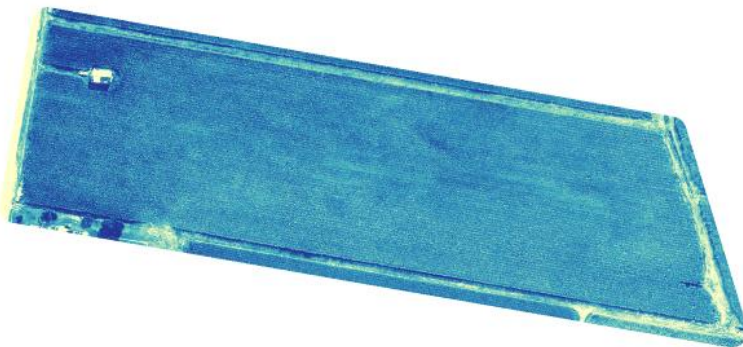
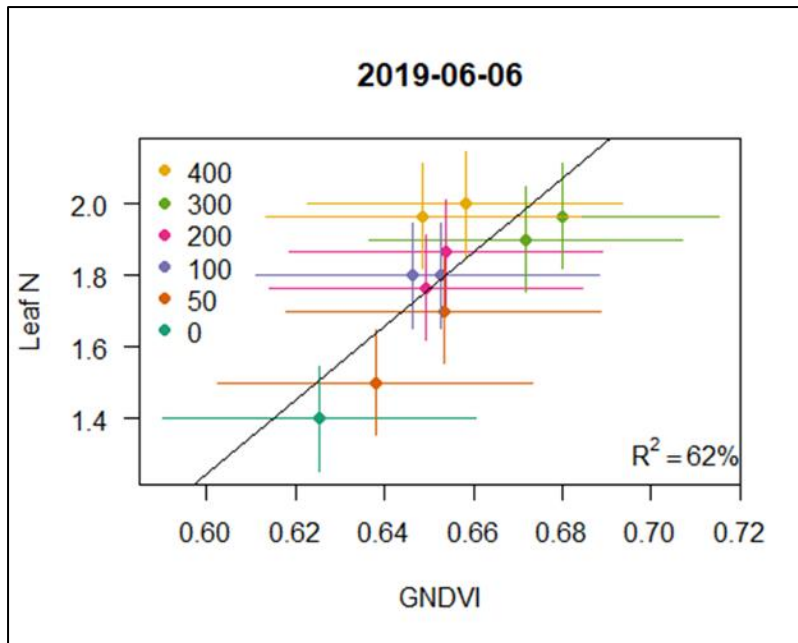


Figure 46: Leaf N vs GNDVI correlation + multispectral orthomosaic at T=218 days

Following a severe frost event on 1st June 2019 and during prolonged cooler weather, the correlation between Leaf N and GNDVI reflectance at 218 days began to weaken, with an R^2 value of 62%.

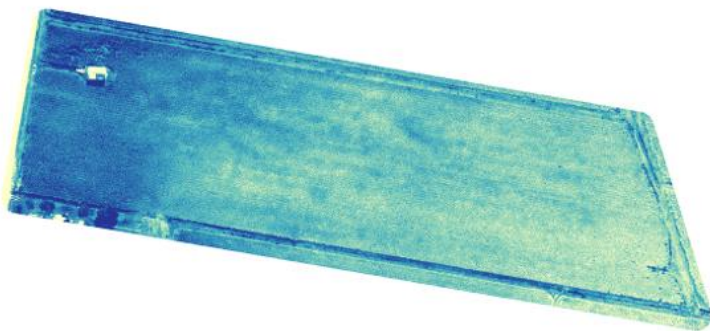
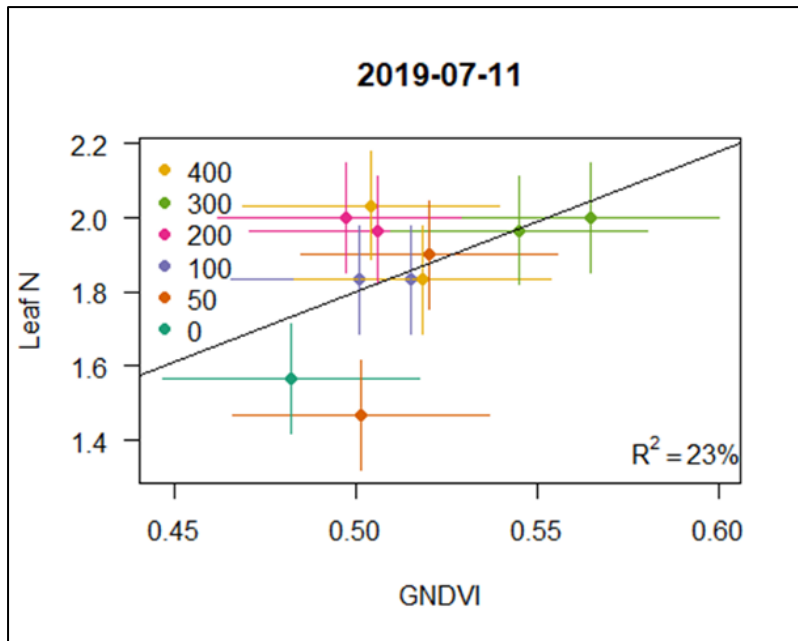


Figure 47: Leaf N vs GNDVI correlation + multispectral orthomosaic at T=253 days

The aerial survey conducted at Woodford Island at T=253 days post fertilizer application revealed the extent of the impact from frost on 1st June and prompted the project team to begin conducting yield assessment and biomass analyses (described elsewhere). Correlation between leaf N and reflectance values was weaker, with $R^2=23\%$.

Site 4:

At Site 4 correlations ranged from very weak ($R^2=16\%$) at T=29 days, to very strong ($R^2=91\%$) at T=281 days (Figure 67). Correlations at T=156 ($R^2=79\%$), T=184 ($R^2=88\%$), 218 ($R^2=79\%$) and 252 ($R^2=89\%$) days were also strong. The correlation scatterplot for each coinciding sampling date (Leaf N + GNDVI) along with the false colour orthomosaic image derived from that date is presented below.

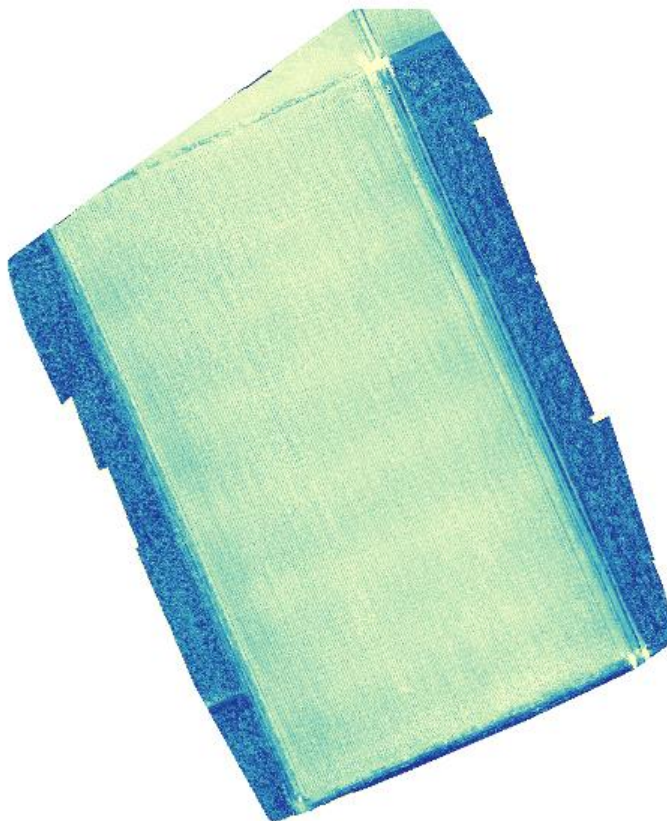
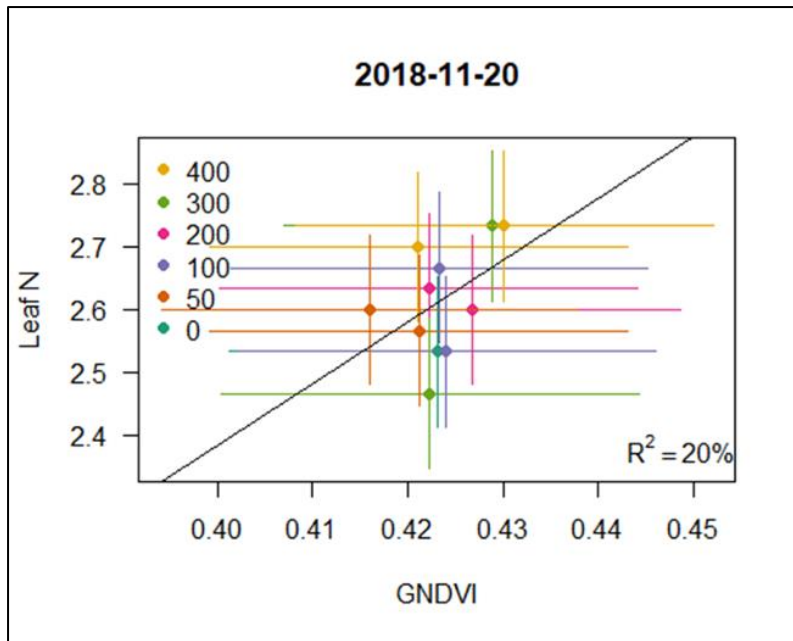


Figure 58: Leaf N vs GNDVI correlation + multispectral orthomosaic at T=14 days

At 14 days after fertilizer application the ground cover was sparse and correlation between leaf N content and reflectance was poor – $R^2=20\%$.

