Australian Government
Department of Agriculture,
Water and the Environment

CRDC

Rural R&D for Profit Program

More Profit from Nitrogen

RRDP1713 (July 2016- June 2018)

Optimising Nitrogen and Water Interactions in Cotton

Final Report

31st August 2018

Revised 22nd July 2020

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This publication is available at https://www.crdc.com.au/more-profit-nitrogen

Disclaimer

Acknowledgements

This project was supported by funding from the Australian Government Department of Agriculture, Water and the Environment as part of its Rural R&D for Profit Program, the Cotton Research and Development Corporation (CRDC) and the Centre for Agricultural Engineering (CAE) at the University of Southern Queensland.

We are indebted to cotton growers Mr Neil and Lachlan Naas (Yargullen, QLD) and Mr Russell Clapham (Pittsworth, QLD) who collaborated with us on this project by hosting our experiment on their properties, communicating with us about key crop management events, and sharing their knowledge. We gratefully acknowledge Mr Ian Grant (Agricultural Chemistry Pty Ltd.), Dr Chris Dowling (Back Paddock Pty Ltd.), and Prof Peter Grace and Dr Clemens Scheer (QUT, Institute for Future Environments, Brisbane) for academic and technical discussions, and knowledge contributions to this research.

Contents

Summary

Organic matter in soil can supply more than 50% of the nitrogen (N) to cotton crops, but this pool of N supply is dynamic and difficult to predict. Soil bacteria are responsible for mineralising soil organic N and hydrolysing dissolved urea to ammonium. Most plants can take up both ammonium and nitrate forms. However, nitrate is susceptible to leaching and can be denitrified into inert and greenhouse gases. Filterable organic N (dissolved organic nitrogen, DON) is the most readily available form for microbial mineralisation and can also leach. The type and timing of N fertiliser and irrigation may regulate N supply and loss, as the severity of soil drying between irrigation events regulates microbial activity. The 'Optimising nitrogen and water interactions in cotton' project investigated how ammonium, nitrate and organic N in soil is affected by urea and DMPP-treated urea fertilisers during wetting and drying cycles of irrigated cotton. DMPP urea is an enhanced efficiency fertiliser that slows the conversion of ammonium to nitrate in soils.

The main objectives of this research were to: (1) investigate how N fertiliser formulations; namely: urea and DMPP-treated urea, and wet/dry cycles affect within-season patterns of soil N supply, (2) identify how well a rapid soil test based on water extraction and measurement of dissolved organic N or potassium chloride-extractable inorganic N species can inform predictions of soil mineralisable N, and (3) suggest how currently available nutrient management DSSs can be improved by improved knowledge of within-season patterns of soil N supply.

The research was conducted in soils established to overhead irrigated cotton on commercial farms over the 2016/17 and 2017/18 seasons in the Darling Downs of south-east Queensland. Soil was sampled after key irrigation or rainfall events, and at critical cotton growth stages. Soil was sampled from outside and inside root exclusion tubes that were placed in the soil to a depth of 300 mm at the beginning of each season, to monitor the plant-available pools of soil and fertiliser N in the presence and absence of roots, respectively. Novel, low-cost, rapid methods were used to measure nitrate, ammonium and total dissolved N (mineral N and DON). The results were compared with conventional N testing methods for their ability to predict crop N availability.

The main findings about patterns of within-season soil and fertiliser N supply were:

- Background soil N mineralisation rates were low and uniform throughout the cotton season,
- Cotton roots actively take up inorganic N well before flowering (<30 days post-emergence),
- DMPP-treated urea inhibits the conversion of hydrolysed urea to ammonium (NH_4^+), as well as inhibiting nitrification,
- 'N-priming' (plant-available N in excess of N supplied by fertiliser application and background mineralisation), recorded in urea-fertilised plots within 60 days after fertiliser application was due to the displacement of soil organic matter (SOM), including dissolved organic N (DON), from organo-mineral complexes by urea-derived NH_4^+,
- Ammonium derived from urea fertiliser 'fixed' to organo-mineral complexes (the difference between soil 2M KCl-extractable NH_4^+-N and water-extractable 2M KCl NH_4^+-N) only became available for plant uptake in the 2016/17 season 115 days after fertiliser application, and

- A rapid water extraction soil test for total dissolved N is a much more sensitive indicator of N supply than conventional soil inorganic N methods within the first 60 days after fertiliser application.

The main findings from the fertiliser leaching trial conducted May 2018 to July 2018 were:

- The displacement of SOM from organo-mineral complexes in the soil by ammonium derived from urea fertiliser requires high soil temperatures for the urease enzyme to rapidly hydrolyse urea to produce high concentrations of ammonium. Below 20°C, the rate of hydrolysis is too slow for any significant SOM displacement to occur, and
- High concentrations of nitrate derived from the fertiliser calcium nitrate are not associated with any increase in dissolved organic matter (DOM) in soil leachate.

Key findings from this study, which may improve nutrient management DSSs are:

- The use of DMPP-coated urea slows the rate of release of ammonium and nitrate substantially within 60 days after fertiliser application, and may compromise early root development,
- DMPP-coated urea could be used as a strategy to reduce nitrate loss by growers applying fertiliser to soils above a temperature of 20°C,
- An N-priming effect associated with the banded application of ammonia-based fertiliser may contribute substantial amounts of previously ‘chemically/microbially protected’ N to the soil mineral N supply,
- The N-priming effect is of significance only when ammonia-based fertiliser is banded into soil at temperatures of above 20°C, and
- Overhead irrigation may provide a more uniform release of mineralised N from soil organic matter over the growing season by avoiding more intense wet/dry cycles associated with flood irrigation.

This research provides growers with information on how the supply of soil and fertiliser N can be better synchronised with crop demand. Better synchronisation of supply and demand will reduce fertiliser use, improve N use efficiency and help sustain productive and environmentally resilient cropping systems.

Future research should aim to:

- Determine the threshold concentration of ammonium and soil temperature within the fertiliser band responsible for displacing SOM from organo-mineral complexes.
- Repeat N use efficiency trials using ^{15}N potassium nitrate, to reduce the fixation of $^{15}NH_4^+$ and the dilution of plant-available ^{15}N by displaced, microbially labile SOM.
- Confirm ‘N-priming’ and the early activity of cotton root proliferation and decay cycles is responsible for the low recovery of ^{15}N in harvested cotton plants fertilised with ^{15}N-labelled urea.

This project was supported by funding from the Australian Government Department of Agriculture and Water Resources as part of its Rural R&D for Profit Program, the Cotton Research and Development Corporation (CRDC), and the Centre for Agricultural Engineering (CAE) at the University of Southern Queensland.

Abbreviations and glossary

CLP	Experimental site at Pittsworth, Queensland (season 2016-2017).
DAF	Days after fertiliser applied.
DMPP	Urea (46% N) treated with 3,4-dimethyl pyrazole phosphate.
DOC	Dissolved organic carbon; organic carbon content of a 1:20 soil water extract filtered <0.45µm
DON	Dissolved organic nitrogen; organic nitrogen content of a 1:20 soil water extract filtered <0.45µm
DIN	dissolved inorganic nitrogen; total inorganic nitrogen (nitrate, nitrite and ammonium) content of a 1:20 soil:water extract filtered <0.45µm and mixed with an equal volume of 4M KCl to preserve N species in 2M KCl
Ext K	Hydrochloric acid-extractable potassium in soil
IR	Infrared
NAS	Experimental sites at Jondaryan, Queensland seasons 2016-2017 and 2017-2018 (INT: intensive site, SAT: satellite site).
NOx	Nitrate extracted from soil or soil water extracts in the presence of nitrite.
SOM	Soil organic matter
TDN	Total dissolved nitrogen; total nitrogen content of a 1:20 soil water extract filtered <0.45µm
Soil 2M KCl N	Total inorganic nitrogen in a soil KCl extract (2M); total inorganic nitrogen (nitrate, nitrite and ammonium) content of a 1:10 soil:KCl extract
TKN	Total Kjeldahl nitrogen; a standard soil chemistry procedure using wet oxidation to volatilise simple organic N and ammonium N compounds to NH_4-N.
UV_{224}	Ultra violet light absorbance at 224 nm, the wavelength of light absorbed by conjugated N-O bonds
$UV_{253.7}$	Ultra violet light absorbance at 253.7 nm, the wavelength of light absorbed by heterocyclic C-C and carbonyl bonds
WE	Water extract; 1:20 soil:water extract
$SUVA_{224}$	Specific UV absorbance at 224nm; UV_{224} divided by TDN indicates the ratio of simple N-O containing compounds in TDN samples
$SUVA_{253.7}$	Specific UV absorbance at 253.7 nm; $UV_{253.7}$ divided by DOC indicates the ratio of heterocyclic organic compounds and carbonyl bonds in DOC samples

1 Project rationale and objectives

Rationale

The severity of dry-wet cycles between rainfall or irrigation events regulates the microbial processes of nitrogen (N) immobilisation and mineralisation, and the conversion of fertiliser-derived ammonium (NH_4^+) to nitrate (NO_3^-). Substantial research has been undertaken on the leaching of NO_3^- in deep drainage (e.g., Silburn et al., 2013), the contribution of surface and groundwater, and N applied through fertigation to nitrous oxide (N_2O) emissions (e.g., Macdonald et al., 2016; Antille, 2018), the role of rotation crops in improving the profitability of cotton and reducing N leaching losses (e.g., Hulugalle and Scott, 2008), on N use efficiency (NUE) in cotton (e.g., Rochester 2011, 2012), and on enhanced efficiency N fertilisers (e.g., Chen et al., 2008). Fewer studies have explored how the microbial processes of N immobilisation, dissimilatory NO_3^- reduction, nitrification and denitrification are affected by the extent of soil drying between irrigation or rainfall events.

Nitrate in alkaline cotton soils is preferentially immobilised by soil microbes if sufficient organic substrate is available (Rochester et al., 1992). However, the availability of organic carbon (C) and nitrate change rapidly when soils are subjected to drying and re-wetting (Mikha et al., 2005). Dissolved organic nitrogen (DON) is a large, potentially available substrate for soil microbes and is susceptible to leaching, but studies on N cycling in soil rarely monitor this fraction (Jones and Willett 2006). Standard laboratory procedures including soil drying and sieving may also profoundly change the availability of organic C, inorganic N and DON (Franzluebbers, 1999), inducing microbial flushes of nitrate (Mian et al., 2008). The application of nitrogenous fertilisers to the soil also changes these dynamics, with high concentrations of nitrate inducing soil bacteria to aerobically reduce nitrate to nitrite (Roco et al., 2016). These studies highlight that change in soil moisture, aerobicity, fertiliser N supply, temperature and organic C, and microbial activity in the field regulate the dynamics of the N cycle in soil (Banerjee et al. 2016). A better understanding of the microbial and chemical dynamics affecting N supply to irrigated cotton crops was therefore needed and was the focus of field studies in this research.

To better understand these dynamics, rapid methods of chemical analysis of field soil samples are required. In a recent research project (SRA NCA012 2013-2014), an established method for quantifying aquatic humic substances was adapted for quantifying soil humic substances. The sensitivity of the technique for monitoring differences in the concentration of humified and more readily available dissolved organic C (DOC) in soils with and without organic amendment was validated by imposing dry-wet cycles on soil samples (Pittaway and Eberhard 2014). Preliminary total dissolved N data indicate this method may be equally as sensitive for monitoring the impact of dry-wet cycles on the mineralisation of soil organic N. The technique is rapid and suitable for soil samples in the field state, with results adjusted later for soil water content. In a recent soil leaching column study using this novel method, high applications of muriate of potash fertiliser inhibited the nitrification of ammonia-based fertilisers in soil (Pittaway et al., 2015), and ammonia-based fertilisers significantly increased the rate of leaching of DOC above that of unfertilised controls (Pittaway et al., 2018).

DON has been used as a surrogate for DOC in soil leachate studies (Jones and Willett 2006), indicating the application of ammonia-based fertilisers to soil may also increase the leaching of DON. The novel and rapid soil N testing methods were applied to field samples in this project, and are the focus of a controlled environment leaching study in this research.

Objectives

The original project objectives were to:

1. Investigate how nitrogen (N) fertiliser formulations; namely: urea and DMPP-treated urea, and wet-dry cycles affect within-season patterns of soil N supply,

2. Identify how well a rapid soil test based on water extraction and measurement of dissolved organic N (DON) can inform predictions of soil mineralisable N, and

3. Suggest how currently available N management DSSs can be improved by improved knowledge of within-season patterns of soil N supply.

After examination of the field experimental data collected over two cotton seasons, further objectives were developed and a leaching column study was conducted to meet these additional objectives:

4. Identify if ammonia-based fertiliser application enhances the release of dissolved organic matter (DOM, which includes DOC and DON) by comparing the effects of ammonium- vs nitrate-based fertilisers on total dissolved N (TDN) and inorganic N concentrations in leachate.

5. Understand the degree to which high concentrations of DOM in soil water extracts interfere with the KCl extraction method for soil mineral N and the persulfate digestion method for TDN. The 2M KCl extraction precipitates colloidal DOM which must be removed prior to flow injection analysis, and high DOM in solution interferes with the hydrazine reaction and persulfate digestion, under-estimating nitrate-N and TDN respectively.

References

Adriaenssens, L., Estarellas, C., Vargas Jentzsch, A., Martinez Belmonte, M., Matile, S., Ballester, P. (2013). Quantification of nitrate-π interactions and selective transport of nitrate using calix[4]pyrroles with two aromatic walls. *Journal of the American Chemical Society, 135*(22): 8324-8330.

Angus, J. F., van Herwaarden, A. F., Fischer, R. A., Howe, G. N., Heenan, D. P. (1998). The source of mineral nitrogen for cereals in south-eastern Australia. *Australian Journal of Agricultural Research, 49*: 511-522.

Antille, D. L. (2018). Evaluation of fertigation applied to furrow and overhead irrigated cotton grown in a black Vertosol in Southern Queensland, Australia. *Applied Engineering in Agriculture, 34*(1): 197-211.

Antille, D. L., Nguyen-Ky, T., Aikins, K. A., Hussein, M. A. H., Singh, S., Luhaib, A. A. A., Singh, A. (2018). Evaluation of NEXEN™ stabilized nitrogen applied to overhead irrigated cotton (*Gossypium hirsutum* L.). ASABE Paper No.: 1800252. St. Joseph, MI.: ASABE. DOI: 10.13031/aim.201800252.

Banerjee, S., Helgason, B., Wang, L., Winsley, T., Ferrari, B., Siciliano, S. (2016). Legacy effects of soil moisture on microbial community structure and N_2O emissions. *Soil Biology and Biochemistry, 95*: 40-50.

Bennett, J., Marchuk, A., Marchuk, S. (2016). An alternative index to the exchangeable sodium percentage for an explanation of dispersion occurring in soils. *Soil Research, 54*: 949–957.

Bremner, J. M. (1960). Determination of nitrogen in soil by the Kjeldahl method. *The Journal of Agricultural Science, 55*(1): 11-33.

Catchpoole, V. R., Weier, K. L. (1980). Water pretreatment helps during extraction of mineral-N from a clay soil. *Communications in Soil Science and Plant Analysis, 11*(4): 327-333.

Chen, D., Suter, H., Islam, A., Edis, R., Freney, J., Walker, C. (2008). Prospects of improving efficiency of fertiliser nitrogen in Australian agriculture: a review of enhanced efficiency fertilisers. *Australian Journal of Soil Research, 46*: 289-301.

Chen, R., Senbayram, M., Blagodatsky, S., Myachina, O., Dittert, K., Lin, X., Blagodatskaya, E., Kuzyakov, Y. (2014). Soil C and N availability determine the priming effect: microbial N mining and stoichiometric decomposition theories. *Global Change Biology, 20*(7): 2356-2367.

Colwell, J. D. (1963). The estimation of the phosphorus fertilizer requirements of wheat in southern New South Wales by soil analysis. *Australian Journal of Experimental Agriculture, 3*(10): 190-197.

Curtin, D., Beare, M. H., Lehto, K., Tregurtha, C., Qiu, W., Tregurtha, R., Peterson, M. (2017). Rapid assays to predict nitrogen mineralization capacity of agricultural soils. *Soil Science Society of America Journal, 81*(4): 979-991.

Franzluebbers, A. (1999). Potential C and N mineralization and microbial biomass from intact and increasingly disturbed soils of varying texture. *Soil Biology and Biochemistry, 31*: 1083-1090.

Gregorich, E. G., Beare, M. H., Stoklas, U., St-Georges, P. (2003). Biodegradability of soluble organic matter in maize-cropped soils. *Geoderma, 113*(3-4): 237-252.

Hullugalle, N., Scott, F. (2008). A review of the changes in soil quality and profitability accomplished by sowing rotation crops after cotton in Australian Vertosols from 1970 to 2006. *Australian Journal of Soil Research, 46*: 173-190.

Jones, D., Willett, V. (2006). Experimental evaluation of methods to quantify dissolved organic nitrogen (DON) and dissolved organic carbon (DOC) in soil. *Soil Biology and Biochemistry, 38*: 991-999.

Lei T., Gu Q. Q., Guo X. H., Ma J. J., Zhang Y., Sun X. H. (2018). Urease activity and urea hydrolysis rate under coupling effects of moisture content, temperature, and nitrogen application rate. *International Journal of Agricultural and Biological Engineering* 11(2): 132–138.

Macdonald, B., Chang, Y., Warneke, S. (2016). Potential contributions of surface and ground water to nitrous oxide emissions from irrigated cotton production systems. *Agricultural Water Management, 168*: 78-84.

Maher, W., Krikowa, F., Wruck, D., Louie, H., Nguyen, T., Huang, W. (2002). Determination of total phosphorus and nitrogen in turbid waters by oxidation with alkaline potassium peroxodisulfate and low pressure microwave digestion, autoclave heating or the use of closed vessels in a hot water bath: comparison with Kjeldahl digestion. *Analytica Chimica Acta, 463*: 283-293.

Maie, N., Knicker, H., Watanabe, A., Kimura, M. (2006). Heterocyclic N in the highly humified humic acids extracted from the subsoil of paddy fields and surface ando soils. *Organic Geochemistry, 37*(1): 12-19.

Mian, I., Riaz, M., Cresser, M. (2008). What controls the nitrate flush when air-dried soils are rewetted? *Chemistry and Ecology, 24*: 259-267.

Mikha, M., Rice, C., Milliken, G. (2005). Carbon and nitrogen mineralization as affected by drying and wetting cycles. *Soil Biology and Biochemistry, 37*: 339-347.

Pittaway, P. A., Melland, A. R., Antille, D. L., Marchuk, S. (2018). Dissolved organic carbon in leachate after application of granular and liquid N-P-K fertilizers to a sugarcane soil. *Journal of Environmental Quality, 47*: 522-529.

Pittaway, P., Eberhard, F. (2014). A UV absorbance test for measuring humified organic carbon in soil. *Proceedings of the Australian Society for Sugar Cane Technologists, 36*: 229-235.

Pittaway, P., Melland, A., Celotto, G., Dowie, J., Shannon, G., Di Bella, L. (2015). Fate of granular versus liquid fertilizers applied to soil leaching columns. *Proceedings of the Australian Society for Sugar Cane Technologists, 37*: 84-90.

Qiu, Q., Wu, L., Ouyang, Z., Li, B., Xu, Y., Wu, S., Gregorich. E. (2016) Priming effects of maize residue and urea N on SOM changes with time. *Applied Soil Ecology*, 100: 65-74

Rayment, G.E., Lyons, D.J. (2011). *Soil chemical methods – Australasia*. CSIRO Publishing, Melbourne.

Rochester, I. J. (2011). Assessing internal crop nitrogen use efficiency in high-yielding irrigated cotton. *Nutrient Cycling in Agroecosystems, 90*: 147-156.

Rochester, I. J. (2012). Using seed nitrogen concentration to estimate crop N use-efficiency in high-yielding irrigated cotton. *Field Crops Research, 127*: 140-145.

Rochester, I., Constable, G., MacLeod, D. (1992). Preferential nitrate immobilization in alkaline soils. *Australian Journal of Soil Science, 30*: 737-49.

Roco, C., Bergaust, L., Shapleigh, J., Yavitt, J. (2016) Reduction of nitrate to nitrite by microbes under oxic conditions. *Soil Biology and Biochemistry, 100*: 1-8.

Scheer, C., Grace, P., De Antoni Migliorati, M., Antille, D. (2017). Fertiliser nitrogen use efficiency in irrigated cotton systems. Proc. of the Australian Cotton Research Conference 'SciCott2017: Cotton science delivering impact'. 5-7 Sept. 2017, CSIRO Discovery Centre, Canberra, ACT, Australia: The Association of Australian Cotton Scientists.

Silburn, D., Foley, J., Biggs, A., Montgomery, J., Gunawardena, T. (2013). The Australian cotton industry and four decades of deep drainage research: a review. *Crop and Pasture Science, 64*: 1049-1075.