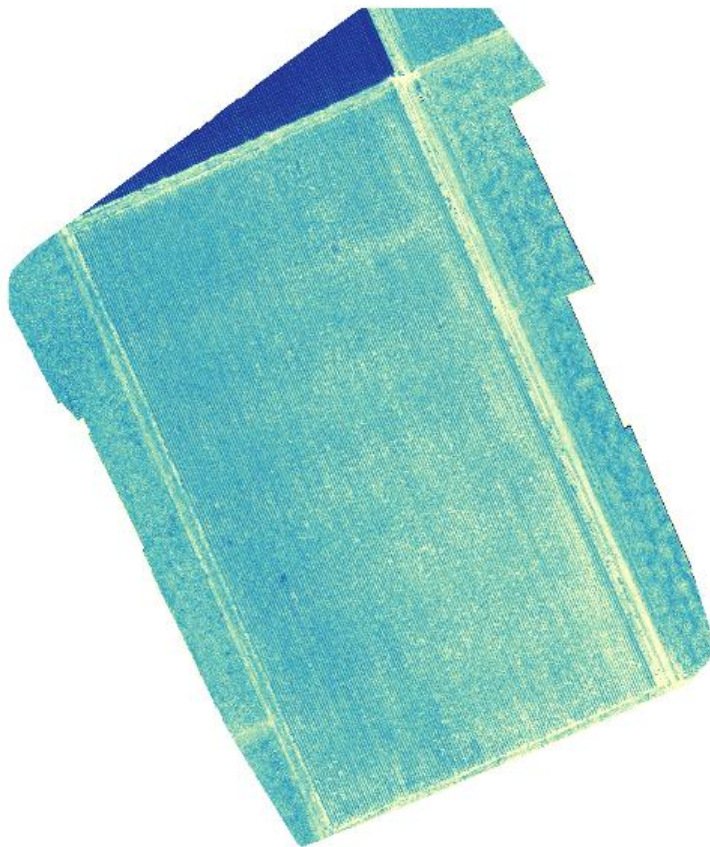
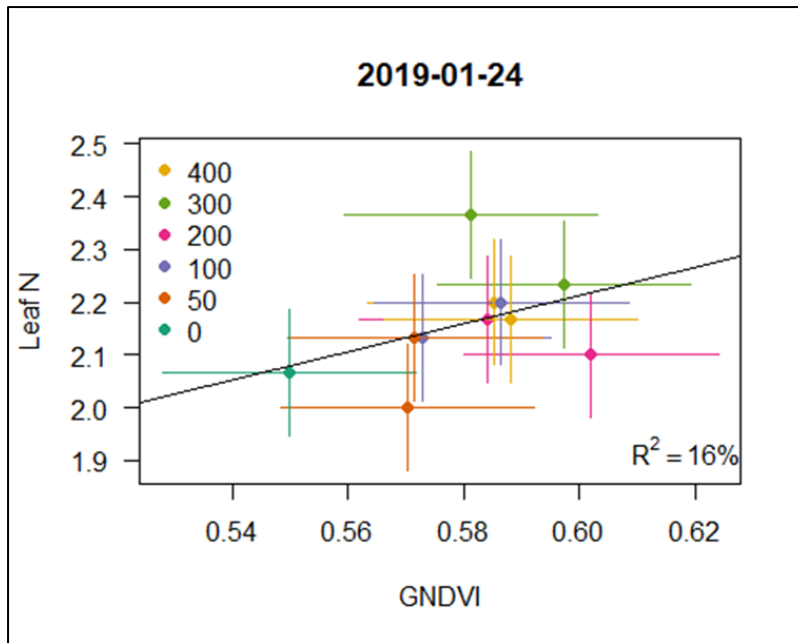


Figure 59: Leaf N vs GNDVI correlation + multispectral orthomosaic at T=79 days

At T=79 days, ground cover had increased considerably, but the correlation between leaf N content and reflectance had not greatly improved ($R^2 = 16\%$). In the orthomosaic image, GNDVI imagery highlights inherent variability across the field.

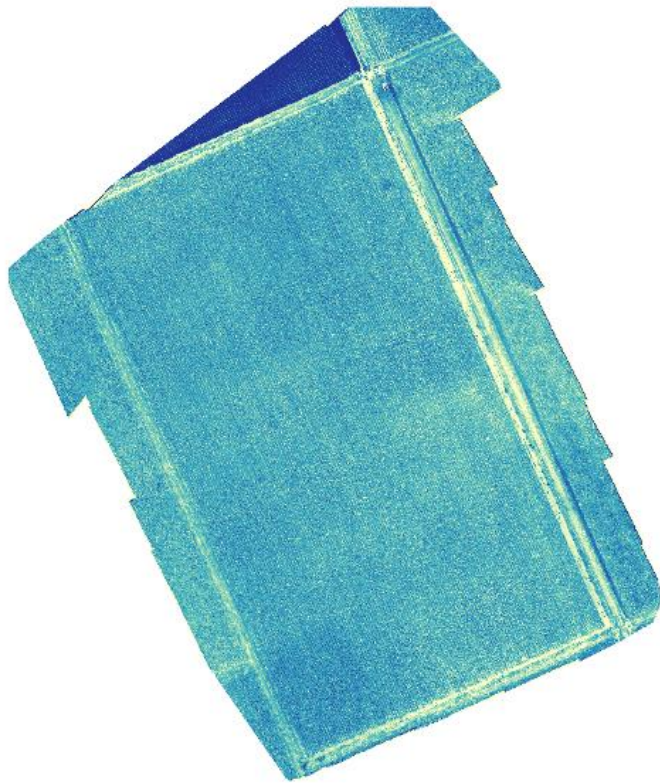
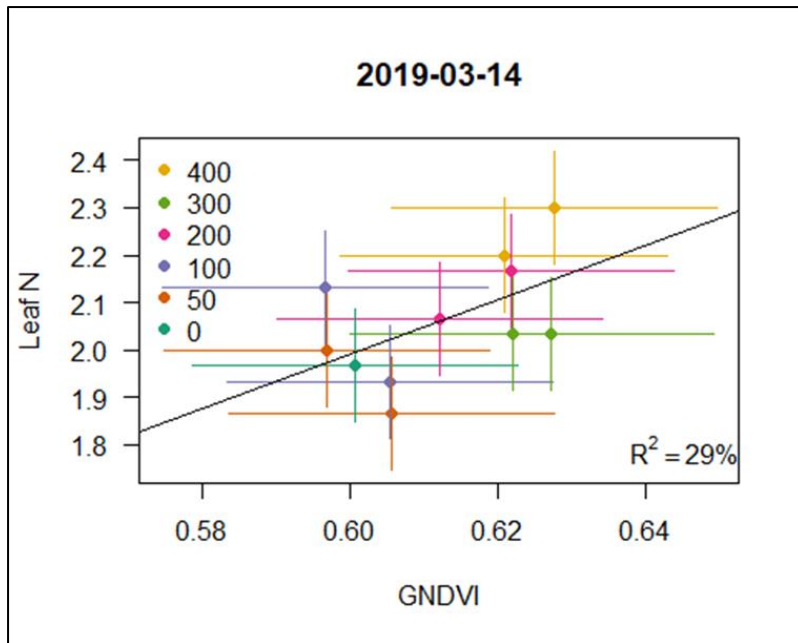


Figure 60: Leaf N vs GNDVI correlation + multispectral orthomosaic at T=129 days

Consistently low rainfall at Site 4 through summer and early autumn slowed growth of the crop during what is normally a peak period of N uptake. At T=129 days the crop appears pale in the orthomosaic image and the correlation between leaf N and reflectance remained poor ($R^2=29\%$).

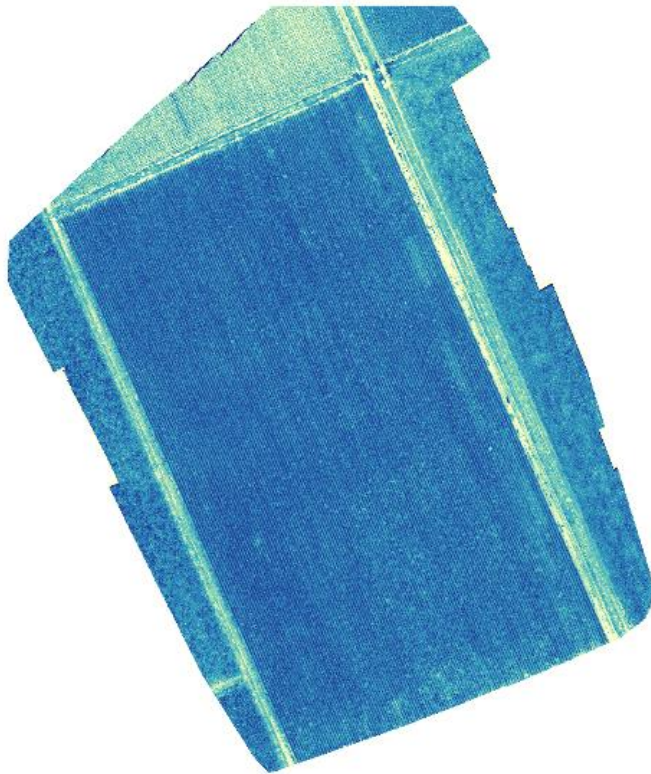
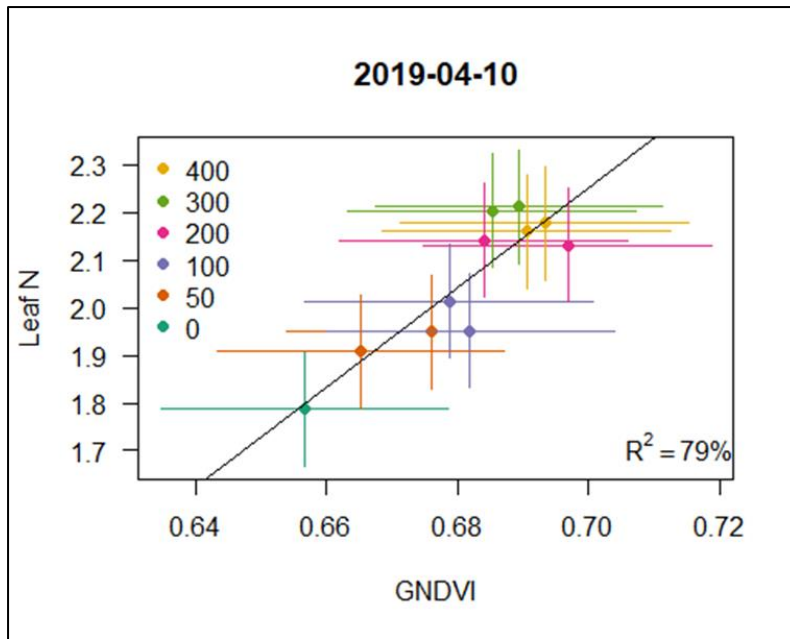


Figure 48: Leaf N vs GNDVI correlation + multispectral orthomosaic at T=156 days

Rainfall in April triggered a growth response from the crop and increased N uptake. At T=156 days the block appeared darker overall in the orthomosaic image, and trial plots with nil or low N application rates are visible in stark contrast. The correlation between leaf N and reflectance strengthened considerably ($R^2=79\%$).

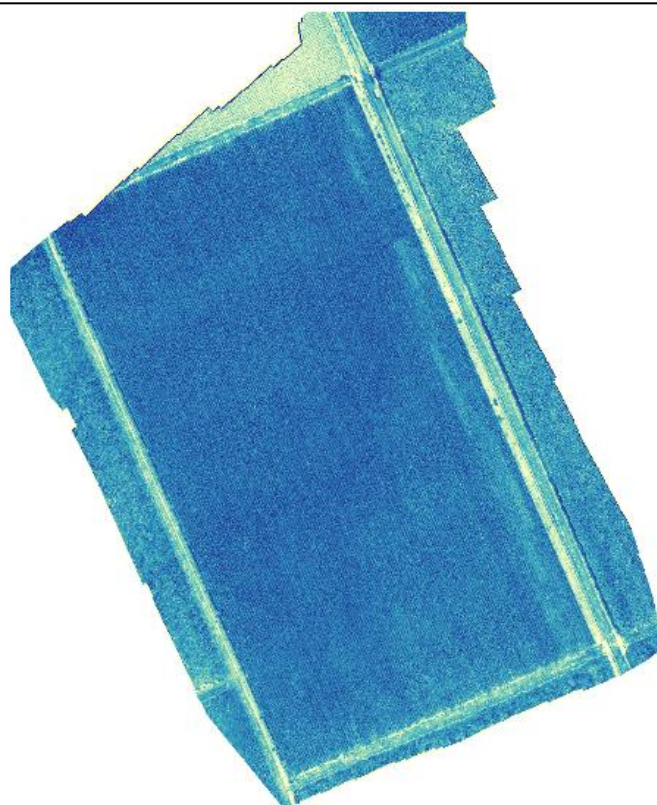
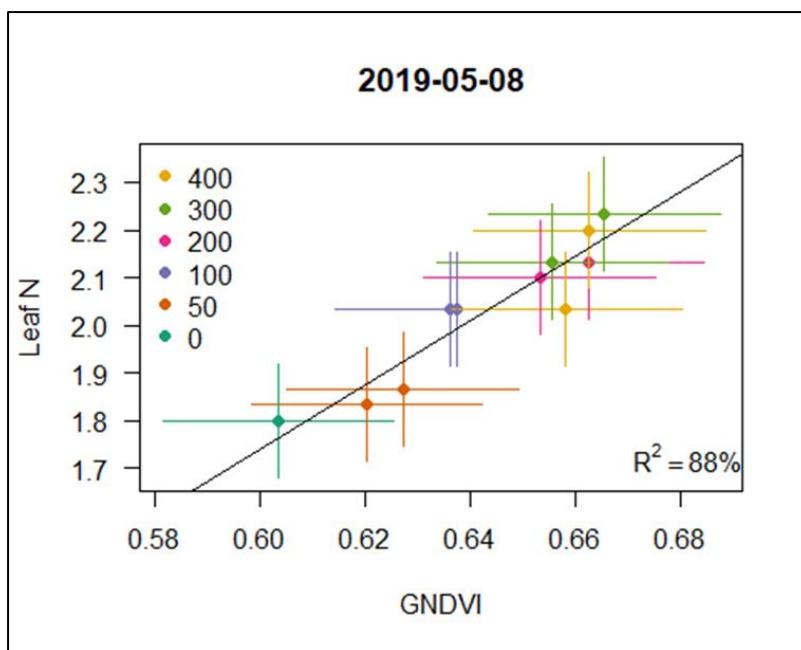


Figure 49: Correlation between GNDVI reflectance and Leaf Nitrogen (%) remained high during the period corresponding with peak crop N demand at Coraki (T=184 days shown)

At T=184 days the correlation between leaf N and GNDVI reflectance continued to strengthen at Site 4 (R²=88%).