Wagai, R., Mayer, L., Kitayama, K., Shirato, Y. (2013). Association of organic matter with iron and aluminium across a range of soils determined via selective dissolution techniques coupled with dissolved nitrogen analysis. *Biogeochemistry, 112*: 95-109.

Walkley, A., Black, I. A. (1934). An examination of the degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil Science, 37*(1): 29-38.

2 Method and project locations

2.1 Field studies

To investigate how N fertiliser formulations and wet-dry cycles affect within-season patterns of soil N supply (Objective 1) two field experiments were conducted over two cotton seasons. The field experiments were conducted on Black Vertosol soils in overhead irrigated paddocks on commercial cotton farms in the Darling Downs of south-east Queensland (Table 1). Results from this research are considered applicable to irrigated cropping production systems on black Vertosols, which rely on the use of synthetic nitrogen fertilisers.

Inorganic N (nitrate, nitrite, ammonium) and organic N (as part of total dissolved N) pools in soil were measured in soil samples collected after key wetting events and at key crop stages throughout two cotton seasons. In the 2016/17 season, soil sampling was timed to match the key crop growth phases of emergence, first flower, peak bloom, open boll and post-harvest. This sequence of sampling monitors the N supply available at key crop growth phases, but misses the critical phase for root development and proliferation (before early flowering), and the key microbial conversion of urea to ammonium carbonate, ammonium carbonate to ammonium, ammonium to nitrate. In the 2017/18 season the sampling frequency before early flowering and within 60 days after fertiliser application was increased (Figure 1). Cool, dry, overcast days during the 2017/18 seedling emergence and establishment phase, substantially slowed crop development. In the 2017/18 season fertiliser application was delayed until 30 days after emergence, whereas in 2016/17 fertiliser application coincided with emergence (Figure 1). Warmer conditions in early December 2017 ensured sufficient number of plants per meter to take the crop to harvest, justifying the application of fertiliser.

The fate of N fertiliser after application to soil is determined in part by soil microbes, and by plant root proliferation and decay cycles. Root exclusion tubes were installed to reduce the impact of root activity on the concentration and transformation of urea fertiliser applied to the soil (Angus et al., 1998). Five root exclusion tubes (300 mm deep, 50 mm diameter) were placed along the fertiliser band within four replicated plots per treatment. Fertiliser was applied after crop emergence in bands that represented farmer practice (4 bands per row at NAS and 2 bands per row at CLP). Fertiliser treatments were: unfertilised control, farmer's rate urea, and farmer's rate urea treated with 3,4-dimethyl pyrazole phosphate (DMPP), commercially known as ENTEC® (46% N; Table 1). Two tubes from each of four replicate field plots (6 m length x 3 or 4 cotton rows depending on site) were combined to produce one composite sample per plot at each sampling time per site. At selected sampling times soil from immediately outside the tubes along the fertiliser band was also sampled to compare 'with root' and 'without root' N pools. Yield (lint + seed) and cottonseed N (in 2017/18; Rochester, 2011) were determined at harvest. At planting and harvest, soil characterisation samples were collected to 90 cm depth at intervals of 15 cm.

Field-moist soil samples were measured for N fractions as per below, and air-dried and ground (<2mm) samples were analysed for $pH_{1:5}$, $EC_{1:5}$, CEC and texture in-house, and for chloride, organic C (Walkley and Black, 1934), available P (Colwell, 1963), soil HCl-extractable K, total Kjeldahl N, field capacity (⅓ bar) and permanent wilting point (15 bar) at a commercial laboratory. Exchangeable dispersive percentage (EDP, Bennett et al. 2016) and exchangeable sodium percentage (ESP) were calculated. Samples dried to 105°C were analysed for soil moisture and bulk density.

A comparison of within-season N supply in soil within and immediately outside root exclusion tubes was done using standard soil KCl-extractable mineral N species for the 2016/17 season and TKN for the 2017/18 season, due to concerns that the KCl extraction method underestimated the NO_x component.

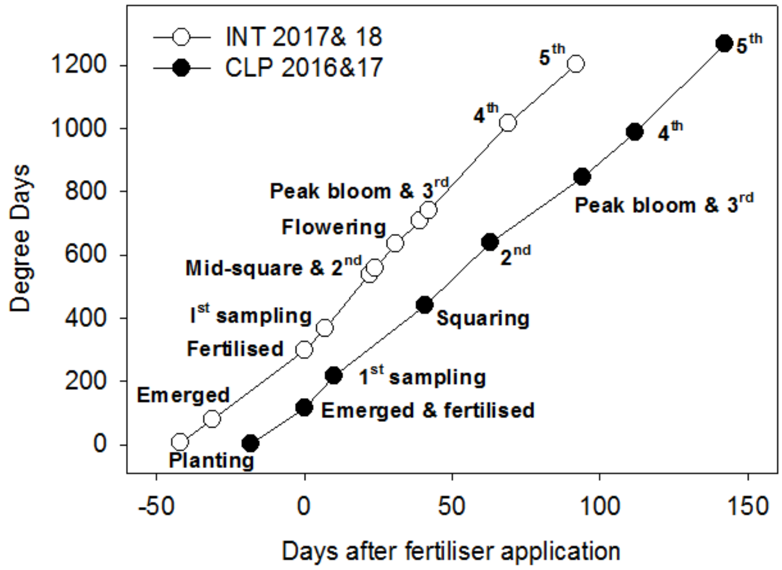


Figure 1. Sampling times and key crop events for the two seasons at the CLP (solid circles) and NAS INT (open circles) sites shown as a function of degree days (base temperature: 14.7°C), and days after fertiliser application.

2.2 Leaching column study

Air-dried soil sampled from unfertilised plots at the 2017/18 INT site was mixed 1:1 by volume with a washed sand (99% quartz sand, Southern Pacific Sands, Australia) to improve the uniformity of drainage. Ninety mm diameter Poly Vinyl Chloride (PVC) pipe cut to 300 mm lengths, fitted with Whatman grade 4 filter paper supported by wire mesh caps fixed to the base of each cylinder, filled with the soil mix were dumped from a height of 70 mm to consolidate to a depth of 200 mm. Soil columns were capillary-watered with de-ionised water for two days, and drained for 24 hr (field capacity). Fertiliser (urea, DMPP-coated urea, or calcium nitrate) was placed in a furrow across the diameter of each cylinder at a rate equivalent to 150 kg ha^{-1} N. An unfertilised control was included. A 2 cm band of soil was placed over each furrow before the start of the trial, which was located in an air-conditioned room set at 25°C. A minimum/maximum thermometer was used to monitor air temperature.

The mass of each soil column was recorded at the start of the trial and immediately prior to each leaching event to calculate the mean gravimetric water loss. The mean volume of water required to bring the columns to field capacity and to produce a leachate volume of about 125 mL, was poured onto a filter paper placed on the surface of the soil. Leaching was repeated at three, 10, 22, and 44 days after fertilizer application (DAF), to determine how the different fertilizer formulations affected the capacity of the soil to immobilise and/or to hydrolyse fertiliser N, and to displace DOC. After the 44 DAF leaching event, the soils in the leaching columns were spread onto aluminium trays to air-dry under ambient temperature conditions.

Leachate collected at each leaching event was analysed for pH, electrical conductivity, UV absorbance, TDN and DOC (oxidative combustion Infra-red method, please refer to Section 2.3 for details), $SUVA_{224}$ and $SUVA_{253.7}$, 2M-KCl-extractable NH_4-N and NO_3-N (Cu-Cd column flow injection analysis, Rayment and Lyons 2011). Air-dried soil removed from the cylinders at the end of the trial was analysed for 2M KCl-extractable NH_4-N and NO_3-N (Cu-Cd column flow injection analysis, Rayment and Lyons 2011), Total Kjeldahl N, and soluble and exchangeable cations (1 M ammonium chloride with pre-treatment for soluble salts, Rayment and Lyons 2011).

2.3 Methods for measuring fractions of soil nitrogen

A soil water extraction method of Pittaway and Eberhard (2014) and a modified Catchpoole and Weieir (1980) 2M KCl-extractable mineral N species method were used to examine the suitability of the soil water extract rapid test method to monitor seasonal change in potentially mineralisable and mineral N pools in soil (Objective 2), All field soil samples were stored at 4°C and were analysed in the field-moist state for all TDN, KCl-extractable mineral N species and total Kjeldahl N (TKN) analyses. Soil moisture content was measured to report results on an oven-dry soil basis (mg kg^{-1}). The nitrogen and carbon fractions measured, and methods used, were;

- Dissolved inorganic N (DIN); The sum of WE ammonium-N and WE NO_x-N measured as 2M KCl-extractable ammonium-N and NO_x-N (nitrate-N in the presence of nitrite) of a 1:20 soil:water extract filtered <0.45µm (Pittaway and Eberhard, 2014) and measured after mixing an equal volume of the soil water extract with 4M KCl (modified from Catchpoole and Weier, 1980).
- Total dissolved nitrogen (TDN; organic N and mineral N) of a 1:20 soil:water extract filtered <0.45µm was measured in-house (oxidative combustion infra-red method; Pittaway and Eberhard 2014) for the soil characterisation and the first two soil samplings of 2016/17, with an out-sourced persulfate digestion – colorimetric flow injection method (Maher et al., 2002) used thereafter.
- Soil 2M KCl N; 2M KCl-extractable ammonium-N and NO_x (nitrate-N in the presence of nitrite) of a 1:10 soil:water slurry (Rayment and Lyons, 2011) using the hydrazine (2016/17) and Cu-Cd (2017/18) flow injection methods.
- Total Kjeldahl N (TKN); air-dried and ground samples (0-30 cm) collected inside and outside root exclusion tubes in 2017/18 were measured for TKN using standard methods (Bremner, 1960).
- SUVA224; SUVA253.7 UV absorbance at 224 nm and 253.7 nm of the filtered 1:20 soil water extract standardised for the concentration of TDN and DOC, respectively. The N-O conjugative bond absorbs at 224 nm, and heterocyclic (aromatic) C-C and carbonyl bonds absorb at 253.7 nm.
- Dissolved organic carbon (DOC) of the filtered 1:20 soil water extract (Pittaway and Eberhard, 2014) was measured using an oxidative combustion infra-red method for the soil characterisation and soil sampled during the 2016/17 cotton growing season. During the 2017/18 season UV absorbance at 253.7 nm was used as a surrogate for heterocyclic dissolved organic carbon to reduce the expense of out-sourced analytical testing.

Table 1. Experimental sites.

Season	Site name	Location	Northing, Easting	Paddock history, farmer's fertiliser regime	Experimental treatments
2016/17	NAS	Jondaryan, Darling Downs, SE Queensland	27°26'51.9"S, 151°33'08.9"E	Pre-plant fertiliser 125 kg/ha N as 31.4: 4.2: 3.5: 5.2 NPKS plus 0.31 Zn blend that includes 23.6% urea-N and 7.8% ammonium-N applied 12th Sept 2016. Mid-crop fertiliser 40 kg/ha N as GranAmm applied in early Jan 2017. Fertiliser applied in 25 cm bands. Cotton planted 14th Oct 2016.	Post-emergence fertiliser 125 kg/ha N as urea or DMPP urea applied on 30th Oct 2016 in 25 cm bands plus a zero fertiliser control treatment. No mid-crop fertiliser applied.
2016/17	CLP	Pittsworth, Darling Downs, SE Queensland	27°49'58.1"S, 151°31'33.3"E	Cotton rotated with corn. Feedlot manure applied at 8t/ha in winter 2016. Crushed bone applied at 8t/ha before the last corn crop. Corn stubble burnt in 2016 because too wet to mulch. Pre-plant fertiliser 140 kg/ha N as a blend of urea, ammonium sulphate, MAP, KCl and micronutrients applied 19th Aug 2016. Mid-crop fertiliser 60 kg/ha N as urea, 50kg/ha muriate of potash applied mid Dec 2016. Fertiliser applied in 50 cm bands. Cotton planted on 21st Oct 2016.	Post-emergence fertiliser 140 kg/ha N as urea or DMPP urea applied on 4th Nov 2016 in 50 cm bands plus a zero fertiliser control treatment. No mid-crop fertiliser applied.
2017/18	INT	Jondaryan, Darling Downs, SE Queensland	27°28'18.4"S, 151°35'29.4"E	Overhead irrigation for 30 years, cotton rotated with corn. 150 kg/ha N as urea applied in mid Oct 2017 in 25 cm bands. Cotton planted 1st Nov 2017.	Post-emergence fertiliser 150kg/ha N as urea or DMPP urea applied on 12th Dec 2017 in 25 cm bands plus a zero fertiliser control treatment. No mid-crop fertiliser applied.
2017/18	SAT	Jondaryan, Darling Downs, SE Queensland	27°28'31.3"S, 151°37'02.9"E	Conversion from furrow irrigation to overhead irrigation, cotton rotated with cotton. 150 kg/ha N as urea applied in mid Oct 2017 in 25 cm bands. Cotton planted 2nd Nov 2017.	Post-emergence fertiliser 150kg/ha N as urea or DMPP urea applied on 13th Dec 2017 in 25 cm bands plus a zero fertiliser control treatment. No mid-crop fertiliser applied.

3 Project achievements

Cotton crop yield and weather

In the 2016-2017 season, between planting (middle of October 2016) and harvest (early May 2017), the CLP site received 116 mm more rainfall plus irrigation (450 mm rain, 398 mm irrigation, 848 mm total) than the NAS site (535 mm of rain, 197 mm of irrigation, 732 mm total). In the 2017-2018 at the NAS site, total rainfall between planting (early November 2017) and harvest (May 2018) was 175 mm, and irrigation was 230 mm at the INT site and 160 mm at the SAT site (405 mm and 335 mm total, respectively).

There were no significant differences (P>0.05) in cotton yield between fertiliser treatments, or between fertiliser treatments and the adjacent commercial crop in 2016-17 season at either site, but yield was significantly lower at the NAS site (Figure 2). Mean (±SD, n=4) treatment yields were 13.9 ±0.7 bales per ha at CLP (commercial crop: 12.3 ±0.21 bales per ha) and 6.5 ±0.56 bales per ha at NAS (commercial crop: 6.8 ±0.65 bales per ha).

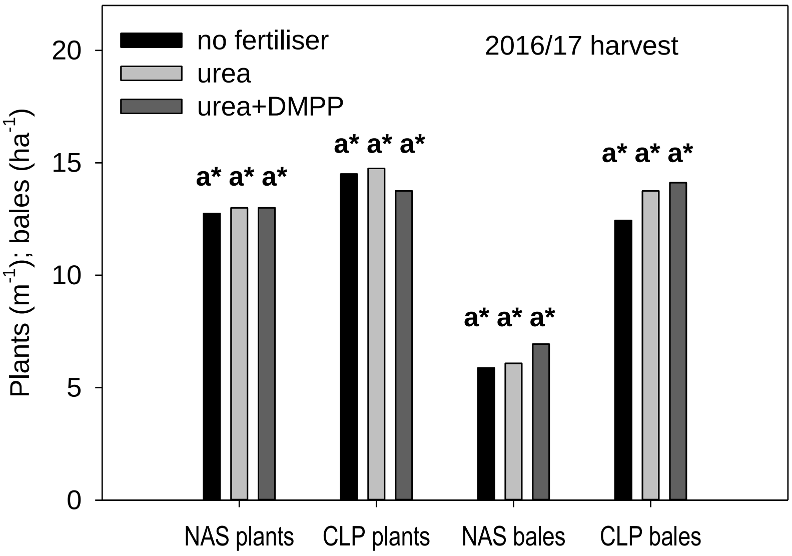


Figure 2. The effect of nitrogen fertiliser type on cotton yield observed in the 2016-2017 season at the CLP and NAS sites. Bars within each triplet with the same letter are not significantly different (P > 0.05). Asterisk indicates the small replicate number limited the power of the analysis of variance to confirm a significant difference where one may exist.

There were no significant differences (P>0.05) in cotton yield between fertiliser treatments, or between treatments and the adjacent commercial crop in 2017-18 season at the NAS sites, but yield was significantly lower at the SAT site (Figure 3). Mean (±SD, n=4) treatment yields were 13.1 ±1.04 bales per ha at INT (commercial crop: 12.3 ±0.36 bales per ha) and 8.6 ±0.34 bales per ha at SAT (commercial crop: 7.5 ±0.04 bales per ha). The agronomic efficiency (bales per kg N applied) was 0.07 ±0.02 and 0.08 ±0.02 bales per kg N applied as urea and DMPP-coated urea respectively (P>0.05).

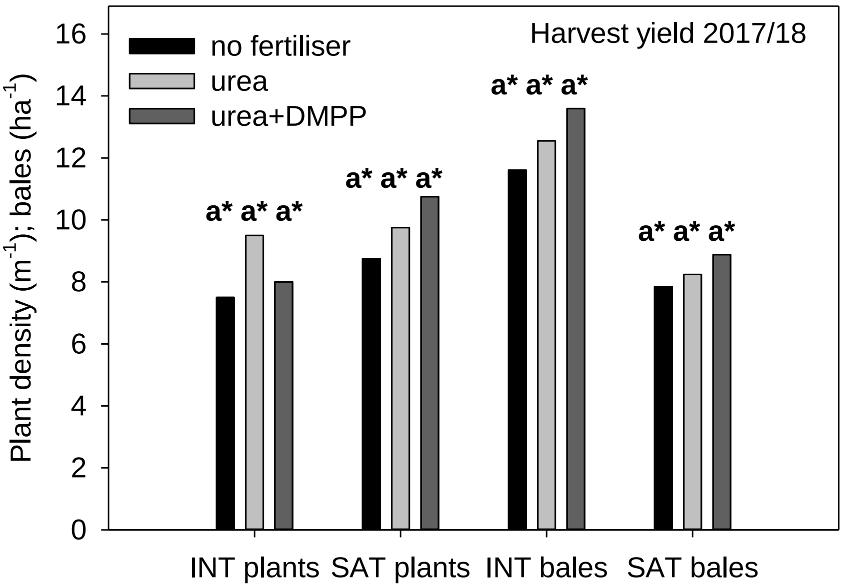


Figure 3. The effect of nitrogen fertiliser type on cotton yield observed in the 2017-2018 season at the NAS sites. Bars within each triplet with the same letter are not significantly different (P>0.05). Asterisk indicates the small replicate number limited the power of the analysis of variance to confirm a significant difference where one may exist.

Soil characteristics

All sites used for field experimentation were black Vertosols (Tables 2-3). Soil profile TDN concentrations in the four unfertilised plots used to characterise the background soil N supply prior to planting in 2016/17 were highly variable (Figure 4). At CLP, the TDN concentration was lower in the upper soil profile than at NAS and there was some evidence of an N bulge at 40-60 cm depth. Samples from 0-90 cm depth had between 58% and 75% clay contents across CLP and NAS sites. Table 4 shows the chemical and physical characterisations of unfertilised soil sampled 11th Nov 2017 at the NAS INT site and 12th Nov 2017 at the NAS SAT site, respectively.

Table 2. Chemical and physical characteristics of unfertilised soil sampled on 24th October 2016 at NAS.

Plot	Depth	Cl	SOC	Colwell P	Ext K	TKN	⅓ bar	15 bar	$pH_{1:5}$	$EC_{1:5}$	Exc Ca	Exc Mg	Exc Na	Exc K	CEC
Unit	**cm**	**mg/kg**	**%**	**mg/kg**	**meq/100g**	**%**	**%**	**%**	**-**	**dS/m**	**meq/100g**	**meq/100g**	**meq/100g**	**meq/100g**	**meq/100g**
2	0-15	26	0.93	33	1.274	0.078	54	37	9.36	0.31	12.06	11.99	2.37	0.61	11.67
2	15-30	59	0.90	6.3	0.588	0.051	71	42	9.65	0.42	10.23	14.41	4.18	0.34	16.81
2	30-45	119							9.72	0.55	8.51	14.70	5.37	0.29	21.04
2	45-60	259	0.62	4.2	0.577	0.040	82	45	9.70	0.74	7.44	15.08	6.58	0.38	24.94
2	60-75	539							9.64	0.97	6.98	16.08	8.31	0.47	28.80
2	75-90	867	0.44	25	0.654	0.025	85	49	9.64	1.21	5.81	15.43	9.14	0.49	32.36
6	0-15	18							9.36	0.29	12.44	12.14	2.48	0.69	11.94
6	15-30	43							9.53	0.40	11.06	14.47	4.78	0.50	18.15
6	30-45	122							9.48	0.55	9.53	15.16	6.42	0.49	22.96
6	45-60	322							9.49	0.77	10.91	20.17	9.88	0.64	26.41
6	60-75	619							9.55	1.00	7.38	14.82	8.70	0.50	30.34
6	75-90	977							9.49	1.30	7.43	15.85	10.07	0.58	32.37
8	0-15	32	1.03	40	1.834	0.075	61	37	9.21	0.31	13.33	12.14	2.24	1.01	11.33
8	15-30	75	0.92	6.0	0.973	0.050	75	44	9.50	0.42	10.98	13.30	3.86	0.47	16.13
8	30-45	167							9.48	0.61	9.89	14.06	5.17	0.50	20.15
8	45-60	289	0.71	9.5	1.095	0.046	72	45	9.49	0.75	9.16	14.87	6.74	0.54	24.25
8	60-75	489							9.54	0.92	8.54	15.24	8.10	0.59	27.69
8	75-90	664	0.85	39	1.209	0.021	84	51	9.53	1.07	8.11	15.76	9.42	0.66	30.57
10	0-15	7.3							9.25	0.31	13.90	13.51	2.63	0.76	11.55
10	15-30	30							9.53	0.42	11.78	13.58	4.26	0.52	16.76
10	30-45	146							9.49	0.60	10.85	14.59	5.74	0.51	20.72
10	45-60	411							9.39	0.81	9.78	15.64	7.16	0.55	24.30
10	60-75	664							9.35	1.13	8.71	15.35	8.06	0.61	27.40
10	75-90	754							9.43	1.17	9.01	14.79	8.32	0.65	28.18

Table 3. Chemical and physical characteristics of unfertilised soil sampled on 17th October 2016 at CLP.