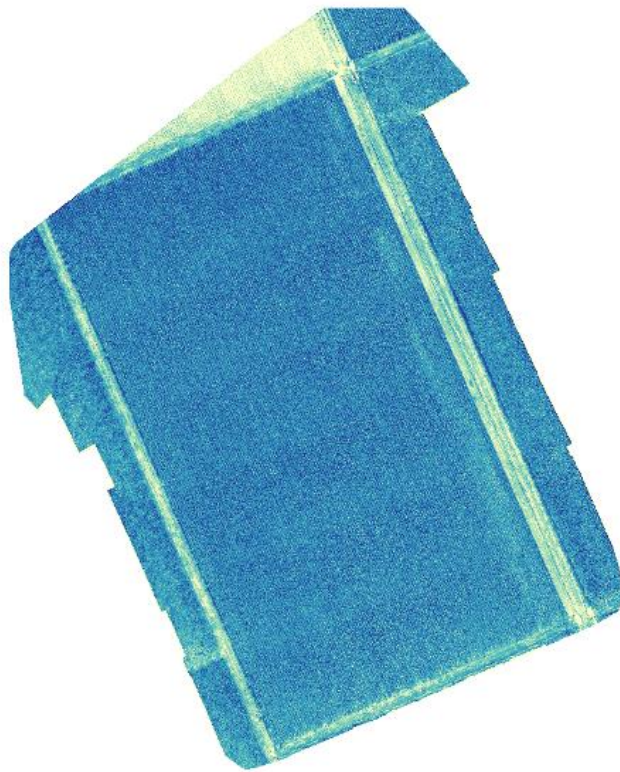
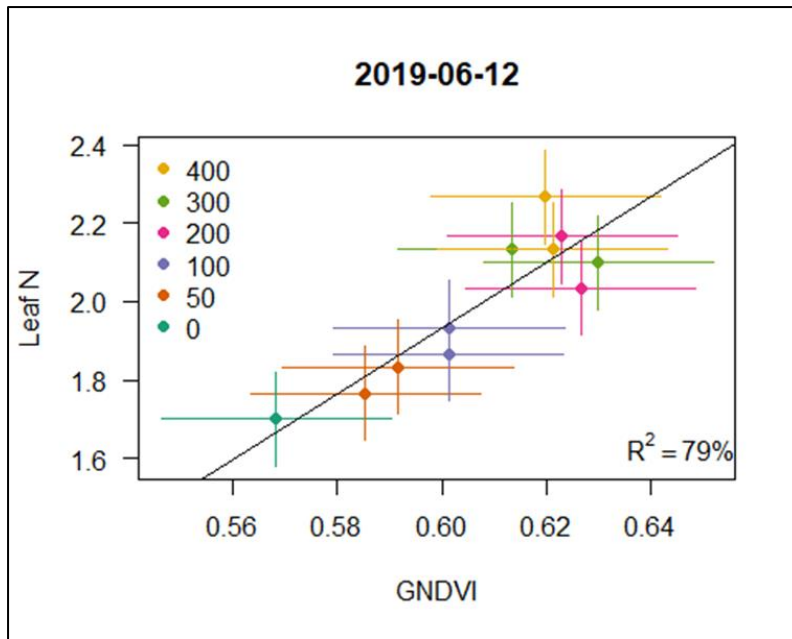


Figure 50: Leaf N vs GNDVI correlation + multispectral orthomosaic at T=218 days

At T=218 days post fertilizer application the correlation remained strong, with $R^2=79\%$.

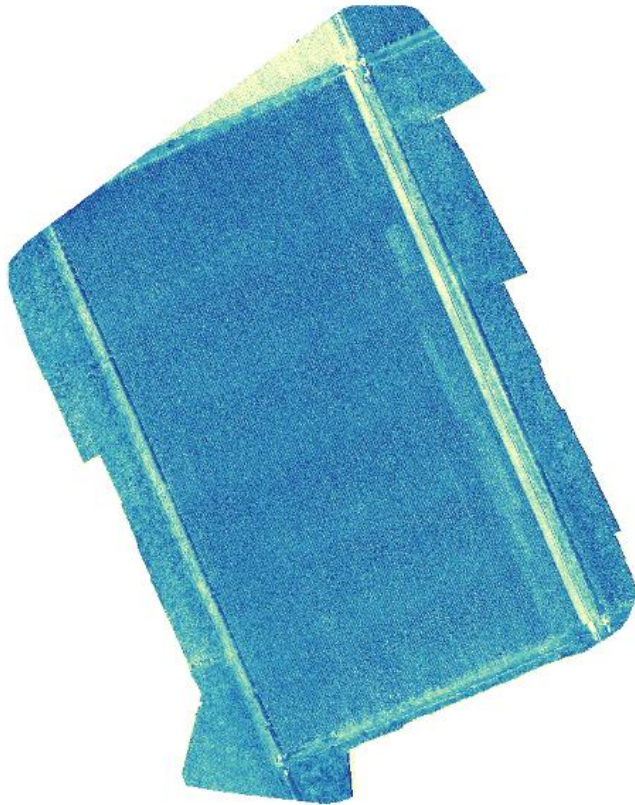
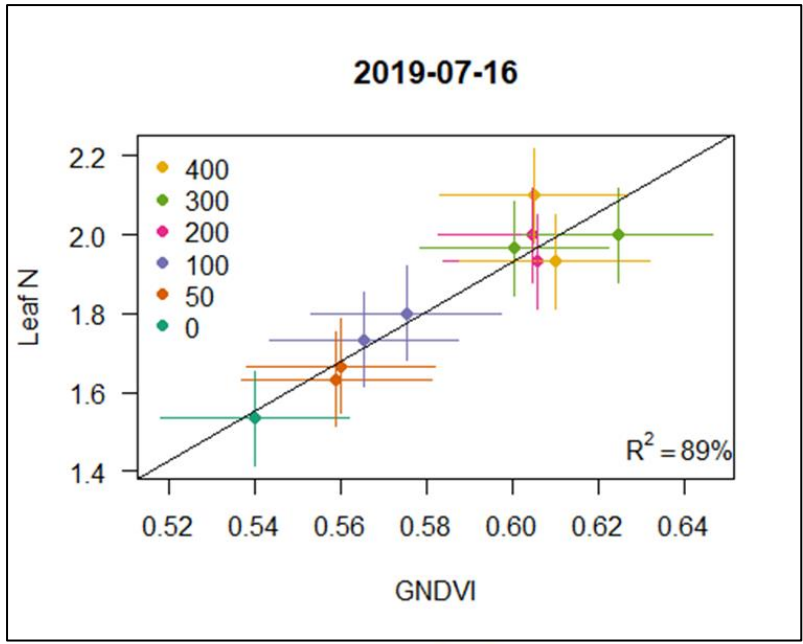


Figure 64: Leaf N vs GNDVI correlation + multispectral orthomosaic at T=252 days

The correlation between leaf N and GNDVI reflectance was maximum at 252-281 days at Site 4. At 252 days $R^2=89\%$.

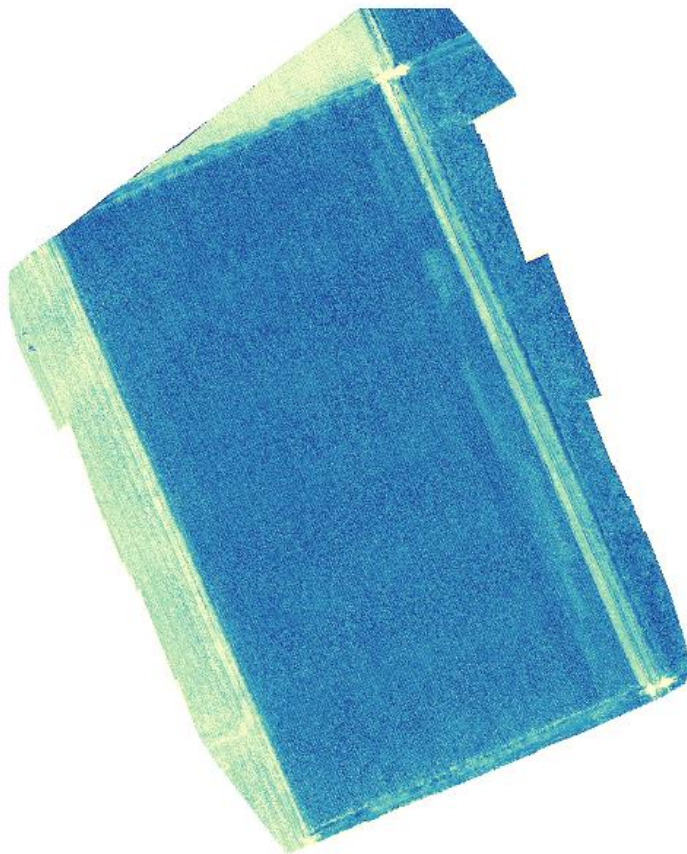
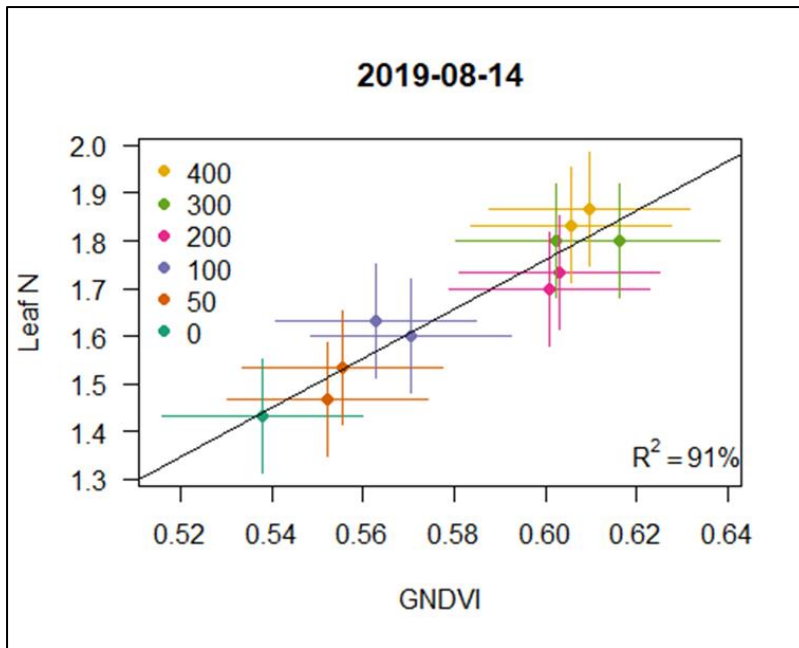


Figure 65: Leaf N vs GNDVI correlation + multispectral orthomosaic at T=281

The strongest correlation between leaf N and reflectance was observed at 281 days post fertilizer application ($R^2=91\%$). This was somewhat longer than observed at Site 3 and may reflect a combination of variety difference and greater moisture deficit during the usual period for peak N uptake.