Plot	Depth	Cl	SOC	Colwell P	Ext K	TKN	⅓ bar	15 bar	$pH_{1:5}$	$EC_{1:5}$	Exc Ca	Exc Mg	Exc Na	Exc K	CEC
Unit	cm	mg/kg	%	mg/kg	meq/100g	%	%	%	-	dS/m	meq/100 g	meq/100 g	meq/100 g	meq/100 g	meq/100 g
2	0-15	8.4	1.31	63	0.943	0.109	54	36	8.78	0.08	12.30	11.43	0.78	0.43	24.9
2	15-30	7.8	1.04	16	0.390	0.072	62	38	9.17	0.12	12.63	14.27	1.70	0.18	28.8
2	30-45	16							9.33	0.20	9.91	13.94	2.57	0.14	26.6
2	45-60	32	0.76	22	0.451	0.050	69	40	9.31	0.28	9.33	15.88	3.77	0.19	29.2
2	60-75	45							9.44	0.32	7.87	15.76	4.29	0.14	28.1
2	75-90	98	0.77	24	0.350	0.041	76	41	9.55	0.42	7.30	15.97	4.62	0.15	28.0
6	0-15	7.1							8.42	0.09	13.26	13.00	0.56	0.47	27.3
6	15-30	15							8.90	0.10	12.51	14.95	1.21	0.20	28.9
6	30-45	26							8.90	0.17	11.55	16.28	1.72	0.24	29.8
6	45-60	33							9.11	0.20	10.75	17.60	2.48	0.21	31.0
6	60-75	46							9.33	0.26	9.04	16.96	2.89	0.16	29.1
6	75-90	56							9.46	0.36	8.70	17.18	3.14	0.20	29.2
8	0-15	11	1.54	85	1.213	0.115	60	38	8.30	0.09	13.97	13.51	0.60	0.61	28.7
8	15-30	18	1.06	30	0.532	0.080	62	38	8.90	0.10	12.95	14.12	1.18	0.25	28.5
8	30-45	34							9.12	0.14	11.25	14.66	1.84	0.20	27.9
8	45-60	46	0.83	38	0.355	0.055	65	40	9.27	0.16	10.22	14.97	2.38	0.16	27.7
8	60-75	65							9.18	0.25	10.13	17.17	2.98	0.25	30.5
8	75-90	108	1.07	49	0.584	0.050	67	41	9.24	0.29	9.39	18.45	3.53	0.27	31.6
10	0-15	12							7.96	0.09	13.27	12.46	0.62	0.54	26.9
10	15-30	15							8.81	0.09	11.24	12.22	1.23	0.23	24.9
10	30-45	23							8.85	0.15	11.41	14.52	2.24	0.31	28.5
10	45-60	31							9.05	0.18	9.84	14.12	2.81	0.18	27.0
10	60-75	41							9.14	0.22	8.83	14.61	3.40	0.19	27.0
10	75-90	54							9.27	0.28	9.18	15.69	3.92	0.18	29.0

Table 4. Chemical and physical characteristics of unfertilised soil sampled 11th Nov 2017 at the INT site and 12th Nov 2017 at the SAT site.

Plot	**Site**	**Depth**	**$pH_{1:5}$**	**$EC_{1:5}$**	**Exc Ca**	**Exc Mg**	**Exc Na**	**Exc K**	**EDP**	**ESP**	**CEC**
Unit	**(NAS)**	**cm**	**-**	**dS/m**	**meq/100g**	**meq/100g**	**meq/100 g**	**meq/100 g**	**%**	**%**	**meq/100 g**
2	INT	**0-15**	8.5	0.18	16.10	17.66	0.17	0.69	3.49	0.49	34.62
2	INT	**15-30**	8.5	0.20	15.23	17.97	0.20	0.29	3.06	0.61	33.70
6	INT	**0-15**	8.5	0.15	15.71	16.75	0.15	0.59	3.30	0.44	33.20
6	INT	**15-30**	8.7	0.19	13.48	15.38	0.17	0.24	2.99	0.58	29.27
8	INT	**0-15**	8.8	0.16	18.45	17.98	0.20	0.65	3.29	0.53	37.28
8	INT	**15-30**	8.4	0.17	17.88	14.26	0.20	0.34	2.82	0.62	32.68
10	INT	**0-15**	7.8	0.38	19.65	13.14	0.17	0.79	3.27	0.51	33.76
10	INT	**15-30**	7.7	0.39	19.80	14.26	0.20	0.68	3.16	0.57	34.93
2	SAT	**0-15**	7.8	0.46	18.96	16.68	0.17	0.92	3.54	0.45	36.73
2	SAT	**15-30**	8.1	0.40	18.73	15.52	0.21	0.52	3.08	0.61	34.98
6	SAT	**0-15**	7.8	0.45	18.70	15.92	0.17	0.86	3.47	0.47	35.64
6	SAT	**15-30**	8.1	0.44	19.74	16.83	0.23	0.62	3.21	0.62	37.42
8	SAT	**0-15**	8.1	0.42	18.50	14.17	0.15	0.82	3.37	0.44	33.64
8	SAT	**15-30**	8.4	0.42	19.32	13.99	0.22	0.55	3.07	0.65	34.08
10	SAT	**0-15**	8.2	0.38	19.12	15.64	0.17	0.74	3.28	0.49	35.68
10	SAT	**15-30**	8.4	0.38	19.44	14.77	0.22	0.55	3.07	0.63	34.98

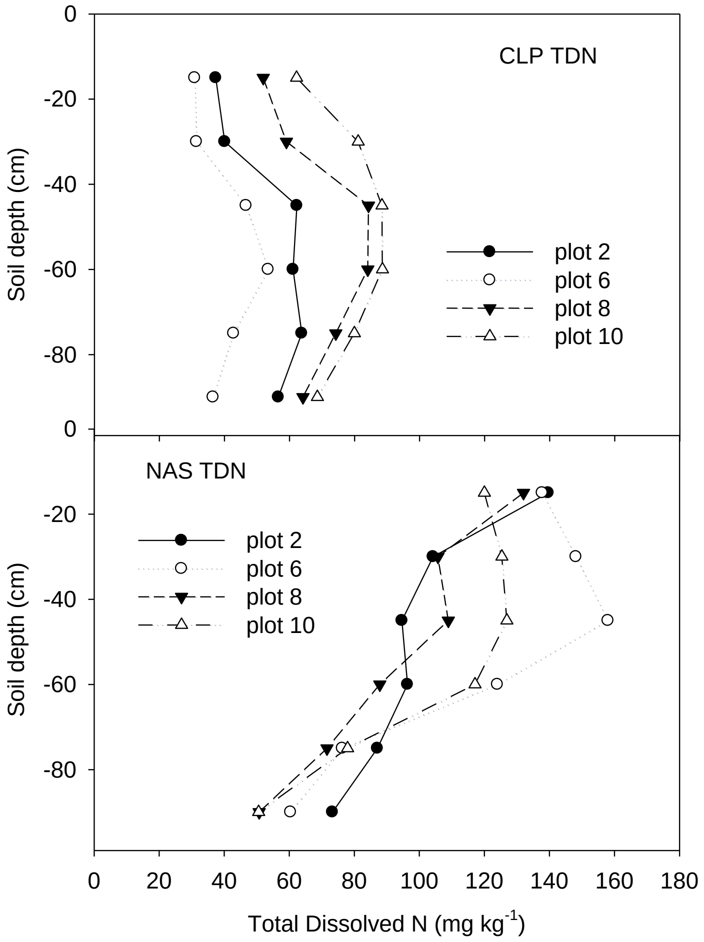


Figure 4. Total dissolved N (TDN) to depth in unfertilised plots at CLP (Pittsworth) and NAS (Jondaryan) in the 2016-2017 season.

The sites selected at the Jondaryan (NAS) property in 20017/18 were again on black Vertosol soil. The INT site had a 30 year history of overhead irrigation, and had been sown to cotton after a corn and winter fallow rotation. The SAT site had recently been converted from furrow to overhead irrigation, and had been sown to cotton after cotton (Figure 5). The INT site had a dedicated irrigator, whereas the irrigator at the SAT site was shared between the cotton crop and an adjacent corn crop. Irrigation at the SAT site was less frequent and higher volume than at the INT site.

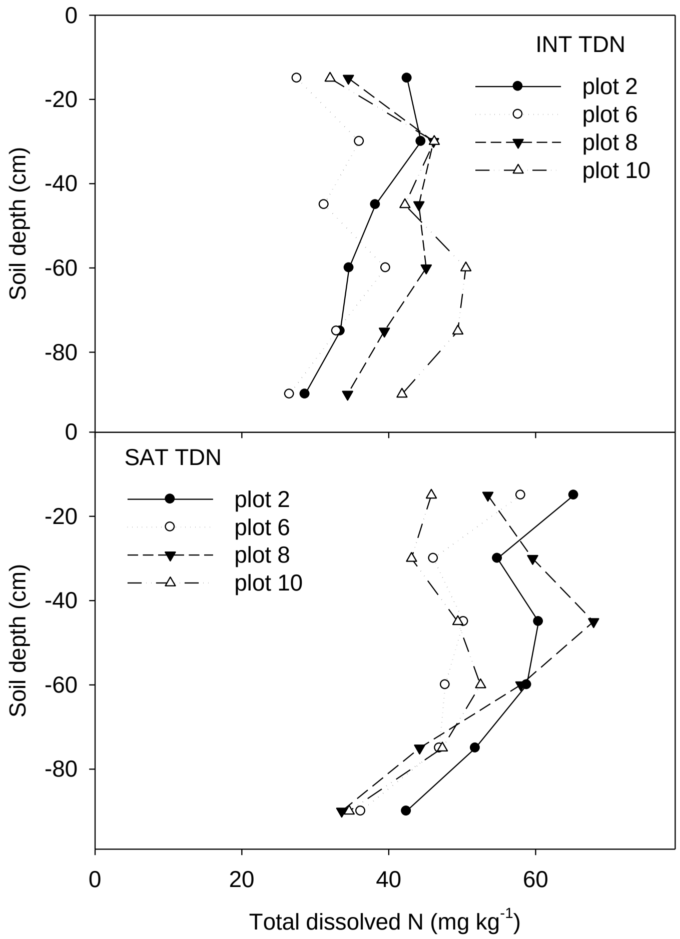


Figure 5. Total dissolved N (TDN) to depth in unfertilised plots for two sites (INT and SAT) at Jondaryan in the 2017-2018 season.

Objective 1: Soil Nitrogen Supply

Key Messages:

- *Background soil N mineralisation rates were low and uniform throughout the cotton season,*
- *Cotton plants take up N from within the fertiliser band, well before flowering.*
- *DMPP inhibits the conversion of ammonium carbonate to ammonium, as well as inhibiting nitrification.*
- *The much slower rate of release of urea from DMPP-coated granules may explain why field trials with DMPP show a significant reduction in GHG emissions, but no yield improvement.*
- *High concentrations of ammonium hydrolysed from banded urea displace SOM from organo-mineral exchange sites in soil, adding extra N (N-priming) to the soil nitrogen supply.*
- *Ammonium N hydrolysed from banded urea, 'fixed' to soil mineral exchange sites was not released until 100 days after fertiliser application in the 2016/17 season.*

NITROGEN SUPPLY OVER THE GROWING SEASON

In the 2016/17 season, the N supplied by urea was greatest within the first 100 days (up to peak bloom (Figure 6). After 100 DAF the TDN concentration within the urea-fertilised tubes at CLP was significantly lower, indicating nitrate losses to leaching. Data for nitrate concentrations are not as statistically significant, as the number of treatment replicates was much lower (four for 2M KCl mineral N analyses, 24 for TDN). Leaching losses were also evident at NAS, with TDN concentrations significantly lower in soil from the unfertilised (control) and DMPP-coated urea tubes by 152 DAF, and in the urea-fertilised tubes by 97 DAF. Nitrate concentrations were consistently two to three times higher than ammonium concentrations in urea treatments. Ammonium concentrations remained higher at CLP, in soil fertilised with DMPP-coated urea. The highest concentration in TDN was recorded at CLP at 10 DAF for the urea and DMPP-coated urea treatments, but was not evident in the 10 DAF ammonium or nitrate mineral N concentrations. A smaller TDN spike was evident in the DMPP-coated urea treatment at NAS, again with no corresponding peak in ammonium or nitrate concentrations. Peaks in N recorded in published inorganic N fertiliser trials have been referred to as N-priming, and have been interpreted as an increase in the rate of mineralisation by soil microbes in response to a luxury mineral N supply (Chen et al., 2014, Qiu et al., 2016). Our results suggest this may not be the case, as the TDN peak occurred rapidly (10 DAF), and was not reflected in the mineral N pool. In the 2017/18 season more sampling was undertaken before 100 DAF to better understand the N-priming effect.

TDN concentrations in the unfertilised plots in the 2016/17 season were uniformly low at CLP over time (TDN in Figure 6). At the NAS site TDN was higher than at CLP (consistent with the higher background pool of N present in the soil profile; Figure 4), with a significant reduction in concentration over the season. Nitrate (in the presence of nitrite) concentrations best reflected the change in TDN in the unfertilised treatments at both sites, reflecting the background rate of microbial mineralisation. In a controlled environment study using the same unfertilised soil maintained at constant moisture (25°C, field capacity) with increasing temperature (Antille et al., 2018), the relationship between cumulative degree-days and soil mineral N (SMN) was (Equation 1):

$$SMN = 11.6 \times DD^{0.42} \text{ (P<0.05, R}^2\text{=0.98)} \qquad [1]$$

In our field study irrigation was a main source of water during the year, with few major rainfall events inducing wet/dry cycles, which are known to stimulate microbial mineralisation (Mikha et al., 2005). Fertiliser application in the 2017/18 season was delayed due to the slow and uneven emergence and early seedling growth at the SAT site. The air temperature had increased substantially by 42 days after planting (Figure 1), when fertiliser was applied at the same rate to both sites (150 kg ha^{-1} N). The TDN concentration was highest at 46 DAF for the urea-fertilised plots (Figure 7), with no evidence of the early 10 DAF TDN spike observed in the 2016/17 season. The first sampling at 7 and 8 DAF (INT and SAT respectively) may have been too early to detect this spike, and the 24 DAF sampling too late. The total inorganic N concentration at 24 and 46 DAF for the urea-fertilised plots exceeded the TDN concentration, suggesting N-priming had occurred. The more frequent sampling within 60 DAF in the 2017/18 season highlighted the capacity of DMPP to inhibit urease activity (Figure 7). DMPP significantly slowed the rate of release of TDN from urea, with a higher proportion of the mineral N remaining in the ammonium-N form. These results indicate DMPP inhibits urease as well as nitrification.

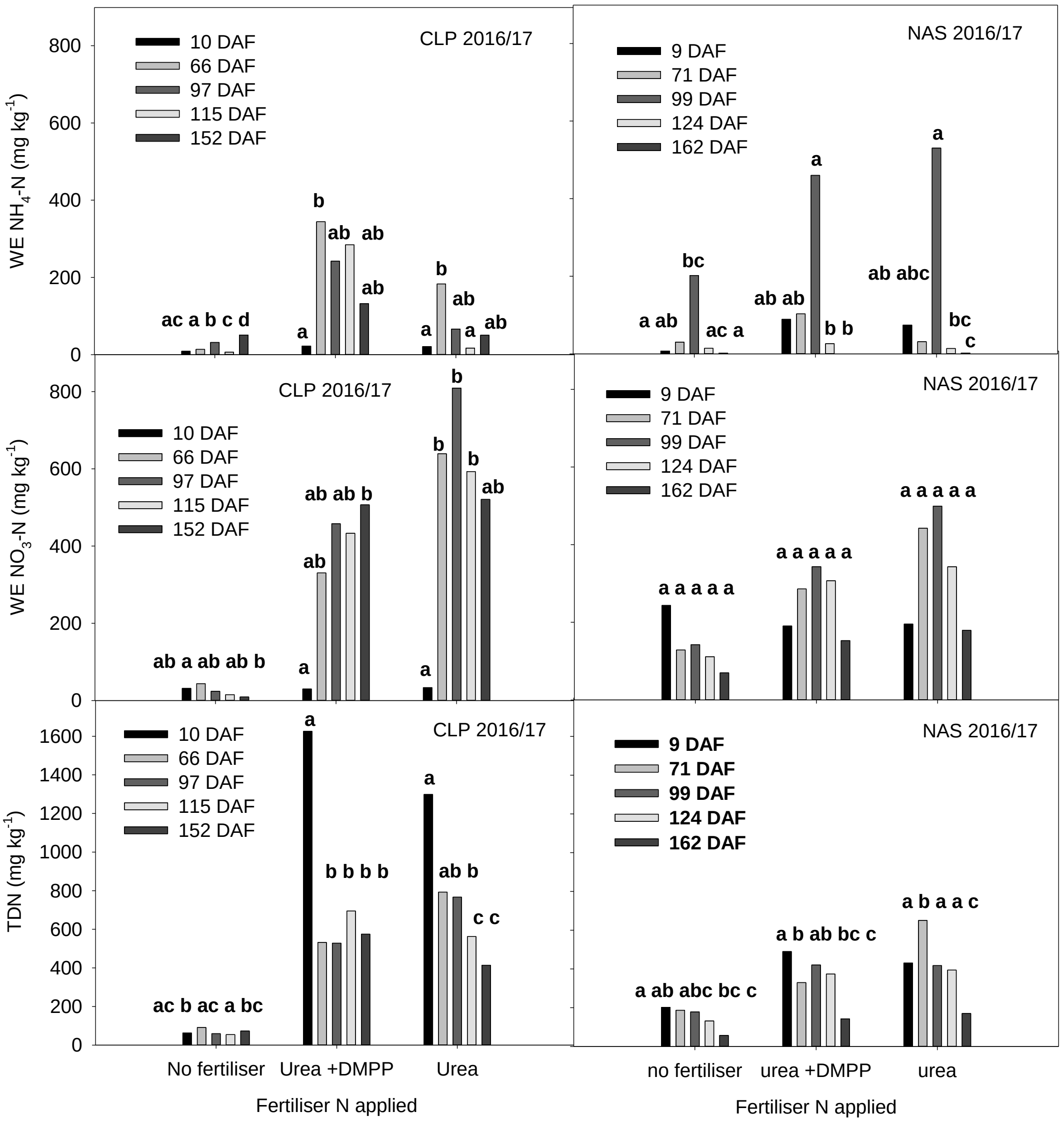


Figure 6. Soil water-extractable NH_4-N and NO_3-N (modified Catchpoole and Weier, 1980 method), and total dissolved N (TDN) in the 0-30 cm depth interval measured from root exclusion tubes at CLP and NAS in the 2016/17 season. Treatments were: zero fertiliser, farmer's rate urea, and farmer's rate urea with DMPP treatments. Different letters within each fertiliser treatment denote statistically different values at a 5% probability level.

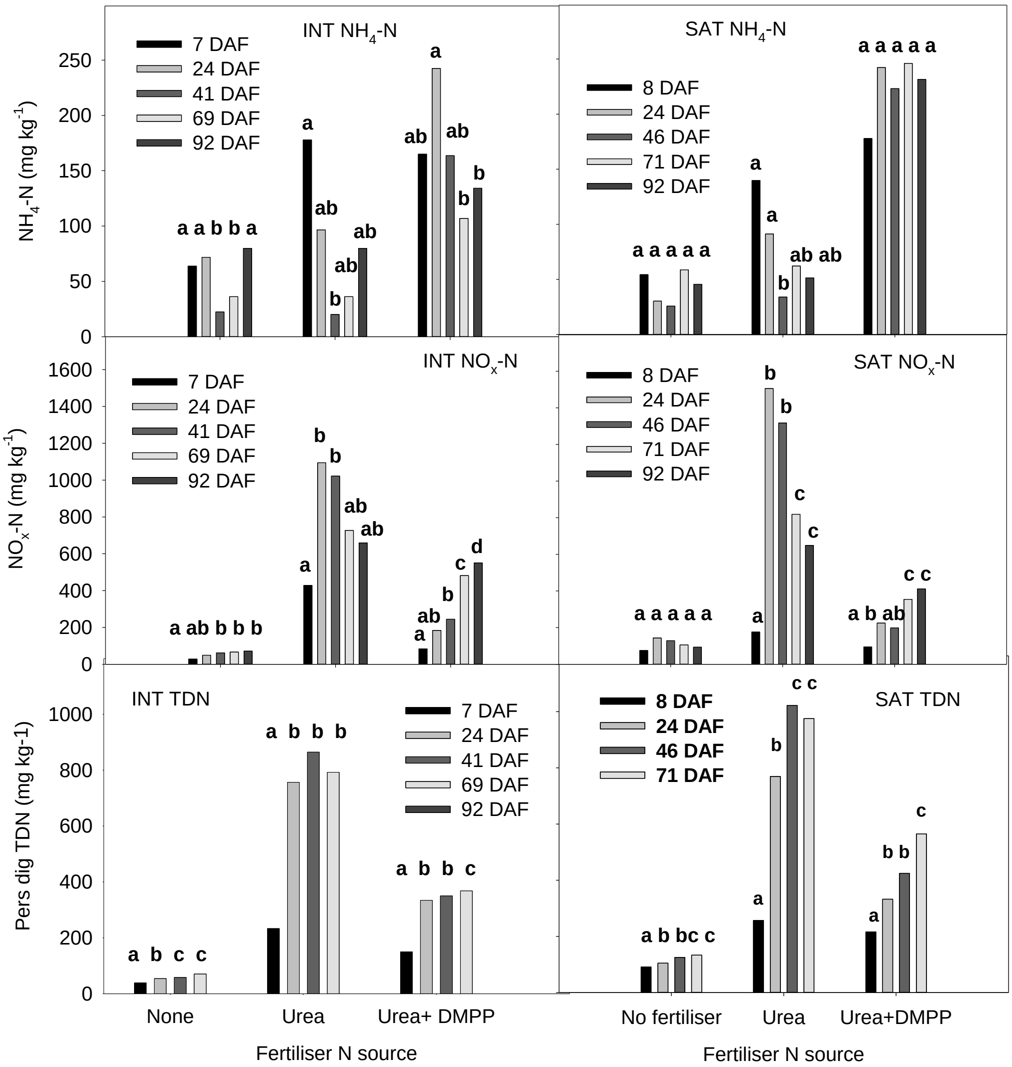


Figure 7. Soil water-extractable NH_4-N, NO_3-N in the presence of NO_2-N (NO_x), and total dissolved N (TDN) in the 0-30 cm depth interval measured from root exclusion tubes at INT and SAT in the 2017/18 season. Different letters within each fertiliser treatment denote statistically different values at a 5% probability level.

ROOT EXCLUSION TUBES INDICATE THE NITROGEN-EXTRACTING CAPACITY OF COTTON ROOTS

The soil KCl-extractable hydrazine reaction method (Rayment and Lyons, 2011) was used to compare the concentration of mineral N in the 2016/17 season, from soil sampled within and immediately outside root exclusion tubes. Soil samples were only analysed for sampling events later than 60 days after emergence. Across all treatments at both sites, the concentration of nitrate in soil sampled from within the root exclusion tubes was consistently greater than from immediately outside (soil outside was sampled along the fertiliser band; Figure 8). Results for nitrate for CLP were significantly greater within root exclusion tubes for all unfertilised treatments except 152 DAF, for all urea-fertilised tubes except 152 DAF, but only for 94 DAF for tubes fertilised with DMPP-coated urea. Nitrite data are not included as results were uniformly low for all sampling dates.

No data was available for the 94 DAF sampling at NAS as not all of the root exclusion tubes could be located. Soil sampled from within root exclusion tubes at NAS had significantly higher nitrate concentrations for all treatments sampled at 74 and 162 DAF, but results for the unfertilised samples at 124 DAF were not significantly different.

These results highlight cotton roots are capable of taking up mineral N from within fertiliser bands within the first 70 days after emergence. Results for ammonium-N were more variable than for nitrate, but coating urea with DMPP increased the proportion of mineral N that was in the ammonium form (Figure 8).

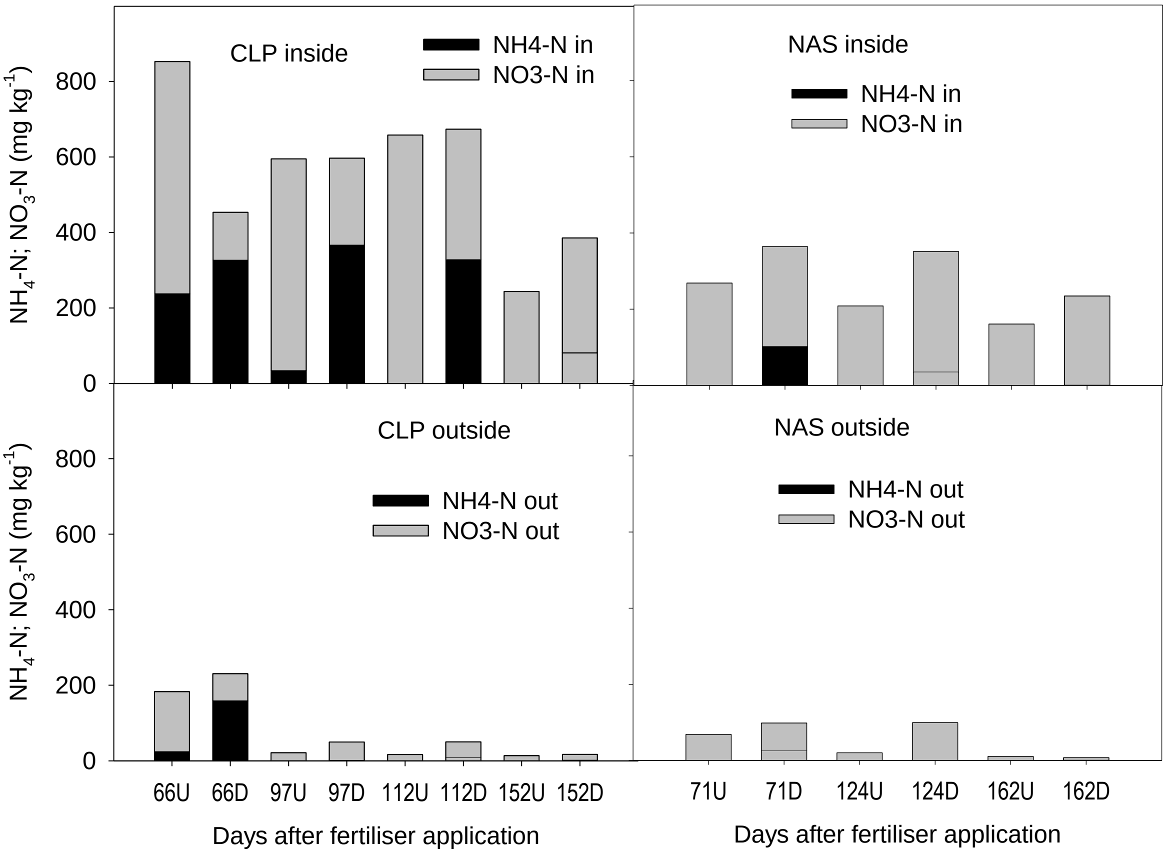


Figure 8. Soil 2M KCl-extractable NO_3-N and ammonium-N in soil sampled from within and immediately outside root exclusion tubes at the CLP and NAS sites over the 2016-17 season. 'C' refers to the unfertilised control, 'U' refers to urea, and 'D' refers to urea coated with the nitrification inhibitor DMPP.

Total Kjeldahl N (TKN) was used to compare the rate of recovery of N from soil within root exclusion tubes and from immediately outside the tubes in the 2017/18 season (Figure 9). At the INT site TKN concentrations within root exclusion tubes were significantly higher than immediately outside, for all sampling times and across all treatments. At this site, cotton roots were actively taking up N from a concentrated urea band within 50 days after sowing, and within 7 days of applying fertiliser. This was not the case at the SAT site, where statistically significant differences in TKN were only consistently recorded at 71 DAF. Soil preparation at this site prior to sowing had been extensive, converting tail drains and beds from furrow irrigation to overhead irrigation.

The SAT site was also irrigated less frequently at higher application rates, as the overhead irrigator was shared between the cotton crop and an adjacent corn crop. The lack of a significant difference in TKN concentrations from within and outside root exclusion tubes until 71 DAF (SAT in Figure 9) indicates seedling growth was less vigorous, resulting in the significantly lower yield (bales per hectare for SAT in Figure 3).

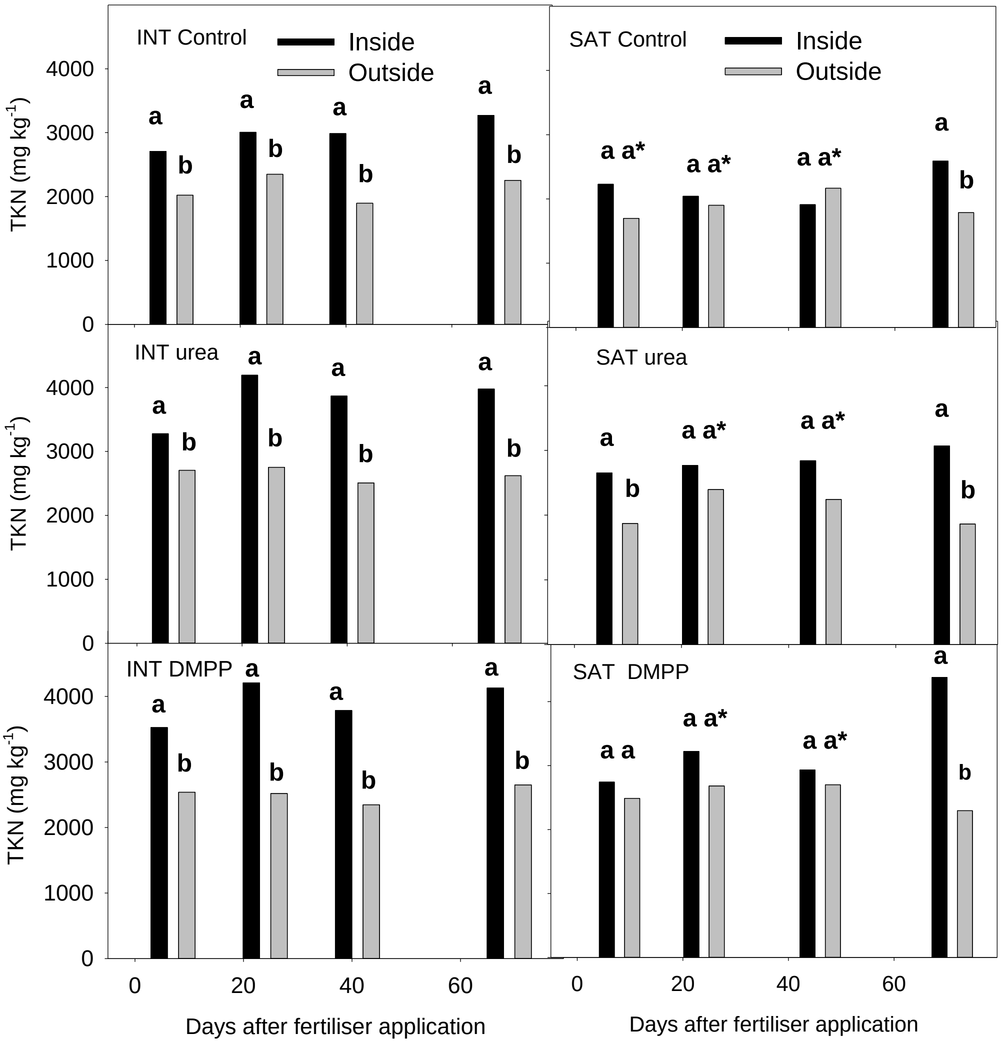


Figure 9. Total Kjeldahl N in soil recovered from within and immediately outside root exclusion tubes placed in the fertiliser row at the SAT site. Letters above the bars within each sampling time which are the same indicate treatments are not significantly different. Letters with an asterisk indicate the replicate size of four reduced the power of the analysis to confirm a significant difference where one may exist.

DMPP REDUCES THE SUPPLY OF FERTILISER N AVAILABLE TO COTTON PLANTS

The concentration of TDN in soil fertilised with DMPP-coated urea was consistently below the concentration for uncoated urea at both sites in 2016/17 (Figure 10), except for the spike in TDN at 10 DAF for DMPP-coated urea. After 100 DAF the DMPP-coated treatments were not significantly different from uncoated urea at NAS, and after 150 days TDN concentrations in the unfertilised and fertilised treatments were not significantly different. The spike in DMPP-coated urea at both sites was unexpected, as mineral N results indicate DMPP inhibits urease as well as nitrification (Figure 11).

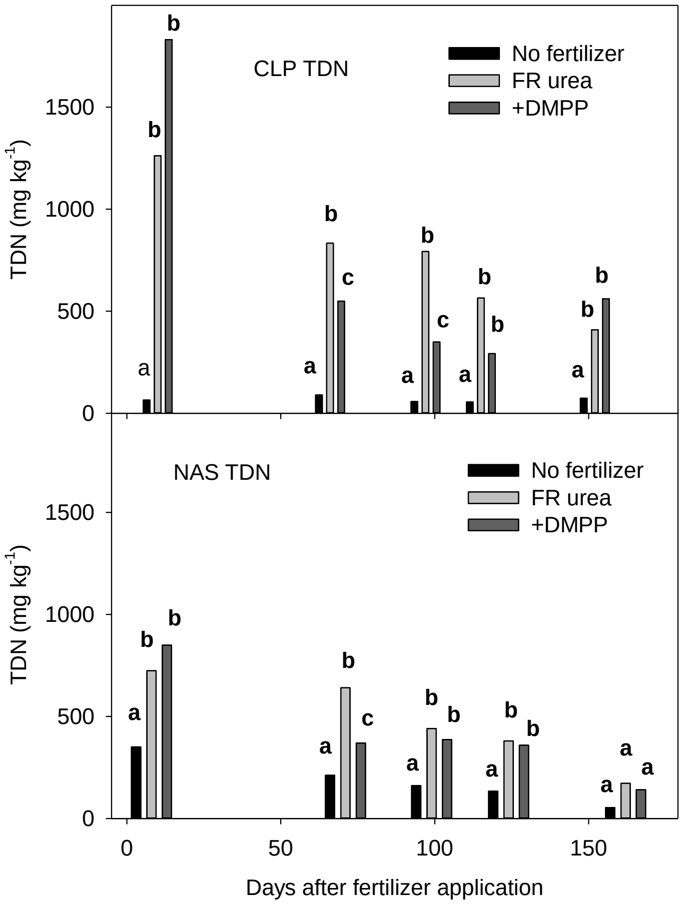


Figure 10. Total dissolved nitrogen (TDN) in soil sampled from within root exclusion tubes over the 2016/17 cotton growing season. Letters above the bars within each sampling time which are the same indicate treatments are not significantly different.

With the exception of 10 DAF and 152 DAF for CLP unfertilised treatments, TDN concentrations were similar to the combined ammonium and nitrate concentrations at CLP and NAS (Figure 11). The analytical method used for the first two TDN and DOC analyses during the 2016/17 cotton season was the oxidative combustion infra-red absorbance method (Pittaway and Eberhard 2014), which may include dissolved but not hydrolysed urea. In-house instrument malfunction after the second sampling resulted in both TDN and DOC analyses being out-sourced to a commercial laboratory using the same method for DOC, but a persulfate digestion, injection flow method (Maher et al., 2002) for TDN. The persulfate digestion method was also used for all 2017/18 TDN analyses. High concentrations of DOM in water extracts are known to interfere with persulfate digestion.

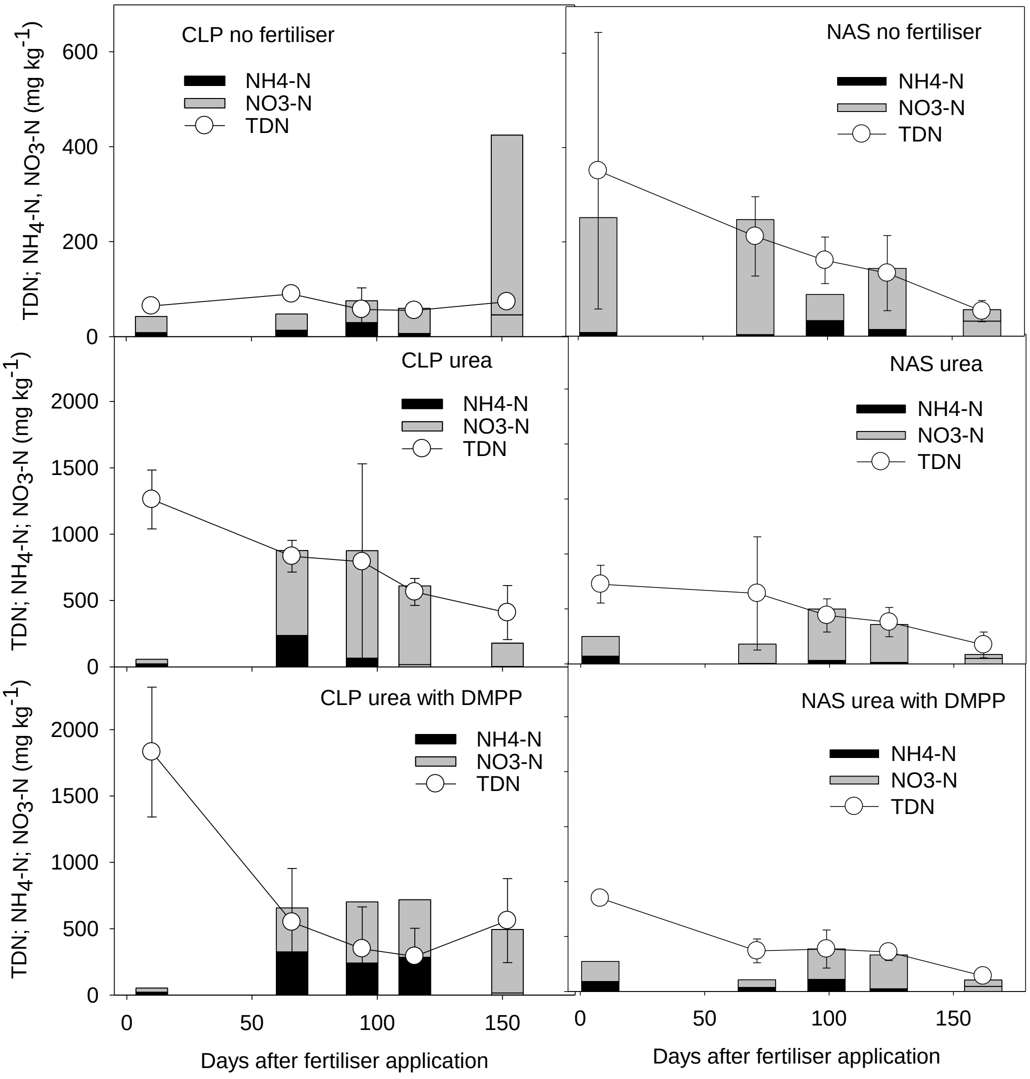


Figure 11. Soil water–extractable 2M KCl ammonium and nitrate, and total dissolved nitrogen (TDN) in soil sampled from within root exclusion tubes over the 2016/17 cotton growing season. Letters above the bars within each sampling time which are the same indicate treatments are not significantly different. The error bars are the 25% confidence limit of the analysis of variance on ranks or the standard error of the means.

More frequent sampling within 60 DAF during the 2017/18 cotton season highlighted the urease-inhibiting and nitrification-inhibiting properties of DMPP (Figure 12). The concentration of TDN in soil sampled from within root exclusion tubes fertilised with DMPP-coated urea was consistently lower than un-coated urea treatments from 8 DAF until 92 DAF. The TDN concentration in soil fertilised with DMPP-coated urea continued to rise until 69 DAF (Figure 7) when the concentration was still only 50 to 60% of the peak urea TDN concentration. This slow early release of mineral N with DMPP-coated urea, at a time when root growth and development is greatest, may explain why yield improvements have not been observed in field trials with this inhibitor. Root proliferation and development is greatest before peak bloom. After peak bloom, roots enter a maintenance phase, with the shoot and blooms the main sink for photosynthate and nutrients.