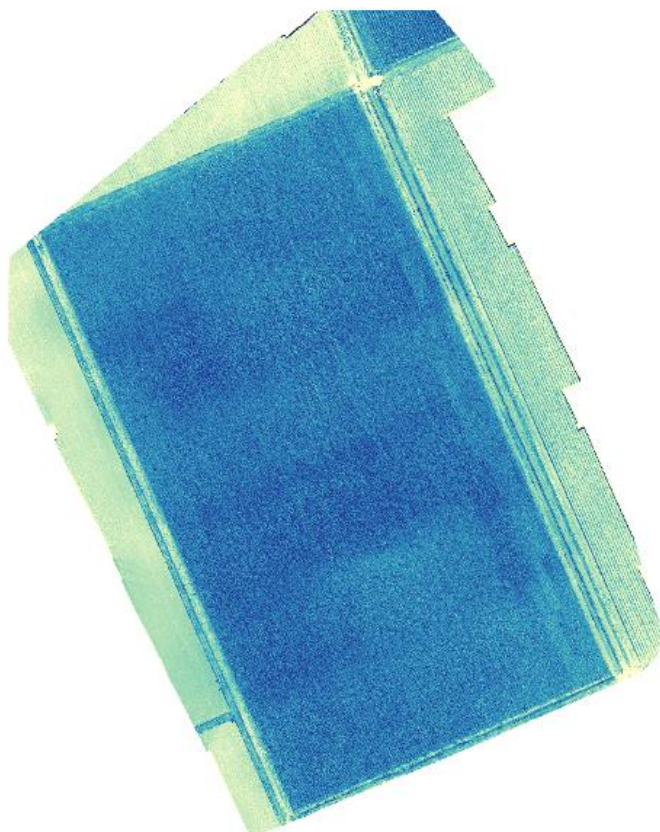
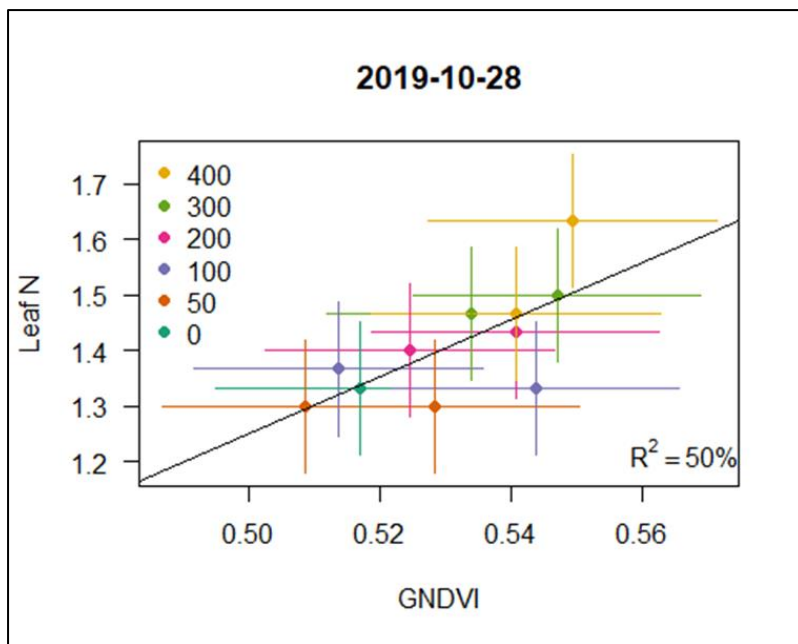


Figure 51: Leaf N vs GNDVI correlation + multispectral orthomosaic at T=356 days

At T=356 days the correlation was weaker ($R^2=50\%$).

As stated, the R^2 values presented above for each site are indicative for cane variety and climatic conditions in the given season, however the data clearly shows that GNDVI can

discriminate between high and low leaf N in the crop, particularly during the middle stages of the measurement period where peak growth and N uptake are occurring. This provides a valuable research tool for the monitoring of N uptake in the crop and could potentially reduce the need for physical leaf sampling.

6.7 Assessing N release from PCU:

6.7.1 Mesh bag methodology

An adjunct experiment to characterize N-release curves for each PCU formulation was set up at each trial site in the 18/19 season. Nylon mesh bags 10cm x 10cm, were prepared, each containing 10 g of either PCU 90 or PCU 270. Bags were deployed to the field in triplicate for each formulation, spaced 30 cm apart and at 5-10 cm soil depth on the shoulder of 3 cane rows adjacent to the field trial. Triplicate bags were then manually retrieved at intervals as set out in Table 34.

Table 24: Mesh bag sampling intervals

Weeks	Months
0	3
1	4
2	5
4	6
6	9
8	12
	15
	18
	24



Figure 52: Mesh bag experiment in situ prior to being covered over with soil

Upon retrieval from the field, the contents of each bag were transferred to a suitable container and any root material removed. A 5g (dry weight) subsample was crushed and extracted in 50mL Type-1 water by shaking for 1 hour. The extract was analysed for total N content in a NATA approved facility. N release curves were derived by first converting %N in the extract to a per gram value. The amount of N present in the sample extracts at time T=0 was then plotted as being 100% and subsequent values for each sample time plotted as a percentage relative to that figure.

N release curves derived from in-field application demonstrate the predictability of product performance.



Figure 68: Mesh bags retrieved from the field with visible root penetration

6.7.2 N release curve results

At the Woodford Island site PCU 90 was reduced to 5% +/- 2.4% of initial N concentration at T=104 days. PCU 270 contained 19% +/- 11.06 %of initial N dose at T=160 days. Variability in these samples was high and may reflect localized moisture and root penetration of the nylon bags.

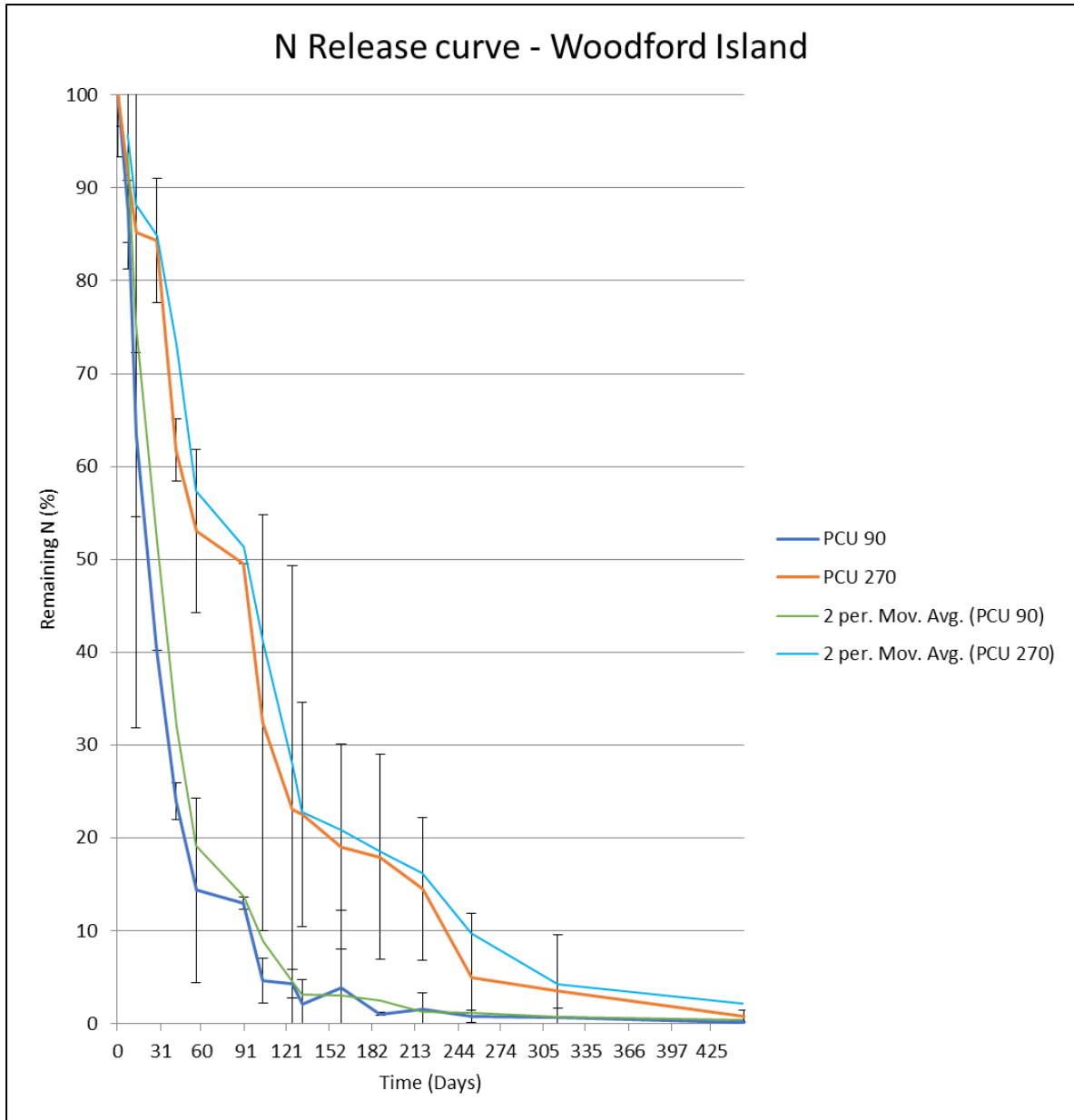


Figure 53: N- release curves for PCU formulations (Woodford Island)

At the Coraki site, PCU 90 pellets retrieved at 129 days contained 4% +/-1 % of initial N dose while PCU 270 retained 11%+/-5.9%.

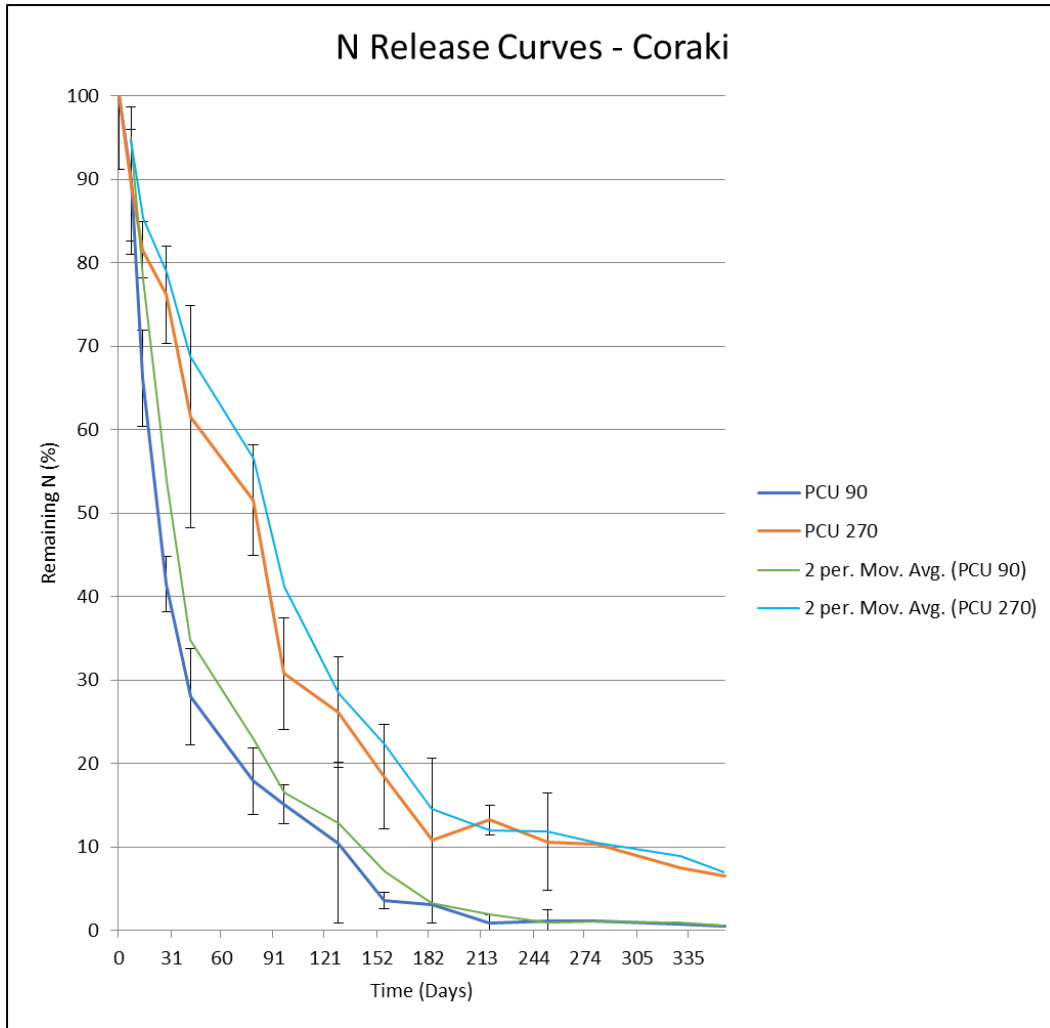


Figure 70: N- release curves for PCU formulations (Coraki)

7.0 Modelling Short and Long Term PMN against MIR Predictions:

7.1 Aim:

Evaluate statistically valid predictive capabilities of Mid-Infrared Red (MIR) spectroscopy for Potentially Mineralizable Nitrogen.

7.2 MIR Methodology:

Mid-Infrared (MIR) spectroscopy in combination with chemometric statistical methods, such as partial least squares (PLS) regression, is increasingly being recognized as a quick and effective tool for measuring numerous soil attributes.

Soil samples from 41 sites across the three NSW cane growing catchments (as described in Section 4.0) were air-dried and finely ground (<75 μm) using a Labtech Essa™ Ring Mill.

Approximately 100 mg of the finely ground soil was then placed into a 0.9 cm diameter stainless steel auto sampler cup and the surface levelled. MIR spectra were acquired using a Thermo Nicolet iS50 FTIR spectrometer (Thermo Fisher Scientific Inc., MA, USA) equipped with a Pike AutoDiff automated diffuse reflectance accessory (Pike Technologies, WI, USA). Each sample was scanned 60 times with a KBr beam-splitter and a DTGS detector, within a spectral range of 7800-400 cm^{-1} at 8 cm^{-1} resolution. The resultant spectra were expressed in absorbance (A) units where $A = \text{Log Reflectance}^{-1}$. An initial background reference scan was made prior to each sample run using a silicon carbide disc assumed to have a reflectivity of 1 (100%).

Proprietary software was used to produce initial predictions from individual soil spectra based upon a regional calibration set (Janik et al 2007) of soil samples held by NSW DPI.



Figure 54: MIR scans were conducted on a Thermo Nicolet iS50 FTIR spectrometer

MIR predictions were modelled against both short term and long term potentially mineralizable N (T=14, 300 and 436 days) for a combined depth of 0-40cm, at University of Queensland and provided as a series of scatter plots with R^2 values indicating the strength of the correlation and predictive capacity. An additional independent model was provided for the Tweed Catchment 14-day incubation (0-20 cm). The data from further independent modelling of catchment and depth is pending.

7.3 MIR Results and correlations:

A typical MIR scan, with laboratory reference shown in red, is depicted in Figure 72 (Tweed dataset shown).