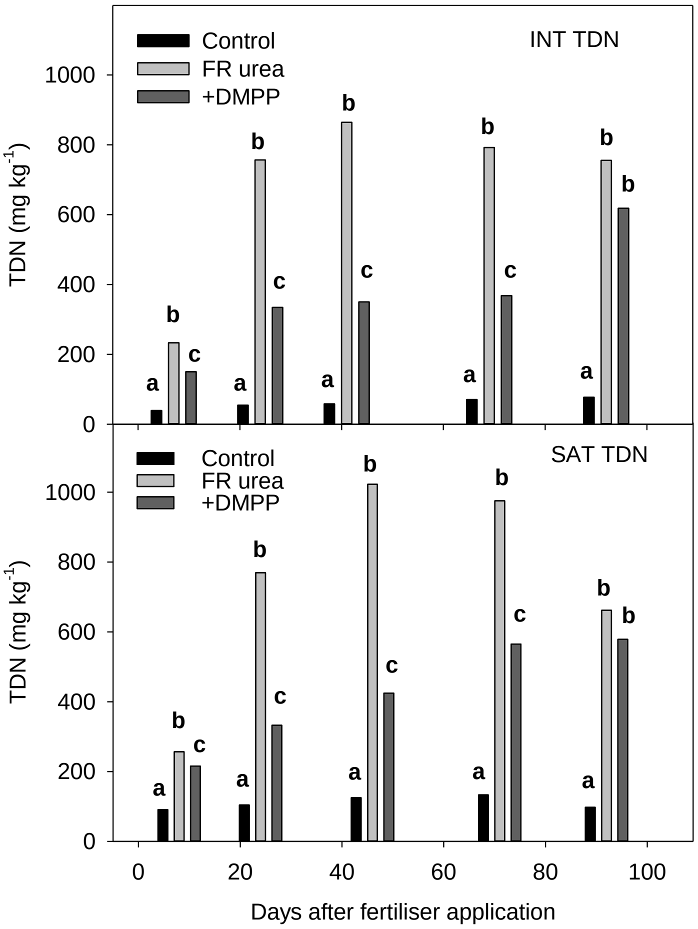


Figure 12. Total dissolved nitrogen (TDN) in soil sampled from within root exclusion tubes over the 2017/18 cotton growing season. Letters above the bars within each sampling time which are the same indicate treatments are not significantly different.

Over the 2017/18 season TDN concentrations were consistently within or close to the combined 2M KCl-extractable ammonium and nitrate concentrations (Figure 13). The much slower rise in TDN and mineral N concentration with DMPP-coated urea, and the higher concentration of ammonium N confirm DMPP inhibits both urease and nitrification. The lack of the spike in TDN observed in the 2016/17 season may reflect the different analytical methods used. The oxidative combustion method was developed for analysing DOC in potable and waste-water municipal supplies, and other than a requirement for filtering out particles exceeding 0.45 µm, is sufficiently robust for the analysis of highly turbid, coloured waters containing high concentrations of DOM. High concentrations of DOM interfere with the persulfate digestion method, and any colloidal particles must be removed before samples can be analysed using flow injection systems (Maher et al., 2002).

High concentrations of DOM also interfere with the hydrazine method used for 2M KCl species (Rayment and Lyons 2011). These differences in method may explain why a spike in TDN was observed a 10 DAF in the 2016/17 season when the oxidative combustion IR method was used, but not at the 7 or 24 DAF in the 2017/18 season when the persulfate digestion method was used.

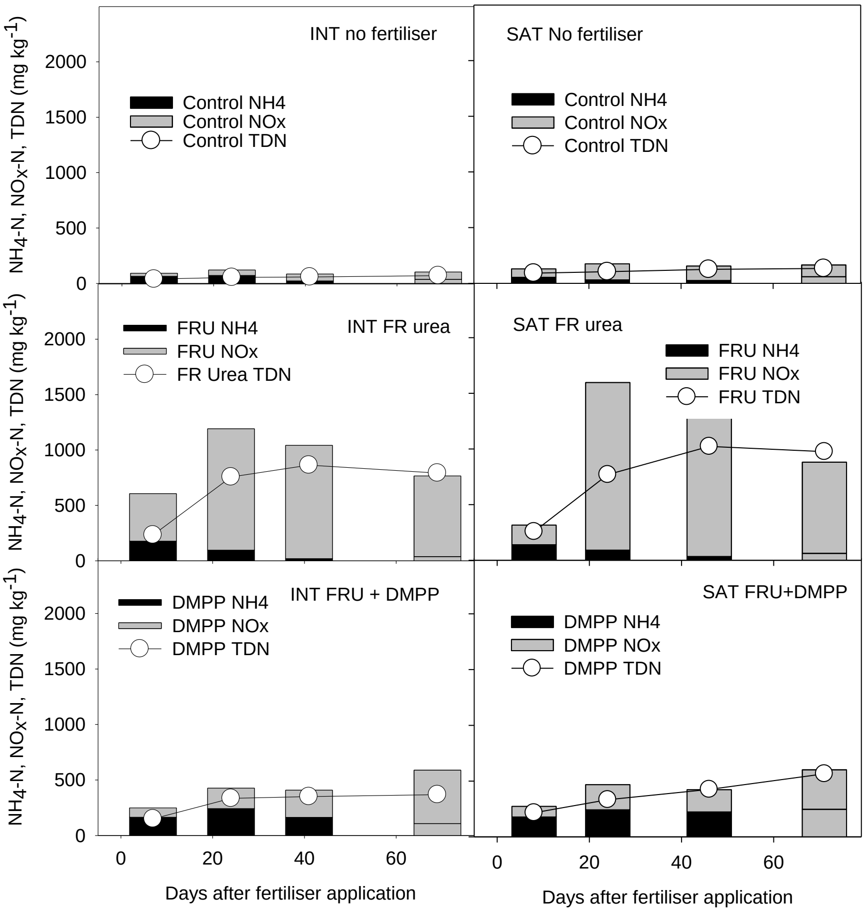


Figure 13. Soil water–extractable 2M KCl ammonium, nitrate in the presence of nitrite (NO_x), and total dissolved nitrogen (TDN) in soil sampled from within root exclusion tubes over the 2017/18 cotton growing season. Letters above the bars within each sampling time which are the same indicate treatments are not significantly different.

HIGH AMMONIUM-N DISPLACES SOIL ORGANIC MATTER FROM MINERAL EXCHANGE SITES

A significantly higher concentration of DOC, coinciding with the spike in TDN (Figure 11), was released into soil fertilised with urea within 10 DAF in the 2016/17 season (Figure 14). The highest DOC concentration was recorded at the site receiving the highest urea application (597 mg/kg N at CLP, 261 mg/kg N at NAS; Table 5), with concentrations in urea treatments at both sites significantly lower than unfertilised and DMPP-treatments by 60 DAF. A significant decline in DOC did not occur in DMPP-coated urea treatments until 152 DAF (Figure 14), consistent with the delayed increase in TDN (Figure 11).

Ammonium-N derived from urea has been implicated in displacing DOM from organo-mineral exchange sites in lighter soils where the cation exchange capacity is largely conferred by heterocyclic organic matter (Pittaway et al., 2018). Absorbance of the soil water extracts at 253.7 nm was used during our field trials to indicate the concentration of carbonyl and heterocyclic bonds in DOM. The reduction in $UV_{253.7}$ absorbance associated with the reduction in DOC indicates ammonium-N derived from urea fertiliser may also be displacing DOM from mineral exchange sites in black Vertosols.

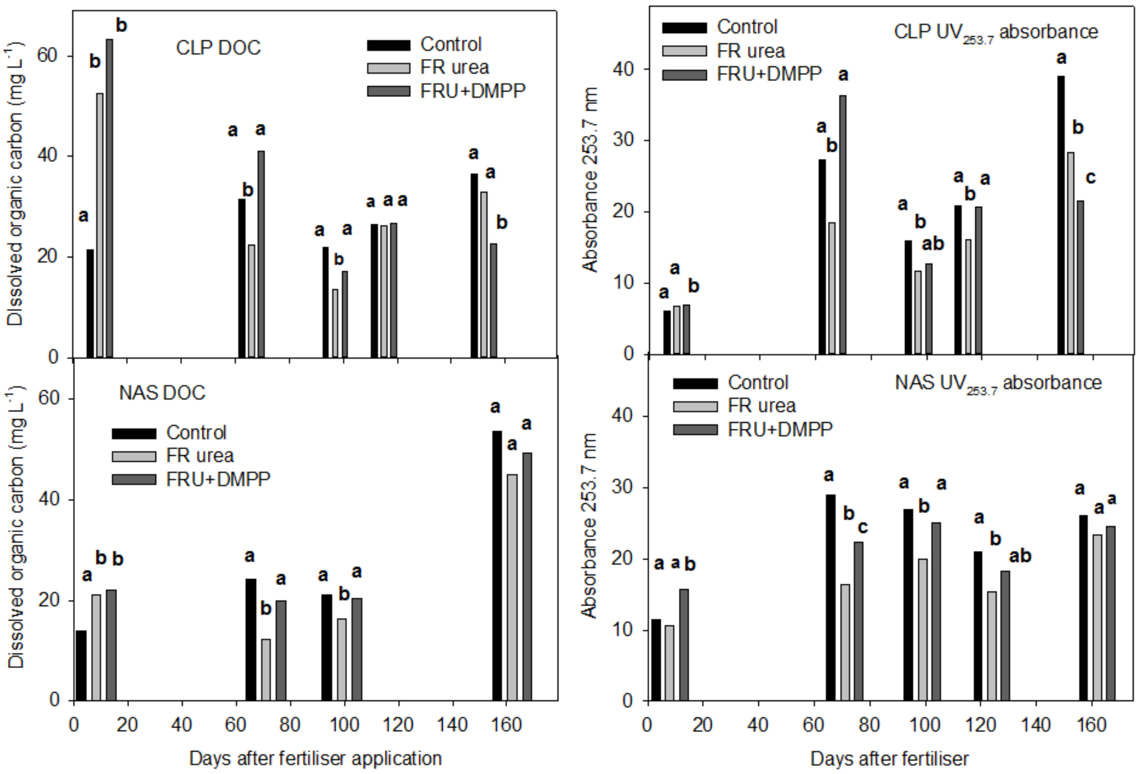


Figure 14. Dissolved organic carbon and UV$_{253.7}$ absorbance of soil water extracts sampled at CLP and NAS in the 2016/17 season for the urea, DMPP urea and control fertiliser treatments over time since fertiliser application. Letters above the bars within each sampling time which are the same indicate treatments are not significantly different.

Table 5. Fertiliser nitrogen (N) application rate at the NAS and CLP properties for the 2016/17 cotton growing season, and at INT in 2017/18. SAT mg/kg rate is in brackets.

Fertiliser N application rate	CLP 2016/17	NAS 2016/17	INT (SAT) 2017/18
N per root exclusion tube (mg/kg)	597	261	461 (455)
Number fertiliser bands in 100 m	200	400	267
N field application rate (kg ha^{-1})	142	129	147

In the 2017/18 season only TDN was monitored in the soil water extracts, with UV$_{253.7}$ absorbance used as a surrogate for DOC. As with the 2016/17 season, an increase in TDN was associated with a decrease in UV$_{253.7}$ absorbance (Figure 15). The loss in absorbance occurred rapidly (by 24 DAF), and was evident as a fading of the ochre-brown colour in unfertilised soil water extracts. The more rapid increase in TDN and loss of UV$_{253.7}$ absorbance over the 2017/18 season may reflect a more rapid rate of urea hydrolysis as an increase in soil temperature may have stimulated the biochemical production and activity of the microbial enzyme urease (Lei et al., 2018).

The significantly lower concentration of DOC in urea-treated soil after 60 and 90 DAF in the 2016/17 season and the significantly lower $UV_{253.7}$ absorbance after 24 DAF in the 2017/18 season indicate the initial release of DOC was lost to microbial mineralisation within root exclusion tubes or leaching below the depth of tubes (30 cm).

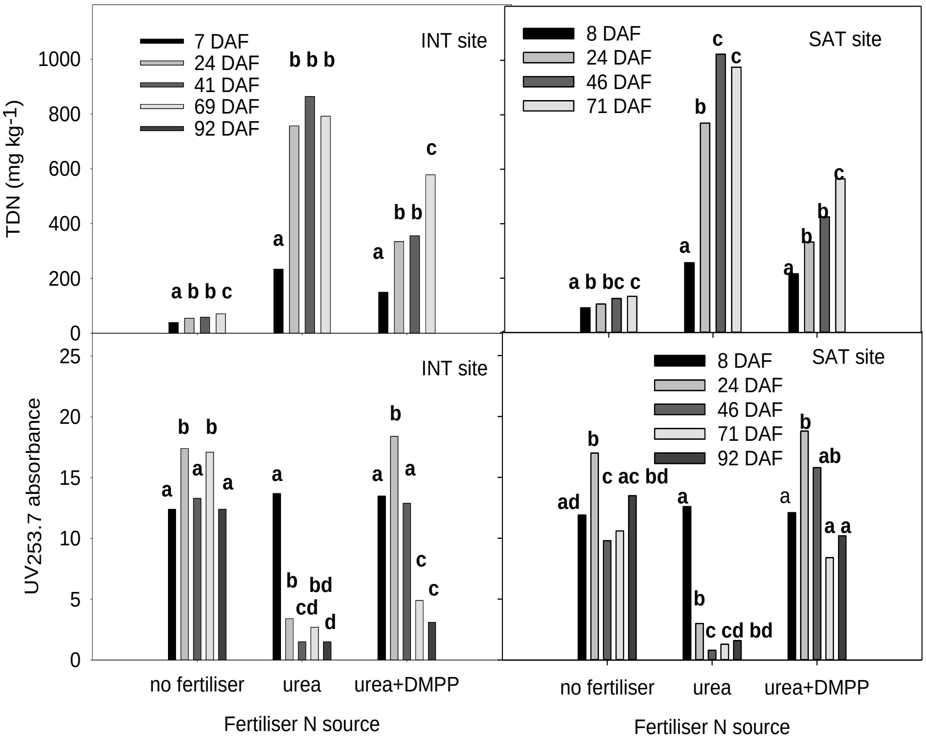


Figure 15. Total dissolved nitrogen (TDN) and $UV_{253.7}$ absorbance of filtered soil water extracts over the 2017/18 season at the INT and SAT sites at Jondaryan. Treatments were no fertiliser, urea, and DMPP-coated urea. The vertical bars are the sampling date (days after fertiliser application; DAF). Letters above the bars within each treatment which are the same, indicate absorbance readings are not significantly different.

DOC was measured in the last soil water extracts sampled at 92 DAF, to confirm the observed reduction in $UV_{253.7}$ absorbance was associated with a loss in DOM (Figure 16). The six replicates for each plot per treatment were pooled, to provide a composite sample for DOC and TDN analysis (x4 replicates per treatment only). Results for DOC were not significantly different, but results for specific UV absorbance at 253.7 nm ($UV_{253.7}$ absorbance divided by DOC concentration; $SUVA_{253.7}$) were significantly different. The heterocyclic (aromatic) composition of DOM was lowest in urea-fertilised soils, and next lowest in the DMPP-coated urea treatments. These results indicate the mechanism of N-priming with the application of concentrated ammonia-based fertilisers to black Vertosol soils may be the chemical displacement of DOM from organo-mineral complexes by ammonium (Pittaway et al., 2018). The composition of DOM includes microbially labile and recalcitrant compounds, with the more chemically complex heterocyclic compounds considered recalcitrant (Gregorich et al., 2003; Curtin et al., 2017). The rapid loss of these recalcitrant DOM compounds to leaching in our study, indicates the mechanism of N-priming induced by ammonia-based fertilisers may be chemical rather than microbial.

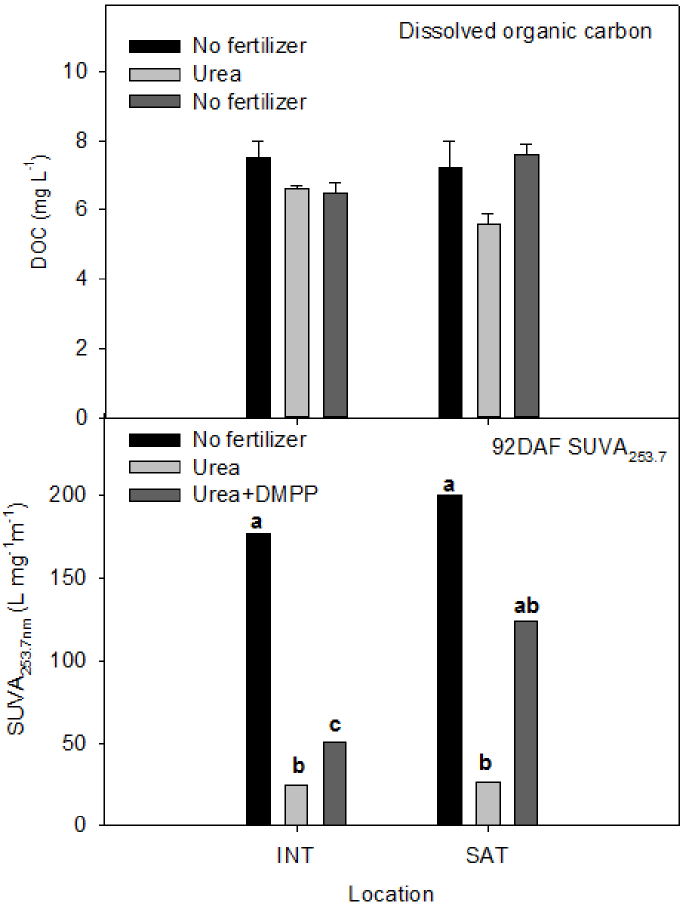


Figure 16. Dissolved organic carbon (DOC) and specific UV$_{253.7}$ absorbance (SUVA$_{253.7}$) of filtered soil water extracts in soil sampled towards the end of the 2017/18 season (92 DAF) at the INT and SAT sites at Jondaryan. Error bars on the DOC vertical bars (results were not significantly different) are the least significant means of the analysis of variance. Letters above the SUVA bars which are the same, indicate results are not significantly different.

AMMONIUM HYDROLYSED FROM BANDED UREA DISPLACES SOIL ORGANIC MATTER FROM MINERAL EXCHANGE SITES

'N-priming' is the term given to the increase in the supply of N measured in soil, which is above the actual concentration of mineral N fertiliser applied and background mineralisation (Chen et al., 2014, Lie et al., 2018). N-priming is often assumed to be an increase in microbial mineralisation in response to luxury mineral N. One advantage of sampling soil from within the confined zone of root exclusion tubes is precise mass balance calculations of the different N pools sampled from within the exclusion tubes over the growing season can be used to compare the supply of N from the different fertilisers and from the background (unfertilised) mineralisation of SOM. The sum of total N derived from urea and TDN or DIN derived from unfertilised soil (supplied N) was compared with TDN and DIN extracted over time in fertilised soil (recovered N). Recovered N was divided by supplied N, and expressed as a percentage. In 2016/17 DIN was calculated as the sum of WE NO3-N, NO2-N and NH4-N, and in 2017/18 as the sum of WE NOx-N and NH4-N. Recovered N was expressed as a percentage of supplied N (Figure 17).

The dotted lines in Figures 17 represent the total amount of N supplied by mineralisation (unfertilised plot data used), and by fertiliser application. Data points above the line indicate the ‘N-priming effect’, where fertiliser application induces excess ‘native soil N’ to be released. In both seasons the spike in recovered N in fertilised treatments occurred within the first 60 DAF (Figure 17), increasing soil TDN at CLP, INT and SAT to twice the supplied N concentration. The rise in TDN was much lower and slower at NAS, reflecting the lower fertiliser application rate (Table 5). The recovery of DIN and TDN from DMPP-coated urea treatments in 2017/18 did not rise above supplied N until 69 DAF (71 at SAT), whereas at CLP in 2016/17, TDN from DMPP treatments was almost 250% of supplied N within the first 10 DAF.

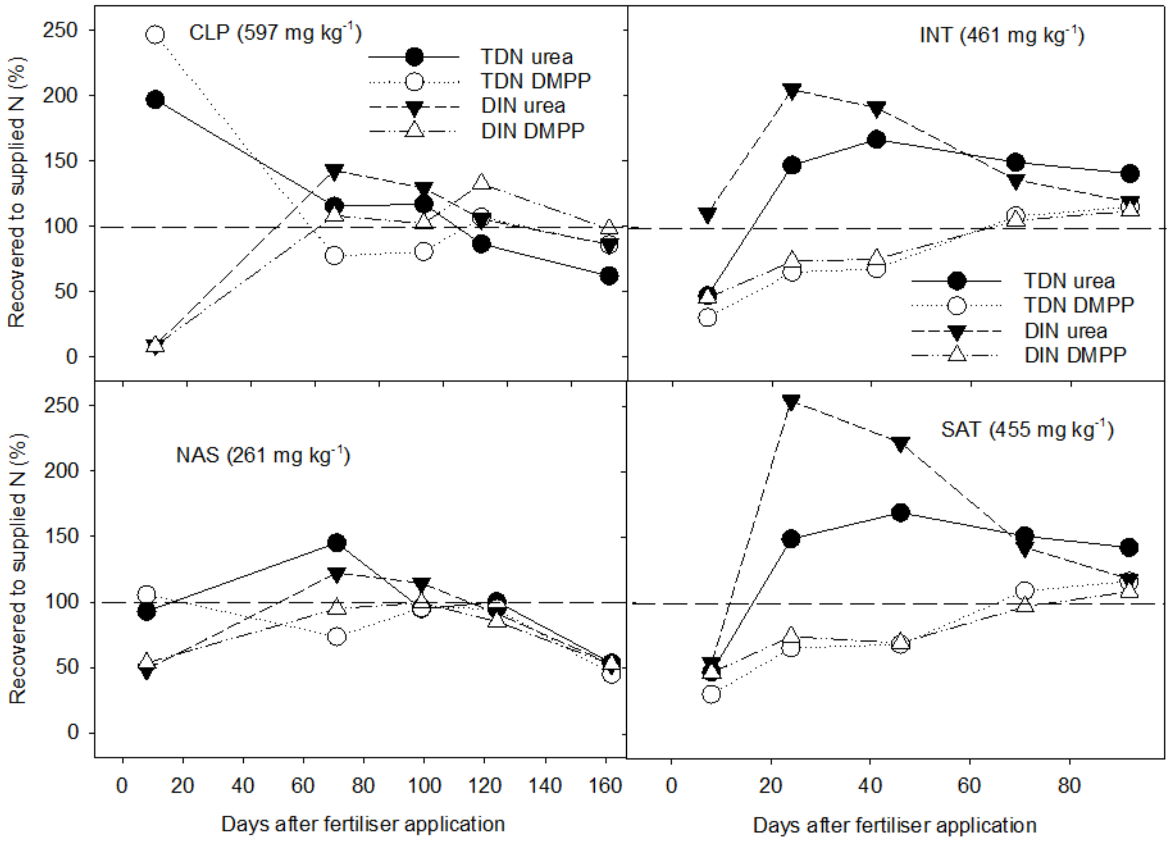


Figure 17. Total dissolved N (TDN) and dissolved inorganic N (DIN) in soil removed from root exclusion tubes (recovered N), divided by supplied N (urea or DMPP-coated urea N plus TDN or DIN in unfertilised soil), expressed as a percentage (dashed line is 100%). Days after fertiliser application is when tubes were removed in 2016/17 (CLP and NAS) and 2017/18 (INT and SAT).

Budget constraints precluded the out-sourcing of DOC testing for the 2017/18 season, so in-house $UV_{253.7}$ absorbance was used as a surrogate for DOC. $UV_{253.7}$ absorbance data for the same soil water-extract measured for TDN highlighted the rapid drop in aromatic compounds coincided with the rapid increase in 'N-priming' (Figure 18). The timing of the drop in absorbance occurred within 20 DAF at both sites, for the urea plots only. A rapid drop was also observed with the DMPP-coated urea, but not until after 60 DAF at INT and 80 DAF at SAT. Aromatic (heterocyclic) SOM is considered to be more microbially recalcitrant than aliphatic (linear) SOM, and should not 'mineralise' rapidly. An alternative hypothesis tested in our recent paper (Pittaway et al., 2018) is the N-priming effect is due to ammonium-N derived from urea fertiliser displacing SOM bound within organo-mineral complexes into solution. This minerally-complexed SOM was previously considered to be chemically protected from microbial degradation (Wagai et al., 2013). The ammonium-N displacing the SOM becomes bound to the mineral exchange sites ('fixed' N), and may not be immediately available for plant uptake.

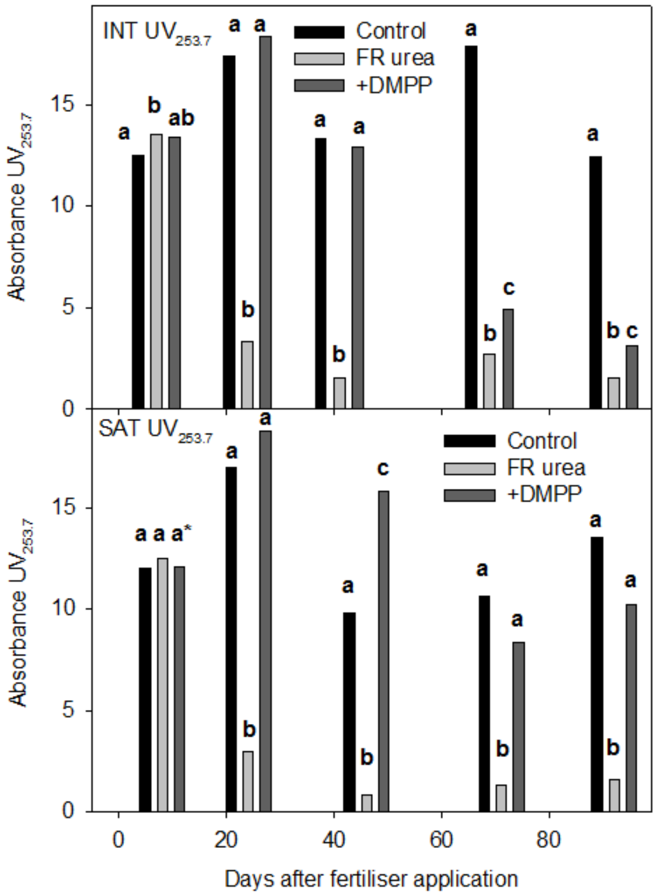


Figure 18. UV absorbance at a wavelength of 253.7 nm ($UV_{253.7}$) of filtered soil water extracts for soil from the INT and SAT sites over the 2017/18 season. Treatments were no fertiliser (Control), farmer rate urea (FR urea), and farmer rate DMPP-coated urea (+DMPP). Letters above treatment bar triplets that are the same indicate UV absorbance values are not significantly different ($P<0.05$).

AMMONIUM-N FIXED TO MINERAL EXCHANGE SITES IS NOT IMMEDIATELY AVAILABLE TO COTTON PLANTS

During the 2016/17 cotton season soil sampled from within and immediately outside root exclusion tubes was analysed for mineral N species using the 2M KCl extraction method (Rayment and Lyons, 2011). The high concentration of the monovalent cation potassium in the 1:10 soil slurry is known to displace ammonium-N from mineral exchange sites, including fixed as well as soluble NH_4-N in the analysis. The novel soil water-extractable 2M KCl method does not add the 2M KCl extracting solution until soil particles have been removed by centrifugation and filtration (Pittaway and Eberhard, 2014). Subtracting results for mineral N species extracted using the novel water extraction method from results for the soil extraction method should indicate the proportion of fertiliser N which is fixed to exchange sites on the clay minerals (Figure 19).

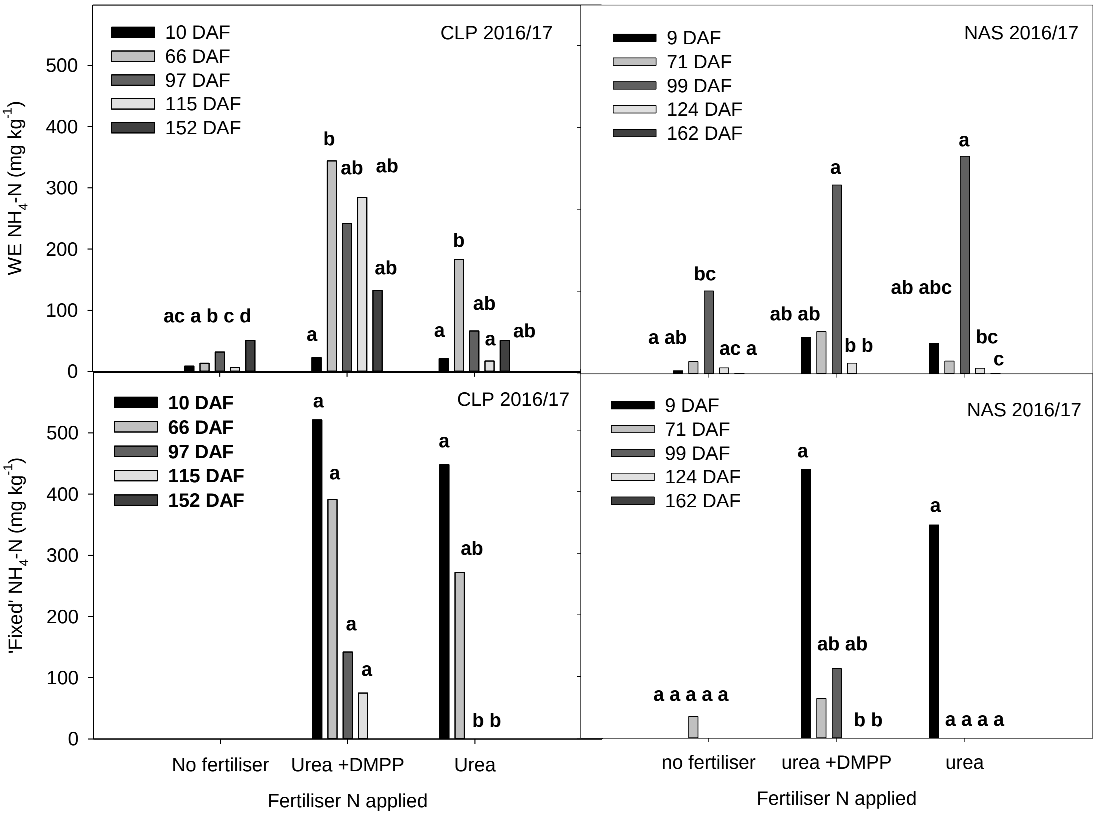


Figure 19. Ammonium-N (NH_4^+-N) concentration of filtered soil water extracts analysed using the modified Catchpoole and Weier (1980) 2M KCl method, and the ammonium-N concentration fixed to clay minerals in soil samples analysed using the standard soil 2M KCl method (Rayment and Lyons, 2011). Fixed ammonium N was calculated by subtracting water extract 2M KCl results from soil 2M KCl results. Letters above bars within each fertiliser treatment indicate mean concentrations are not significantly different (P<0.05).

In the 2016/17 season ammonium fixed to clay mineral exchange sites did not become available until 99 days after the fertiliser had been applied. The slow-release impact of fertiliser N fixed to exchange sites, and the extra N released in SOM displaced by the ammonium (N-priming) may in part explain why ^{15}N isotope studies recover only 25% of labelled urea from plant biomass harvested at the end of the season. The extra unlabelled N released due to N-priming may be twice that of the N supplied by inorganic fertiliser and unfertilised soil (Figure 17), and along with the portion of labelled N fixed to clay exchange sites, may dilute the concentration of labelled N taken up by roots during the first 60 or so days before peak bloom, when root activity and proliferation is greatest.

N-PRIMING ONLY OCCURS WHEN WARM SOIL TEMPERATURE STIMULATES THE RAPID ENZYMIC HYDROLYSIS OF UREA TO AMMONIUM

The leaching trial conducted at the end of the 2017/18 cotton growing season was designed to confirm SOM displaced from mineral exchange sites by ammonium was not mineralised by soil microbes, but leached below the depth of the root exclusion tubes. The facilities and equipment used were the same as the facilities used in the study that first established the displacement of

SOM by ammonium hydrolysed from urea fertiliser (Pittaway et al., 2018). The only difference was the published study was conducted over the summer months, whereas the cotton soil leaching trial was conducted over the winter months. The air conditioner in the facility was set at 25°C.

Leachate samples were analysed at 3, 10, 22, and 44 days after urea, DMPP-coated urea or calcium nitrate was added to the leaching columns at the equivalent of 150 kg ha^{-1} of banded N. Results for N species and DOC were calculated as mg leached per soil column, with TDN and DOC measured in-house using the oxidative combustion infra-red method (Pittaway and Eberhard, 2014). The concentration of leachate TDN in cylinders fertilised with calcium nitrate had increased by 10 DAF, reaching a maximum by 20 DAF (Figure 20). Concentrations of dissolved inorganic carbon (DIC in Figure 21) indicate urea had dissolved and started to hydrolyse only after 20 DAF, but the TDN concentration was less than a tenth of the concentration derived from calcium nitrate. No corresponding increase in DOC was observed with the increase in TDN with calcium nitrate, which is to be expected as nitrate does not displace DOM on mineral exchange sites.

Over the 44 day leaching trial we were unable to reproduce the N-priming and DOC leaching effect observed in the 2017/18 leaching trial, despite the same rate of fertiliser being applied to the soil columns. The concentration of TDN in leachate from the urea treatments was about one tenth the concentration recorded in the soil water extract (Figure 21), and the absorbance of UV light at 253.7 nm wavelength by leachate was less than one twentieth of the light absorbed by the soil water extracts from the 2017/18 field trial. The air temperature in the facility during the leaching trail was substantially below the air temperature prevailing during the 2017/18 field trial. The capacity of the air conditioner to maintain 25°C was compromised by the very low day and night temperatures, and by the strong, cold winds. The median maximum temperature was 18.5°C, and the median minimum was 13.5°C. Under these very low temperatures, the rate of urea hydrolysis by the enzyme urease would have been very slow (Qiu et al., 2018), reducing the ammonium-N concentration below the threshold required for the chemical displacement of DOM from mineral exchange sites (chemical N-priming).

Future experimental work (leaching study) may need to be conducted, but replacing the leaching columns with smaller cylinders of soil maintained at 75% field capacity, placed in a water bath set at 30°C. Under these conditions the hydrolysis of urea to ammonium should be rapid (Qiu et al., 2018), producing the N-priming effect and DOC leaching observed in the 2016/17 field trial at CLP, and at both sites in the 2017/18 field trials. Only two treatments may need to be tested, namely: urea and calcium nitrate applied at the equivalent of 150 kg ha^{-1} of banded N. Soil water extracted from the cylinders should produce sufficiently concentrated DOM in solution to enable a comparison of the sensitivity of the oxidative combustion infra-red and persulfate digestion methods for TDN, and to determine the quantity of nitrate, which may be complexed with colloidal DOM present in the filtered water extracts.

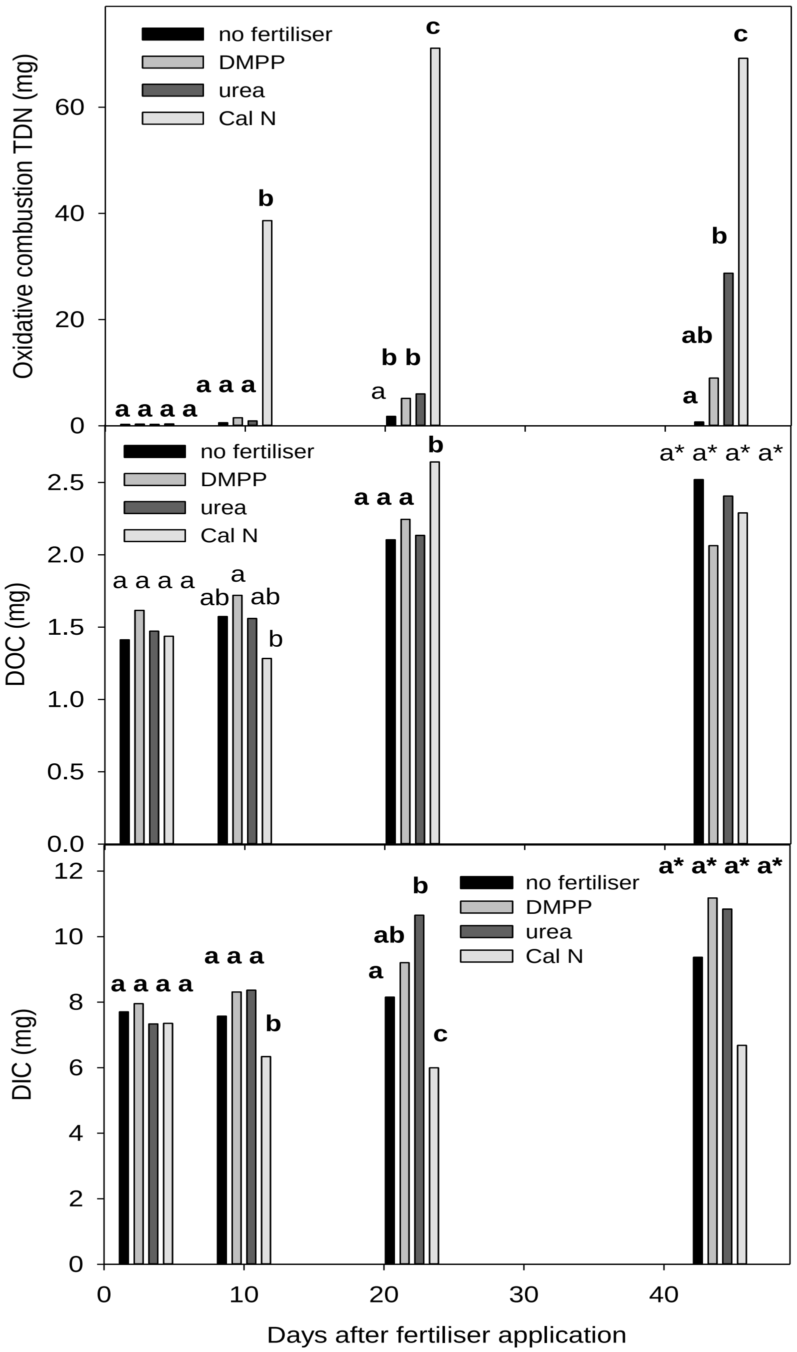


Figure 20. Total dissolved N (TDN), dissolved organic carbon (DOC and dissolved inorganic carbon (DIC) in leachate from soil columns (mg per column), fertilised with urea, DMPP-coated urea, calcium nitrate or no fertiliser, Letters above bars within each sampling time indicate mean (median) concentrations are not significantly different (P<0.05).

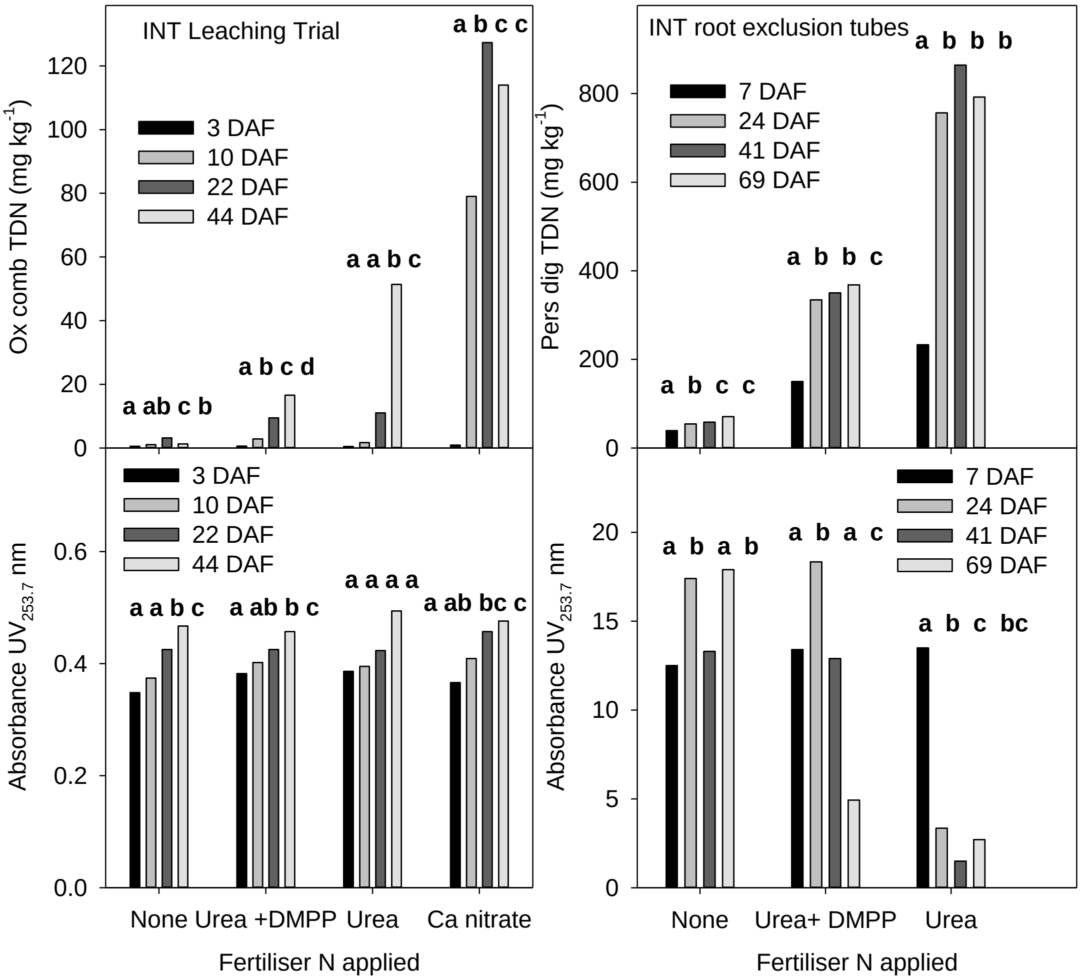


Figure 21. Total dissolved N (TDN) in leachate measured using the oxidative combustion infra-red method, and in soil water extracts sampled from within root exclusion tubes measured using the persulfate digestion method in the 2017/18 field trail, and UV absorbance of leachate and soil water extracts, Letters above bars within each fertiliser treatment indicate mean concentrations are not significantly different (P<0.05).