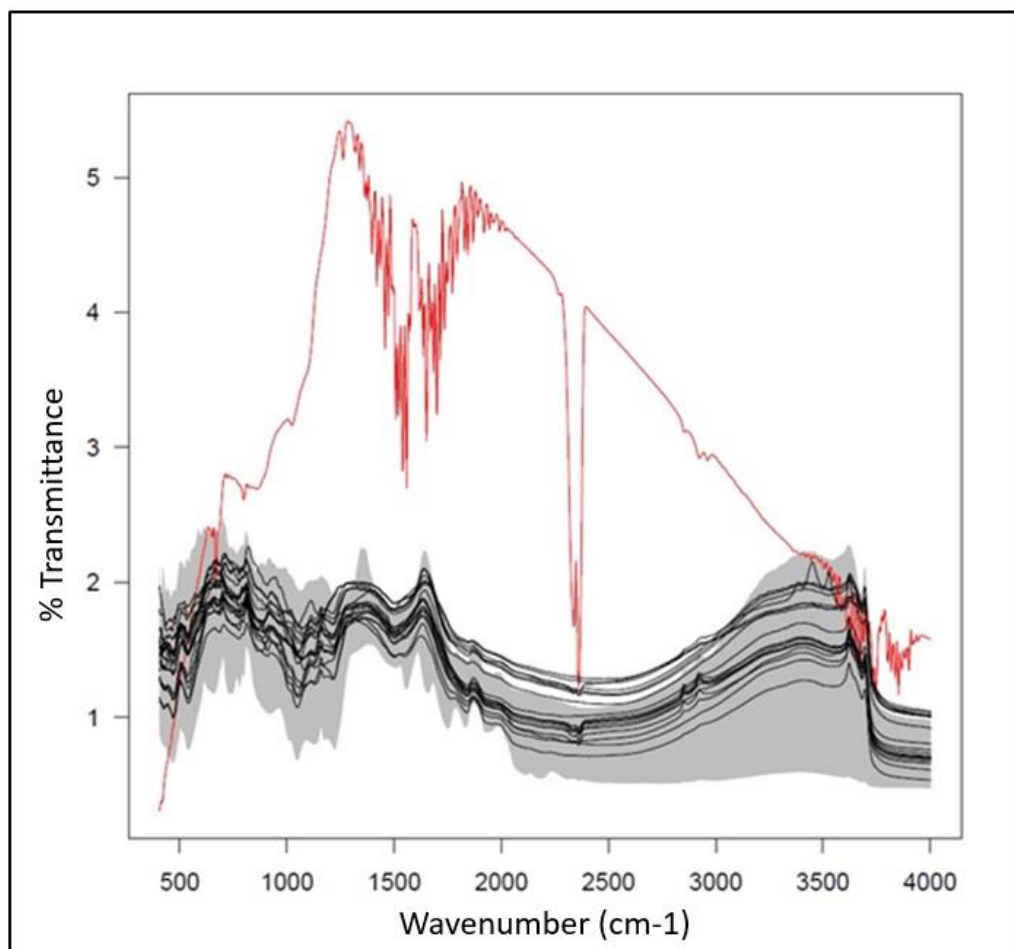


Figure 55: Characteristic MIR waveband scan (tweed catchment soil samples shown)

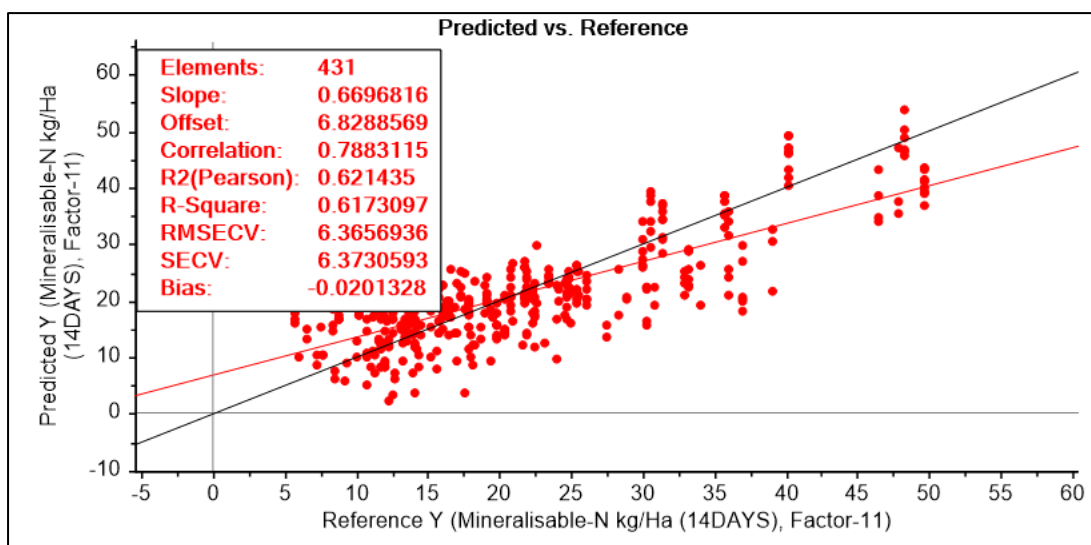


Figure 73: MIR/NIR correlation with 14-day PMN incubation – 41 sites across 3 catchments. Note, the black line represents the 1:1 ratio.

Data from 14-day PMN (0-40 cm) as described in Section 2, modelled against MIR predictions from the three NSW sugarcane growing catchments combined, gave a correlation with an $R^2=61.7\%$.

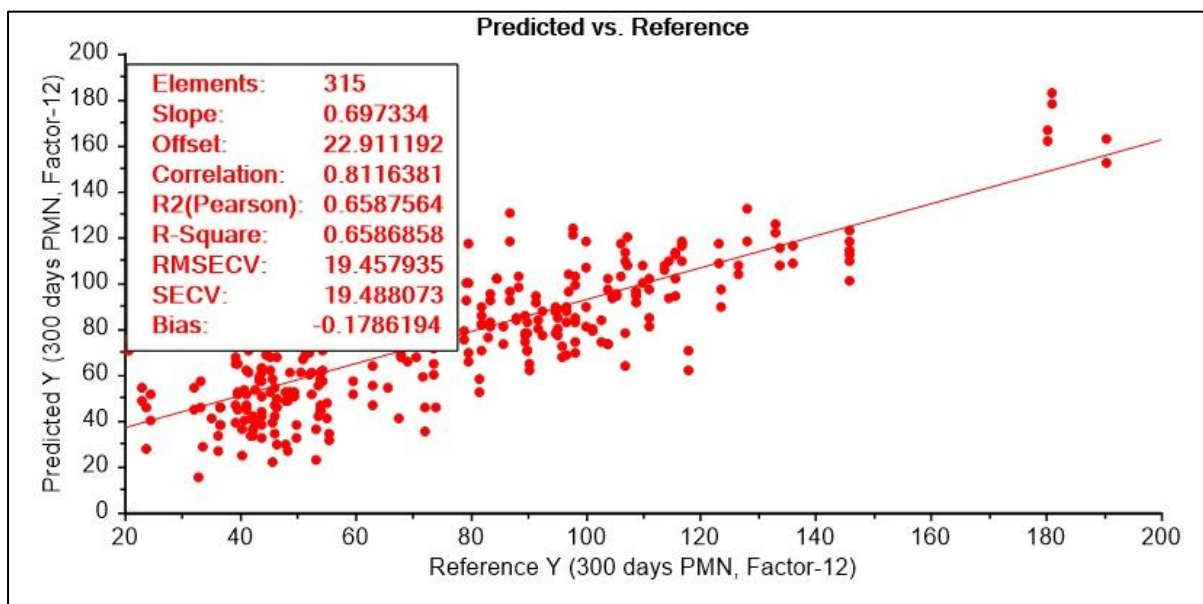


Figure 56: MIR/NIR correlation with 300-day PMN incubation – 27 sites

Modelling 300-day PMN (0-40 cm) against MIR predictions for the three NSW sugarcane growing catchments combined returned a correlation with $R^2=65.9\%$

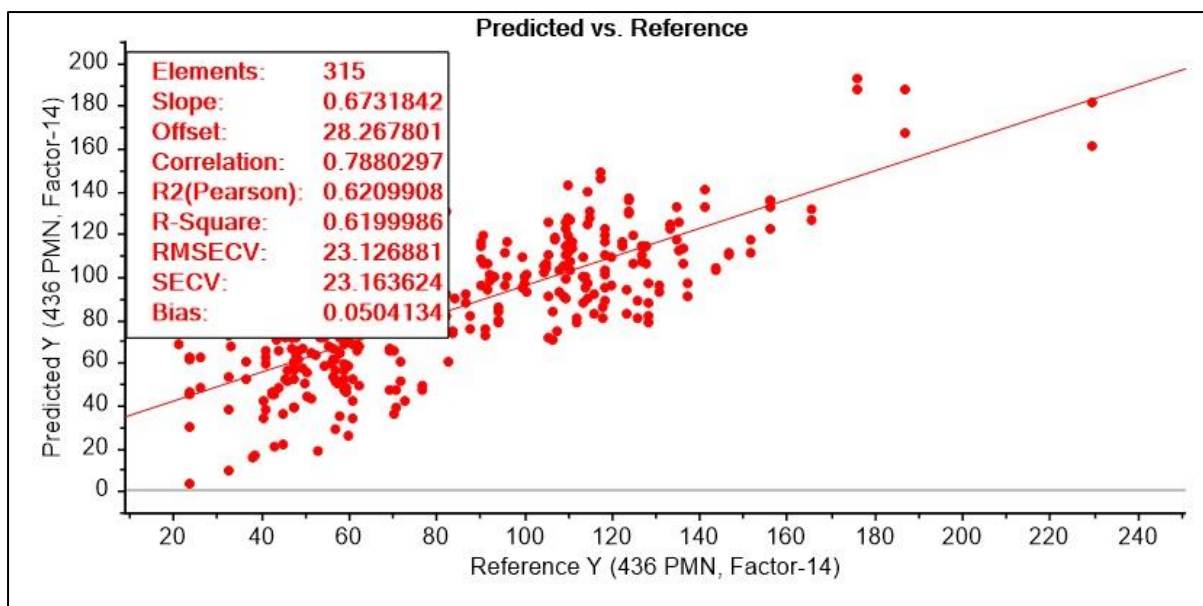


Figure 57: MIR/NIR correlation with 436-day PMN incubation – 27 sites

Modelling 436-day PMN (0-40 cm) against MIR predictions for three NSW sugarcane growing catchments combined returned a correlation with $R^2=61.9\%$.