Objective 2: Suitability of rapid soil test methods for predicting soil mineralisable nitrogen

Key Messages:

- *Soil water extracts can be prepared in multiple replicates on field-moist soil, and with access to in-house analytical equipment, TDN, DOC and UV absorbance can be completed within 24 hours.*
- *The modified Catchpoole and Weieir (1980) 2M KCl-extractable inorganic N method can preserve soil water extract samples for several weeks, with minimal change in ammonium or nitrate concentrations.*
- *Our knowledge of the mechanism of N-priming associated with the application of banded ammonia-based fertilisers adds to our ability to predict how fertiliser application will affect the pool of potentially mineralisable N.*

- *Use of UV absorbance at 224 nm (the wavelength of light absorbed by the oxygen-nitrogen bond in nitrate) and SUVA*$_{224}$ *(UV*$_{224}$ *absorbance divided by TDN) indicate high concentrations of nitrate derived from fertilisers may complex with colloidal soil organic matter, interfering with some standard methods for analysing mineral N concentrations in soil.*

Total dissolved N (TDN) is sufficiently sensitive to detect statistically significant differences in the concentration of fertiliser N supplied by urea fertiliser and DMPP-coated urea. The TDN test measures the concentration of N in the <0.45µm soil water fraction, which is the fraction most likely to represent the soil solution moving to roots, and which microbes are most likely to interact with (Curtin et al., 2017). The mass balance in Figures 17 and 18 highlight the sensitivity of root exclusion tubes and the soil water extraction method in quantifying N-priming, and the inhibitory impact of DMPP on key microbes in the soil N cycle. The modified Catchpoole and Weier (1980) method of preparing soil water extracts as 2M KCl solutions within 6 hours of extraction, ensures microbial and chemical stability for several weeks, improving the accuracy of mineral N analyses. Subtracting results for 2M KCl-extractable NH_4-N in soil water extracts (modified Catchpoole and Weier 1980 method) from the standard analysis of 2M KCl-extractable NH_4-N in soil provides an estimate of the concentration of NH_4-N fixed to soil mineral exchange sites (Figure 19).

The discrepancy in the highest mineral N and TDN values recorded for urea-treated plots in 2017/18 season (Figure 13) indicates some NO_3-N is complexing with aromatic (heterocyclic) dissolved organic matter, which may not be recovered during persulfate digestion (Maher et al., 2002). Further evidence for the complexing of NO_3-N in heterocyclic compounds is in the UV_{224} (Figure 22) and $SUVA_{224}$ data (Figure 23). The N supply in unfertilised plots should only be from the microbial mineralisation of labile organic compounds. UV_{224} absorbance is consistently high in the unfertilised (Control) plots. This is not the case for the urea-applied plots, where UV_{224} absorbance rapidly drops, at a corresponding rate to the drop in absorbance at 253.7 nm (heterocyclic C and carbonyl bonds absorb light at 253.7 nm).

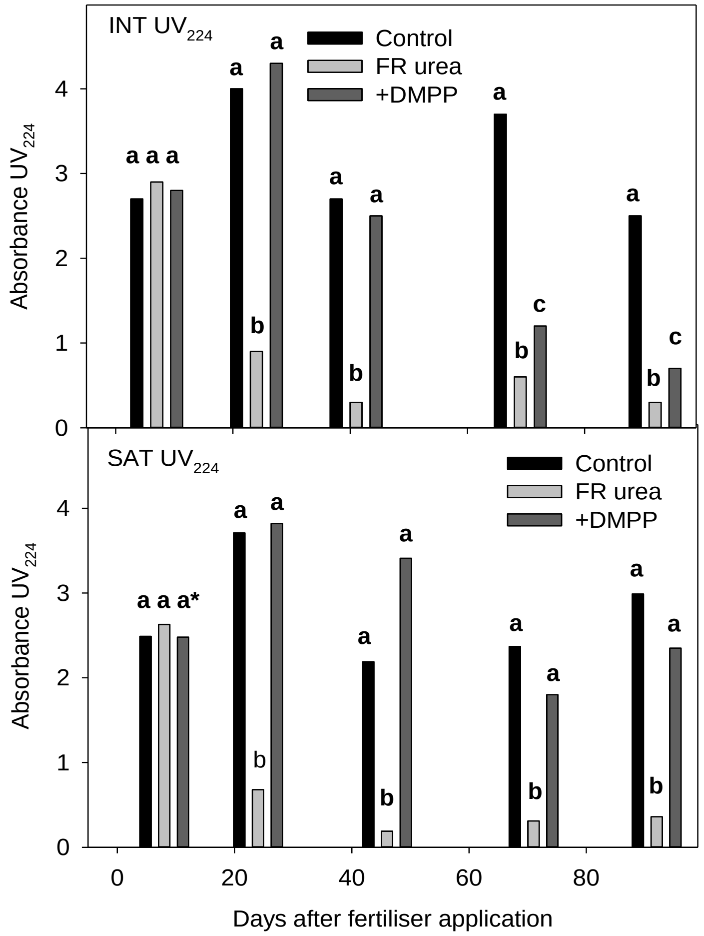


Figure 22. UV absorbance at 224nm for soil in root exclusion tubes at the INT and SAT sites over the 2017-18 season. Letters above bars that are the same are not significantly different (P<0.05) between treatments within sampling times

Specific UV_{224} absorbance of filtered leachate samples collected during the May-June 2018 leaching trial using air-dried, unfertilised soil from INT are substantially lower (less than one hundredth) than $SUVA_{224}$ values for unfertilised INT soil water extracts sampled from the field in 2017/18 (Figures 23 and 24). Nitrate bound in heterocyclic organic complexes does not absorb at 224 nm, with absorbance shifted to higher wavelengths. However, if the heterocyclic compound is precipitated by 2M KCl, or if the compound is filtered or centrifuged out of solution, the nitrate bound in the compound may not be detected. Further experimentation is required to resolve these problems.

Nitrate bound in heterocyclic complexes is not necessarily irreversibly bound or unavailable for microbial metabolism or plant uptake. Recent research indicates heterocyclic compounds may explain the selective uptake of nitrate across plant cell walls (Adriaenssens et al., 2013). Heterocyclic N has also been extracted from humic acids in the subsoil of rice paddy fields (Maie et al., 2006), but the authors could not propose a mechanism for the formation of these compounds. Our hypothesis is aromatic (heterocyclic) organic matter in the soil solution binds with nitrate. These organic compounds are hydrophilic and may explain the rate of leaching of nitrate derived from fertilisers to the subsoil.

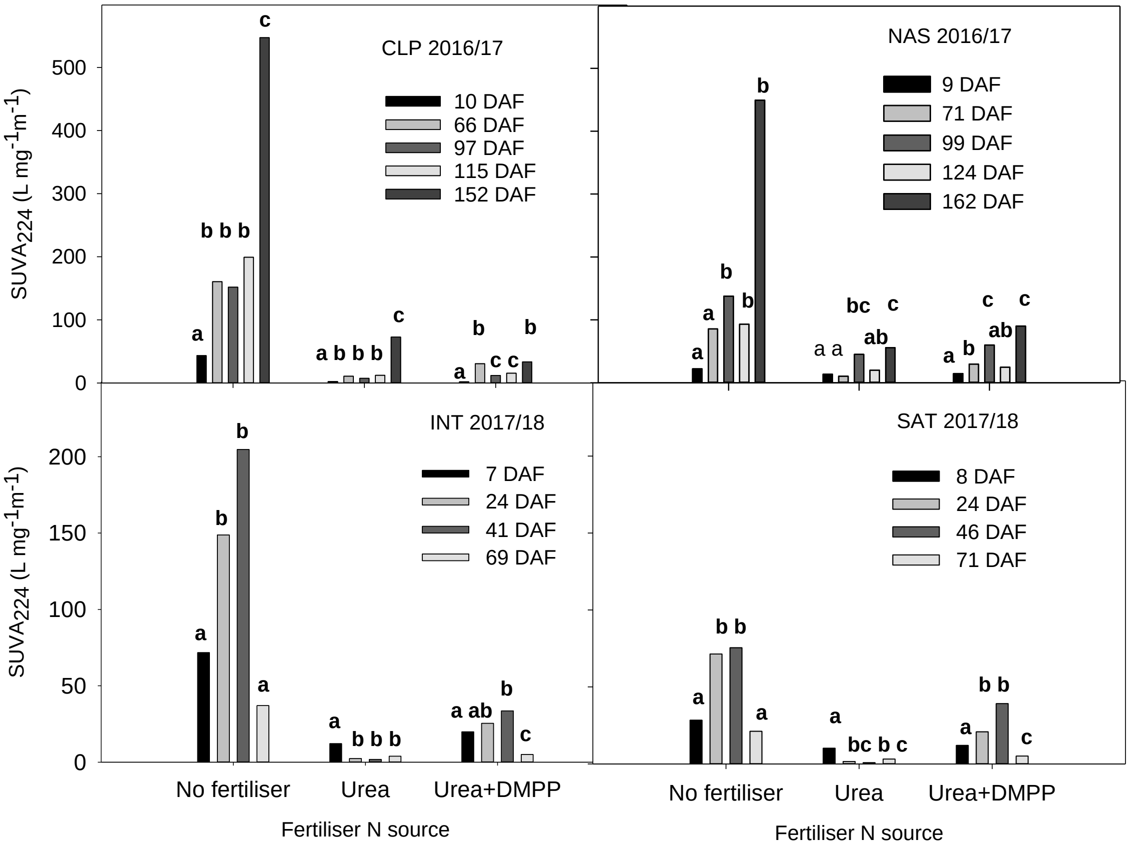


Figure 23. Specific UV absorbance at 224nm (SUVA$_{224}$; UV$_{224}$ absorbance divided by TDN) for soil in root exclusion tubes at the CLP and NAS sites over the 2016-17 season, and the INT and SAT sites over the 2017/18 season. Letters above bars that are the same are not significantly different (P<0.05) within treatments between sampling times.

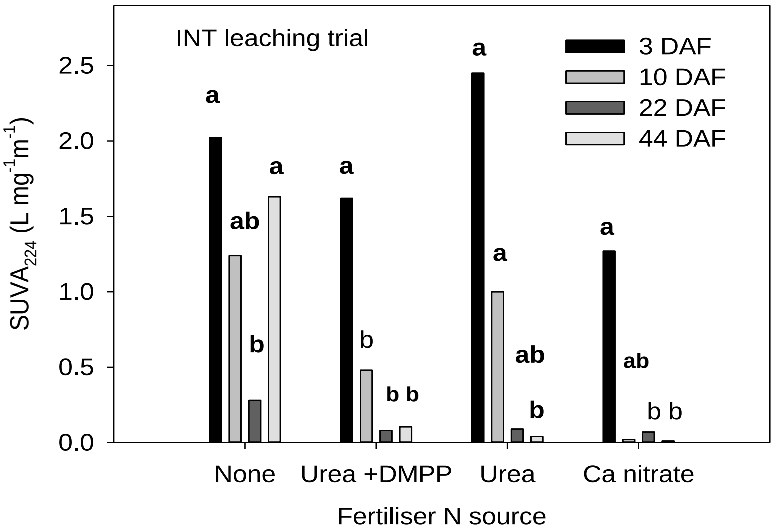


Figure 24. Specific UV absorbance at 224nm (SUVA$_{224}$; UV$_{224}$ absorbance divided by TDN) for 0.45µm-filtered leachate collected from soil columns filled with a 1:1 by volume mix of air-dried INT soil from unfertilised plots and washed quartz sand. Letters above bars that are the same are not significantly different (P<0.05) within treatments between sampling times.

Objective 3: Key findings from our study, which may improve nutrient management DSSs are:

- Overhead irrigation may provide a more uniform release of mineralised N from SOM over the growing season by avoiding more severe wet/dry cycles typically associated with flood/furrow irrigation.

- Cotton plants within 60 days after sowing are able to take up mineral N from urea banded in black Vertosol soils.

- The use of DMPP-coated urea slows the rate of release of NH_4-N and NO_3-N significantly within 60 days after fertiliser application, and may compromise early root development and seedling vigour.

- The N-priming effect associated with the application of ammonia-based fertilisers may contribute substantial amounts of previously 'chemically/microbially protected' N to the soil mineral N supply.

- The N-priming effect only occurs when the ammonia-based fertiliser is concentrated within a band, and the soil temperature is above 25°C, conducive to the rapid hydrolysis of urea to ammonium.

- Ammonium derived from fertiliser which becomes fixed to mineral exchange sites during N-priming may not be available for plants until 100 days after fertiliser application.

- The associated processes of N-priming and ammonium fixation are likely to dilute the concentration of ^{15}N-labelled urea fertiliser applied in field trials, reducing the recovery of ^{15}N in harvested biomass, which may under-estimate the fertiliser use efficiency of cotton.

3.1 Project level achievements

Objective 1: Investigate how N fertiliser formulations; namely: urea and DMPP-treated urea, and wet-dry cycles affect within-season patterns of soil N supply,

- At the project level, our results have demonstrated root exclusion tubes can be used successfully in black Vertosol soils managed with overhead irrigation. Other teams working within the MPfN project on furrow-irrigated clay soils found the use of root exclusion tubes too difficult to continue.

- The use of root exclusion tubes enabled us to validate the capacity of cotton roots to take up nitrogen from within banded urea fertiliser within 60 days of sowing, and to calculate the amount of extra N released during N-priming (the displacement of SOM by high concentrations of fertiliser-derived ammonium). Prior to our study, scientists assumed N-priming was an increase in the rate of microbial mineralisation, stimulated by a luxury supply of mineral N.

- Our inability to replicate N-priming and the associated loss of heterocyclic SOM recorded in the field trials in the leaching trial, supports the findings of a recently published study on the kinetics of the urease enzyme (Qiu et al., 2018). Temperatures of above 25°C are required for the rapid hydrolysis of urea.

- The use of root exclusion tubes and the modified Catchpoole and Weier (1980) 2M KCl-extraction method enabled us to calculate the concentration of fertiliser-derived ammonium-N fixed to mineral exchange sites during N-priming, and the delay in fixed ammonium-N becoming available in the soil solution. The process of N-fixing has been studied previously, but the amount and rate of release of fixed ammonium has not previously been calculated.

- The use of root exclusion tubes, and the use of novel rapid analytical methods has enabled us to validate the compound DMPP inhibits the microbial processes of urea hydrolysis and nitrification. Prior to our study the assumption was DMPP only inhibits nitrification.

- We were not able to document major differences in seasonal patterns of N supply in association with wet/dry cycles, as during the 2016/17 and 2017/18 cotton growing seasons much of the water applied was through overhead irrigation. The sampling of root exclusion tubes and adjacent soil immediately outside the tubes was standardised to within 3 days of a major irrigation or rainfall event to maximise the likelihood of sampling during peak microbial activity. Very few heavy summer storms occurred over the duration of the study, so sampling was restricted to after relatively uniform irrigation events. Further analysis of seasonal change in TDN and mineral N at the SAT and INT sites may be informative, as the frequency and volume of irrigation water applied at these two sites varied considerably.

Objective 2: Identify how well a rapid soil test based on water extraction and measurement of dissolved organic nitrogen can inform predictions of soil mineralisable nitrogen

- The use of soil water extracts enabled us to rapidly measure TDN concentrations and to preserve inorganic N species ammonium, nitrate and nitrite in a 2MKCl solution prior to analysis using the hydrazine or Cu-Cd column flow injection methods. Differences over time in TDN and mineral N enabled us to monitor change in the different pools of N over the season. Further analysis of this data may provide more insights into the rate of mineralisation of soil organic matter, as the <0.45μm size fraction is the fraction most likely to move in the soil solution.

- Predicting the rate of soil organic N mineralisation is not straight-forward, as TDN contains microbially labile and recalcitrant organic compounds. However, we were able to demonstrate predicting the soil N mineralisation rate after the addition of banded ammonia-based fertiliser is confounded by N-priming and ammonium fixation.

Objective 3: Suggest how currently available nitrogen management DSSs can be improved by improved knowledge of within-season patterns of soil N supply.

- Knowing the hydrolysis of urea to ammonium slows substantially in soil at temperatures of below 20°C may improve DSSs, as the risk of volatilisation and leaching losses from urea fertiliser applied weeks before sowing, into soil routinely below 20°C, will be much lower than from later applications of urea to warmer soils.

- Knowing DMPP inhibits both the hydrolysis of urea and nitrification will most certainly improve nitrogen management DSSs.

- Knowing ammonia-based fertilisers applied in a concentrated band to soil above a temperature of 25°C can release substantial concentrations of N from previously unavailable SOM may improve DSSs by improving our knowledge of how the dilution of applied fertiliser with N-priming may under-estimate calculations of the N fertiliser use efficiency of cotton.

Objective 4: Identify if dissolved organic matter leaches as a result of addition of ammonium-based N fertiliser by comparing the effects of ammonium- *vs* nitrate-based fertilisers on DOM leaching.

- The inability of the air conditioner to maintain room temperature at 25°C during the duration of our leaching trial over winter in 2018 confirmed N-priming associated with banded urea fertiliser is only likely to occur at soil temperatures of above 25°, when the enhanced activity of the urease enzyme in soil rapidly hydrolyses urea to ammonium.

- We were able to demonstrate high concentrations of nitrate released very rapidly from the dissolution of the fertiliser calcium nitrate did not increase the concentration of DOC or absorbance at the wavelength of 253.7 nm, indicating high concentrations of nitrate do not displace SOM from organo-mineral complexes.

- We hope to use equipment purchased by the project (water bath) to undertake a smaller study using the same soil mix as in the leaching trial, to use our novel methods to monitor the concentration of TDN, DOC, UV_{224}, $UV_{253.7}$, $SUVA_{224}$, $SUVA_{253.7}$ and 2M KCl-extractable inorganic N species in soil water extracts sampled at 5 and 25 days after applying urea or calcium nitrate in a band equivalent to 150 kg ha^{-1}. The advantage of the water bath study is we will be able to maintain the soil temperature at 30°C, and the soil water content at 75% field capacity (Qiu et al., 2018).

Objective 5: Understand the degree to which the KCl extraction method for soil mineral N and the persulfate digestion method for TDN do/not recover all soil nitrate.

- We were not able to achieve this objective as the maximum temperature in the air-conditioned room used for the leaching trial was not sufficiently high to induce N-priming. The rate of enzymic hydrolysis of urea to ammonium was too slow to induce the peak in ammonium required to displace SOM from mineral exchange sites. We could not compare the efficiency of the persulfate digestion and oxidative combustion methods in measuring TDN in leachate containing high concentrations of colloidal DOM, and no precipitated organic colloid was evident in soil water extracts diluted 1:1 with 4M KCl.

- We hope to produce sufficient displaced DOM in the smaller water bath study to be able to pool samples of filtered soil extract to produce sufficient precipitated DOM for analysis.

Progress against CRDC milestones and DAWR KPIs

Please refer to the Table on the following pages.

KPI No.	**DAWR** **KPI description**	**CRDC MS No.**	**CRDC MS description**	**Progress achieved against DAWR KPIs and CRDC Milestones**
3.2	Provide an update on cotton field mineralisation experiments in Queensland (Output 6 (a))	**1.1**	Establish season 1 field experiment	Completed. Activities: Two overhead irrigated cotton fields on two Darling Downs properties were established and monitored during the 2016/17 cotton season. Five root exclusion tubes were placed along the fertilizer band within 4 replicated plots per treatment. Treatments were unfertilized, farmer's rate urea (FRU), and FRU+DMPP. Findings: Recovering soil cores in root exclusion tubes after irrigation or rainfall events in black clay soils can be achieved in practice. Sampling soil in the presence of actively growing roots, substantially under-estimates the N supply available to the plant.
3.2	Provide an update on cotton field mineralisation experiments in Queensland (Output 6 (a))	**1.2**	Conduct and report on season 1 field experiments	Completed. Activities: Data analysis for season 1 (field) experiments was completed. Preliminary results derived from these experiments were presented at the 2017 AACS in August 2017, and at the MPfN forum in the Gold Coast. Preliminary findings were generally well-received by the scientific audience at both events. Findings: Adding DMPP to urea significantly retards the conversion of NH_4 to NO_3 up to the peak bloom phase. Lack of agronomic response to DMPP-treated urea may reflect the preferential uptake of NO_3-N by cotton roots i.e., nitrogen saved in denitrification with DMPP, may not necessarily be taken-up by the crop.
3.2	Provide an update on cotton field mineralisation experiments in Queensland (Output 6 (a))	**1.3**	Establish season 2 field experiments	Completed. Activities: Season 2 field experiments were established by 30/11/2017. Fertiliser treatments of urea, DMPP urea and a control were applied to two irrigated field sites on one farm in the Darling Downs to study soil N supply at key cotton growth stages. Five root exclusion tubes were placed along the fertilizer band within 4 replicate plots per treatment following the same protocol to the previous season. Findings: Sampling soil in the presence of actively growing roots substantially under-estimates the soil/fertiliser N supply to the plant. Sampling within root exclusion tubes provides a more accurate estimate of the N supply available to plants.