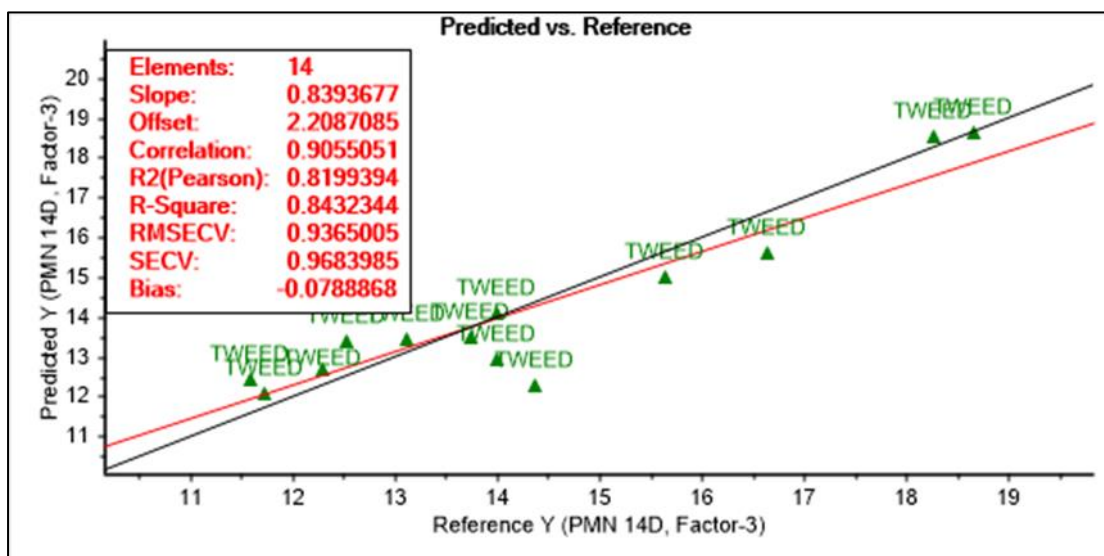


Figure 58: MIR Correlation with 14-day incubation – Tweed catchment 0-20cm. The black line indicates the 1:1 ratio

Each catchment was modelled separately to account for varying soil physio-chemical properties (Tweed data supplied). There was a strong correlation ($R^2=84.3\%$) between MIR predictions and 14-day PMN (0-20 cm). In the 20-40cm profile the prediction was not as strongly correlated, with $R^2=56.1\%$ (Figure 77).

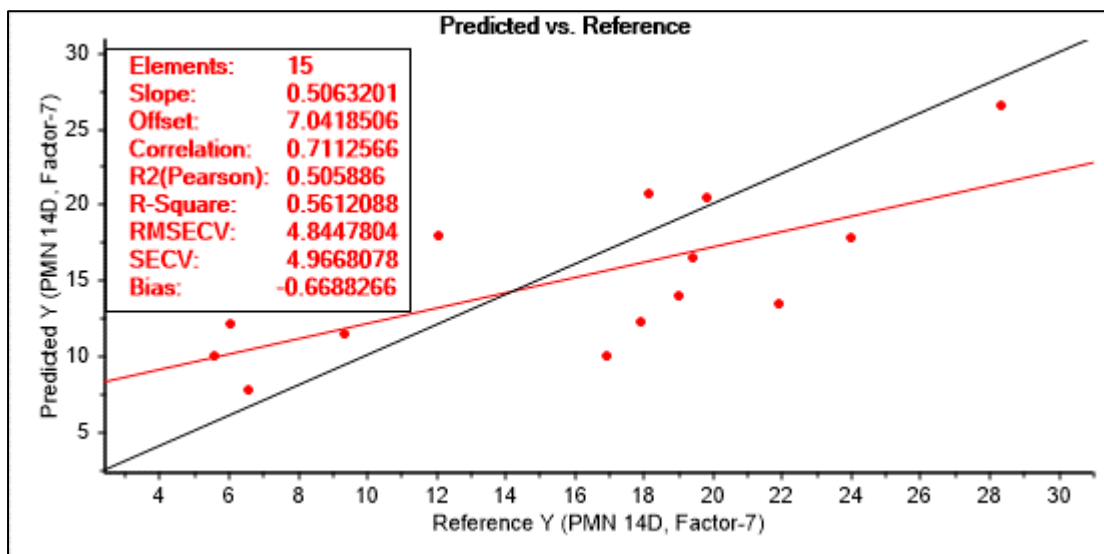


Figure 59: MIR Correlation with 14-day incubation – Tweed catchment 20-40 cm. Note, the black line represents the 1:1 ratio.

8.0 Conclusions

The project concluded from 4 replicated field trials in northern NSW that controlled release N fertiliser provided no benefit to yield or agronomic fertiliser N use efficiency. Seasonal conditions during the trial duration was not conducive to N loss pathways (ie, low rainfall). The project generated data on the release patterns of N from PCU90 and PCU270, as well as the fertiliser N content of the 3rd leaf on monthly assessments, and used this data to calibrate multispectral imaging for future assessments of crop N uptake. A high correlation was developed between leaf N content and imaging at around 160 days after the emergence of ratoons. Information on N release and N uptake could be used in simulation analysis to quantify and explain the effects of climate, soil type and management on agronomic and environmental outcomes from using PCU in cropping systems. If seasonal conditions (in particularly rainfall) can be predicted, recommendations on PCU formulation, rate and timing could be delivered specifically for the seasons/years where N loss pathways are 'predicted' to be significant. Hence it is recommended that data generated by this project be used to verify models and decision support tools based on improved seasonal climate forecasting.

The supply of N from the soil (sum of existing mineral N stores and PMN) varied significantly (range between ca. 100-560 units N/ year), therefore having this information before implementing the 6ES could assist in refining recommendations on N application doses. Three of the four field trials showed very flat response curves of sugarcane yield to increasing N rates. It was concluded that this was likely due to PMN supply from these field sites. As a rapid and inexpensive test has been developed based on MIR to predict PMN, it is recommended that a pilot study be conducted via the guidance of Sunshine Sugar agricultural services where 100 paddocks in NSW are sampled and N recommendations are based on: a) existing 6ES protocols, and b) more informed 6ES (ie based on MIR prediction of PMN). A number of split paddocks based on both recommendations would be required to assess differences in harvestable yield, and this would then allow a robust assessment of

the relative economics of both approaches. This pilot study would also help to inform the future viability of a commercial testing service for PMN.

9.0 References:

Allen, Diane & Bloesch, P. & Orton, T. & Schroeder, B. & Skocaj, D. & Wang, Weijin & Masters, B. & Moody, P. (2019). Nitrogen mineralisation in sugarcane soils in Queensland, Australia: I. evaluation of soil tests for predicting nitrogen mineralisation. *Soil Research*. 57. 10.1071/SR19031.

Bell, MJ, 2014 A review of nitrogen use efficiency in sugarcane. Sugar Research Australia Limited. <http://hdl.handle.net/11079/14735>

Bremner, J.M., 1965. Nitrogen availability indexes. In: Black, C.A. (Ed.), *Methods of Soil Analysis*, Part 2. American Society of Agronomy, Madison, WI, pp. 1324-1345.

Hunt, E.R.J.; Hively, W.D.; Daugtry, C.S.T.; McCarty, G.W. Remote sensing of crop leaf area index using unmanned airborne vehicles. In *Proceedings of the Pecora 17 Conference*, American Society for Photogrammetry and Remote Sensing, Denver, Colorado, 18–20 November 2008.

Janik LJ, Skjemstad JO, Shepherd KD, Spouncer LR (2007) The prediction of soil carbon fractions using mid infra-red-partial least square analysis. *Australian Journal of Soil Research* 45, 73-81

Jarrell, W. M. and Beverly, R. B. 1981. The dilution effect in plant nutrition studies. *Advanced Agronomy*, 34: 197–224.

NATIONAL SOIL CARBON RESEARCH PROGRAMME: FIELD AND LABORATORY METHODOLOGIES Jonathan Sanderman, Jeffrey Baldock, Bruce Hawke, Lynne Macdonald, Athina Massis-Puccini and Steve Szarvas CSIRO Land and Water, 7: 14-15

Saunders DH, Ellis BS, Hall A (1957) Estimation of available nitrogen for advisory purposes in Southern Rhodesia. *Journal of Soil Science* 8: 301-312.

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, Moody PW, Bell MJ and Garside AL (2005) Nitrogen fertiliser guidelines in perspective. *Proceedings of the Australian Society of Sugar Cane Technologists* 27: 291-304.

SRA Australian Sugarcane Nutrition Manual 2018 edition, pp48

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.