5.2	Provide an update on cotton field mineralisation experiments in Queensland (Output 6 (a))	**1.4**	Conduct and report on season 2 field experiments. Final Report.	Completed. Activities: Season 2 field experiments were conducted. Comparison of N supply inside and outside root exclusion tubes was done using total Kjeldahl N on undried (field-state) soil samples, rather than using KCl extractable mineral N as in the 2016/17 season due to concerns over nitrate recovery in the KCl method. A draft final report was prepared. Findings: Our results highlight cotton is capable of extracting fertilizer N within 40 days after emergence, when root proliferation is greatest.
2.4, 3.1, 4.2	Implement the communication and extension plan and hold an annual project partners' forum. Promote project activities and outcomes at events that are expected to include: regional and national conferences, industry workshops, seminars and field days. (Output 3b)	**1.5**	Participate in the proposed cross-industry annual forum for all the researchers involved in the RR&D4P II Nitrogen program	Completed. Activities: Dio Antille and Pam Pittaway participated in the 2017 annual MPfN forum in the Gold Coast and as well as the 2018 forum held in Darwin, July 2018.
2.4, 3.1, 4.2	Implement the communication and extension plan and hold an annual project partners' forum. Promote project activities and outcomes at events that are expected to include: regional and national conferences, industry workshops, seminars and field days. (Output 3b)	**1.6**	Engage with the NSW DPI cotton project (Graeme Schwenke / Guna Nachimuthu), the dairy projects (David Rowlings QUT, Warwick Dougherty NSW DPI, Helen Suter, Melbourne Uni) and the sugar project (Lukas Van Zwieten, NSW DPI)	Completed. Activities: Dio Antille and Pam Pittaway participated in the 2017 annual MPfN forum in the Gold Coast as well as the 2018 forum held in Darwin, July 2018. Alice Melland and/or Dio Antille have participated in MPfN program management committee meetings. Discussions with fellow researchers standardized methods for the design and use of root exclusion tubes. Findings: Root exclusion tubes are feasible in overhead irrigated systems, but not in flood irrigated systems (NSW DPI experience).
5.2	Provide an update on cotton field mineralisation experiments in Queensland (Output 6 (a))	**1.7**	Is the N-priming observed with the application of N fertilisers caused by hydrolysed ammonium displacing SOM from organo-mineral complexes?	Completed. Activities: A controlled environment soil column leaching study was conducted to compare the effects of ammonium- vs nitrate-based fertilisers on DOM leaching. We were unable to reproduce N-priming as temperatures over the winter period was too cold for rapid rates of urea hydrolysis. We confirmed N-priming only occurs in soils at a temperature of above 20°C.

3.2	Provide an update on cotton field mineralisation experiments in Queensland (Output 6 (a))	**2.1**	Conduct a controlled wet-dry cycle laboratory study and validate rapid soil N test methods against conventional tests	Completed. Activities: Data from a rapid water extraction of soil with a mineral N and total dissolved N analytical method were compared with a conventional 2M KCl extraction and mineral N analysis on field soil samples and with an out-sourced TDN analytical method. Findings: The water extract method for monitoring microbial transformations of urea was more sensitive for NH_4-N and NO_x-N at lower concentrations. However, recoveries of NH_4-N were significantly higher with the conventional 2M KCl soil extraction method, as including soil in the 2M KCl extraction released fixed ammonium from mineral exchange sites. Subtracting 2M KCl-extracted mineral N in water extracts from mineral N extracted from soil indicated the concentration of ammonium N fixed, and the rate at which it was released. Data from the 2017/18 cotton season highlight an N-priming effect associated with ammonia-based fertilizer may increase the soil N supply by a factor of 60% above applied fertilizer and N mineralised from unfertilized plots early in the season.
5.2	Provide an update on cotton field mineralisation experiments in Queensland (Output 6 (a))	**2.2**	Process and analyse field experiment soil samples for total dissolved N and mineral N using internal and external laboratories.	Completed. Activities: Soil from inside root exclusion tubes was analysed for water –extractable total dissolved N, water-extractable mineral N (with KCl preservation) and 2M KCl-extractable NO_x-N and NH_4-N. Comparing TDN and mineral N from inside and immediately outside root exclusion tubes highlighted the capacity of cotton seedlings to extract N from banded fertilizer. Findings: Soil water extraction requires no soil preparation, and replicate samples can be prepared rapidly, with in-house analysis for TDN and mineral N occurring within 24 hr. The modified Catchpole & Weier (1980) 2M KCl method can preserve N species in water extracts for several weeks prior to analysis. Results for NH_4-N and NO_x-N confirmed DMPP slows the rate of release of fertilizer N substantially, by inhibiting urease (slow release of NH_4-N) and nitrification (slow release of NO_3-N). Comparison of in-house TDN (combustion method) and external lab TDN (persulfate digestion) methods showed that when DOC in samples is low, TDN results are comparable.

5.2	Provide an update on cotton field mineralisation experiments in Queensland (Output 6 (a))	**2.3**	To what extent does KCl extraction for soil mineral nitrogen recover soil nitrate?	Completed. Activities: A soil column leaching study was conducted to compare the effects of ammonium- vs nitrate-based fertilisers on DOM leaching. Findings: Temperatures below 20°C constrain urea hydrolysis, so there was insufficient colloidal DOM in leachate to complete this analysis.
3.1	Implement the communication and extension plan and hold an annual project partners' forum. Promote project activities and outcomes at events that are expected to include: regional and national conferences, industry workshops, seminars and field days. (Output 3b)	**3.1**	Contribute to the development of BMP recommendations and recommendations for N fertiliser DSS enhancements	Completed. Please also refer to Appendix 6.5 for further information on DSS-related work. Activities: Discussions with the QUT cotton N research team led by Prof Peter Grace, who are assessing DSS development opportunities, were established. Analytical data derived from the field experiments have been provided to the QUT team along with a copy of this report, to help with the interpretation of such data. The USQ team has also provided recommendations to the QUT team on how our findings may be used to further develop DSS tools currently used by growers and advisers (e.g., Nutilogic, BackPaddock). Specifically, the findings from our study which may improve nutrient management DSSs are: (1) The use of DMPP-coated urea slows the rate of release of NH_4-N and NO_3-N within 60 days after fertiliser application, and may compromise early root development if applied close to planting. (2) The N-priming effect associated with the application of ammonia-based fertiliser may contribute substantial amounts of previously 'chemically/microbially protected' N to the soil mineral N supply. (3) The diluting effect of extra soil N released as a result of N-priming may result in the under-estimation of N fertilizer use efficiency by cotton. (4) Urea fertilizer applied to cold soil weeks ahead of planting may not be as prone to volatilization and leaching as fertilizer applied later on in the season as temperatures of below 20°C substantially slow the rate of hydrolysis of urea to ammonium. (5) Overhead irrigation may provide a more uniform release of mineralised N from SOM over the growing season by avoiding the wet/dry cycles associated with flood or furrow irrigation.

3.2 Contribution to program objectives

The knowledge gained from our study benefits primary producers by establishing:

- Cotton roots are capable of extracting N fertiliser from concentrated urea granule bands well before flowering.

- Early season pre-plant applications of urea when soil temperatures are routinely below 20°C is unlikely to increase fertiliser losses to volatilisation or leaching, as the enzyme urease requires temperatures well above 20°C to rapidly hydrolyse urea to ammonium.

- DMPP-coated urea is only likely to reduce nitrate leaching losses if applied as a side-dressing later on in the season, when high soil temperatures stimulate the rapid hydrolysis of untreated urea to ammonium.

- The lack of yield increase with DMPP-coated urea applied at planting in field trials may be due to the inhibitory effect of DMPP on urea hydrolysis and nitrification, slowing the rate of release of fertiliser N.

- The application of dissolved ammonia-based fertilisers through overhead irrigators is unlikely to induce N-priming - even in soils experiencing temperatures above 25°C, as the concentration of ammonium per unit area will be relatively low.

Our project strengthens pathways to extend the results of rural R&D, including understanding the barriers to adoption by:

- Providing insights into the mechanism of N-priming and the amount of extra soil N that may be released by high ammonium concentrations derived from banded urea. This extra pool of soil N may substantially dilute ^{15}N urea in field trials, significantly under-estimating the actual N fertiliser use efficiency of cotton.

- Discussing the findings of our results with Ian Grant (Director of the analytical company Agricultural Chemistry), with Chris Dowling (Director of the consulting company Back Paddock), and with the growers on whose properties the research was undertaken, (Lachlan Naas, Russell Clapham) and their agronomists.

We have established and fostered industry and research collaborations that form the basis for ongoing innovation and growth of Australian agriculture by:

- Designing our project to complement research already undertaken by QUT in the CRDC-funded project ‘Determining optimum nitrogen strategies for abatement of emissions for different irrigated cotton systems’ (CRDC/AOTGR2-0008). Specifically, our project has contributed analytical data collected over two cotton seasons from candidate experimental sites in Jondaryan and Pittsworth to assist the development/upgrade/testing of DSS tools currently used by the industry for nitrogen budgeting purposes.

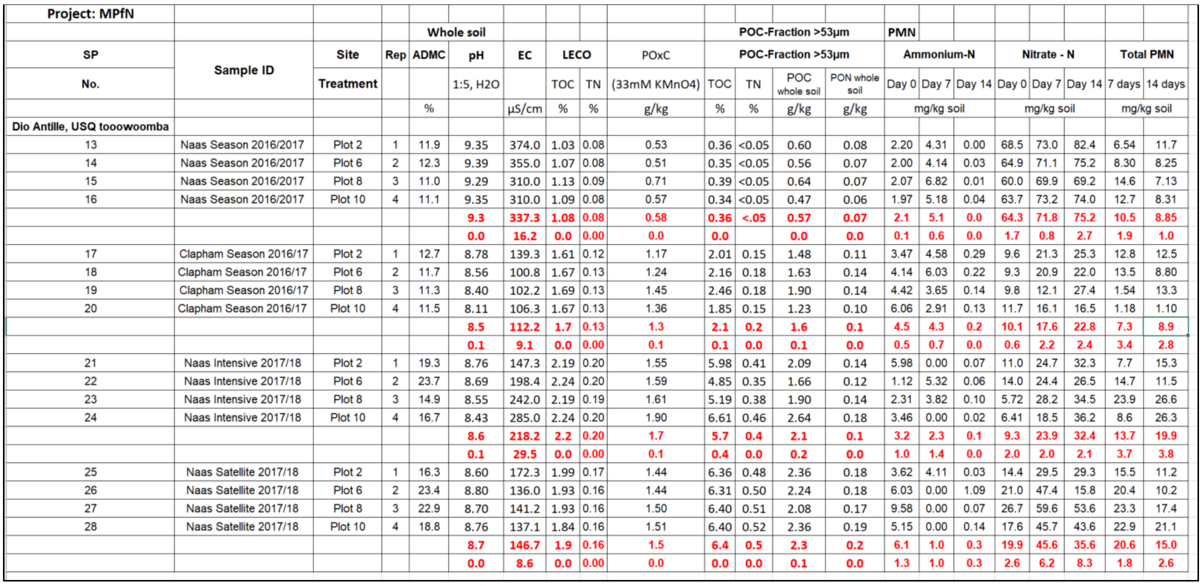
- Participating in the two More Profit from Nitrogen workshops held in the Gold Coast in 2017 and Darwin in 2018, delivering a paper at the 2017 edition of the AACS Conference in Canberra in 2017, and by presenting our results to cotton growers and agronomist at a workshop held at USQ-CAE in August 2018.

3.3 Collaboration

The experimental design was decided in consultation with industry researchers and agronomists (Dr Chris Dowling, Dr Graeme Schwenke, Dr Guna Nachimuthu, Mr Jon Baird, Dr Clemens Scheer).

Discussions with Dr Phil Moody (Department of Environment and Science), resulted in collaborative research. The objective of this collaboration was to value-add to the individual More Profit for Nitrogen projects by undertaking additional soil N mineralisation potential and soil carbon analyses that could be correlated with actual soil N supply in the field measured by crop N uptake from the nil applied N treatment. A set of soil samples was collected from our experimental sites both at Pittsworth and Jondaryan and sent for analysis to Dr Moody. The analytical results provided by Dr Moody from our experimental sites are shown in Table 5.

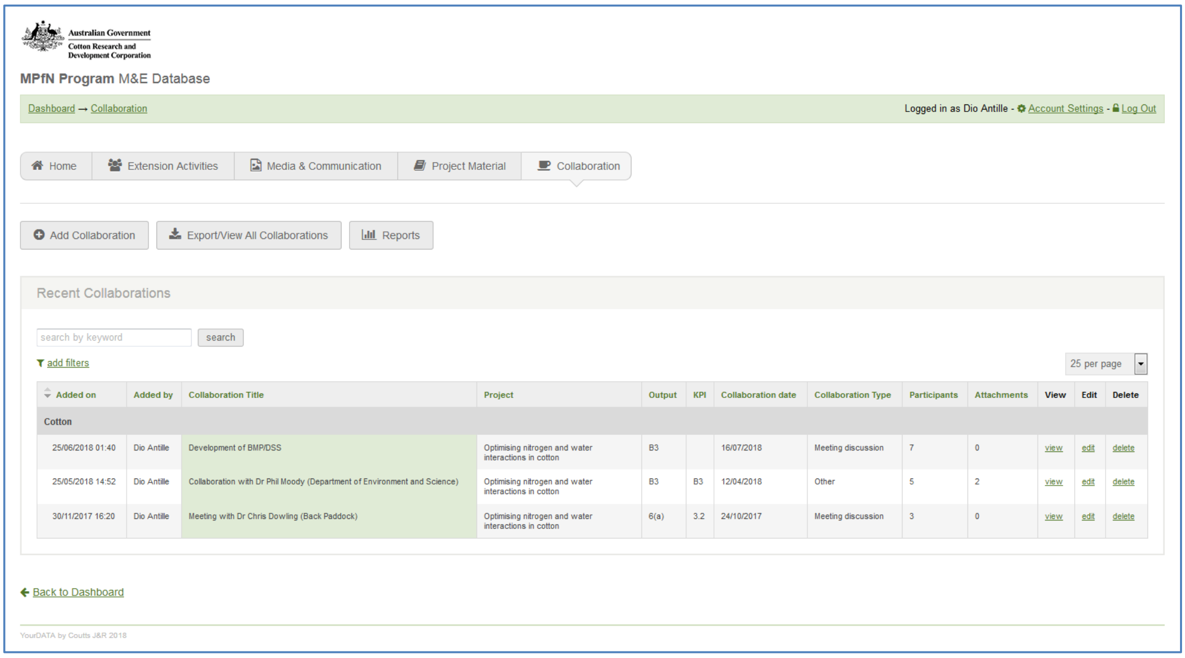
Table 5. Summary of analytical results provided by Dr P. Moody from samples collected from the zero-N plots at the Jondaryan and Pittsworth sites, respectively.



Project: MPfN																					
				Whole soil						POC-Fraction >53µm				PMN							
SP	Sample ID	Site	Rep	ADMC	pH	EC	LECO		POxC	POC-Fraction >53µm				Ammonium-N			Nitrate - N			Total PMN	
No.		Treatment			1:5, H2O		TOC	TN	(33mM KMnO4)	TOC	TN	POC whole soil	PON whole soil	Day 0	Day 7	Day 14	Day 0	Day 7	Day 14	7 days	14 days
				%		µS/cm	%	%	g/kg	%	%	g/kg	g/kg	mg/kg soil			mg/kg soil			mg/kg soil	
Dio Antille, USQ tooowoomba																					
13	Naas Season 2016/2017	Plot 2	1	11.9	9.35	374.0	1.03	0.08	0.53	0.36	<0.05	0.60	0.08	2.20	4.31	0.00	68.5	73.0	82.4	6.54	11.7
14	Naas Season 2016/2017	Plot 6	2	12.3	9.39	355.0	1.07	0.08	0.51	0.35	<0.05	0.56	0.07	2.00	4.14	0.03	64.9	71.1	75.2	8.30	8.25
15	Naas Season 2016/2017	Plot 8	3	11.0	9.29	310.0	1.13	0.09	0.71	0.39	<0.05	0.64	0.07	2.07	6.82	0.01	60.0	69.9	69.2	14.6	7.13
16	Naas Season 2016/2017	Plot 10	4	11.1	9.35	310.0	1.09	0.08	0.57	0.34	<0.05	0.47	0.06	1.97	5.18	0.04	63.7	73.2	74.0	12.7	8.31
					9.3	337.3	1.08	0.08	0.58	0.36	<.05	0.57	0.07	2.1	5.1	0.0	64.3	71.8	75.2	10.5	8.85
					0.0	16.2	0.0	0.00	0.0	0.0		0.0	0.0	0.1	0.6	0.0	1.7	0.8	2.7	1.9	1.0
17	Clapham Season 2016/17	Plot 2	1	12.7	8.78	139.3	1.61	0.12	1.17	2.01	0.15	1.48	0.11	3.47	4.58	0.29	9.6	21.3	25.3	12.8	12.5
18	Clapham Season 2016/17	Plot 6	2	11.7	8.56	100.8	1.67	0.13	1.24	2.16	0.18	1.63	0.14	4.14	6.03	0.22	9.3	20.9	22.0	13.5	8.80
19	Clapham Season 2016/17	Plot 8	3	11.3	8.40	102.2	1.69	0.13	1.45	2.46	0.18	1.90	0.14	4.42	3.65	0.14	9.8	12.1	27.4	1.54	13.3
20	Clapham Season 2016/17	Plot 10	4	11.5	8.11	106.3	1.67	0.13	1.36	1.85	0.15	1.23	0.10	6.06	2.91	0.13	11.7	16.1	16.5	1.18	1.10
					8.5	112.2	1.7	0.13	1.3	2.1	0.2	1.6	0.1	4.5	4.3	0.2	10.1	17.6	22.8	7.3	8.9
					0.1	9.1	0.0	0.00	0.1	0.1	0.0	0.1	0.0	0.5	0.7	0.0	0.6	2.2	2.4	3.4	2.8
21	Naas Intensive 2017/18	Plot 2	1	19.3	8.76	147.3	2.19	0.20	1.55	5.98	0.41	2.09	0.14	5.98	0.00	0.07	11.0	24.7	32.3	7.7	15.3
22	Naas Intensive 2017/18	Plot 6	2	23.7	8.69	198.4	2.24	0.20	1.59	4.85	0.35	1.66	0.12	1.12	5.32	0.06	14.0	24.4	26.5	14.7	11.5
23	Naas Intensive 2017/18	Plot 8	3	14.9	8.55	242.0	2.19	0.19	1.61	5.19	0.38	1.90	0.14	2.31	3.82	0.10	5.72	28.2	34.5	23.9	26.6
24	Naas Intensive 2017/18	Plot 10	4	16.7	8.43	285.0	2.24	0.20	1.90	6.61	0.46	2.64	0.18	3.46	0.00	0.02	6.41	18.5	36.2	8.6	26.3
					8.6	218.2	2.2	0.20	1.7	5.7	0.4	2.1	0.1	3.2	2.3	0.1	9.3	23.9	32.4	13.7	19.9
					0.1	29.5	0.0	0.00	0.1	0.4	0.0	0.2	0.0	1.0	1.4	0.0	2.0	2.0	2.1	3.7	3.8
25	Naas Satellite 2017/18	Plot 2	1	16.3	8.60	172.3	1.99	0.17	1.44	6.36	0.48	2.36	0.18	3.62	4.11	0.03	14.4	29.5	29.3	15.5	11.2
26	Naas Satellite 2017/18	Plot 6	2	23.4	8.80	136.0	1.93	0.16	1.44	6.31	0.50	2.24	0.18	6.03	0.00	1.09	21.0	47.4	15.8	20.4	10.2
27	Naas Satellite 2017/18	Plot 8	3	22.9	8.70	141.2	1.93	0.16	1.50	6.40	0.51	2.08	0.17	9.58	0.00	0.07	26.7	59.6	53.6	23.3	17.4
28	Naas Satellite 2017/18	Plot 10	4	18.8	8.76	137.1	1.84	0.16	1.51	6.40	0.52	2.36	0.19	5.15	0.00	0.14	17.6	45.7	43.6	22.9	21.1
					8.7	146.7	1.9	0.16	1.5	6.4	0.5	2.3	0.2	6.1	1.0	0.3	19.9	45.6	35.6	20.6	15.0
					0.0	8.6	0.0	0.00	0.0	0.0	0.0	0.1	0.0	1.3	1.0	0.3	2.6	6.2	8.3	1.8	2.6

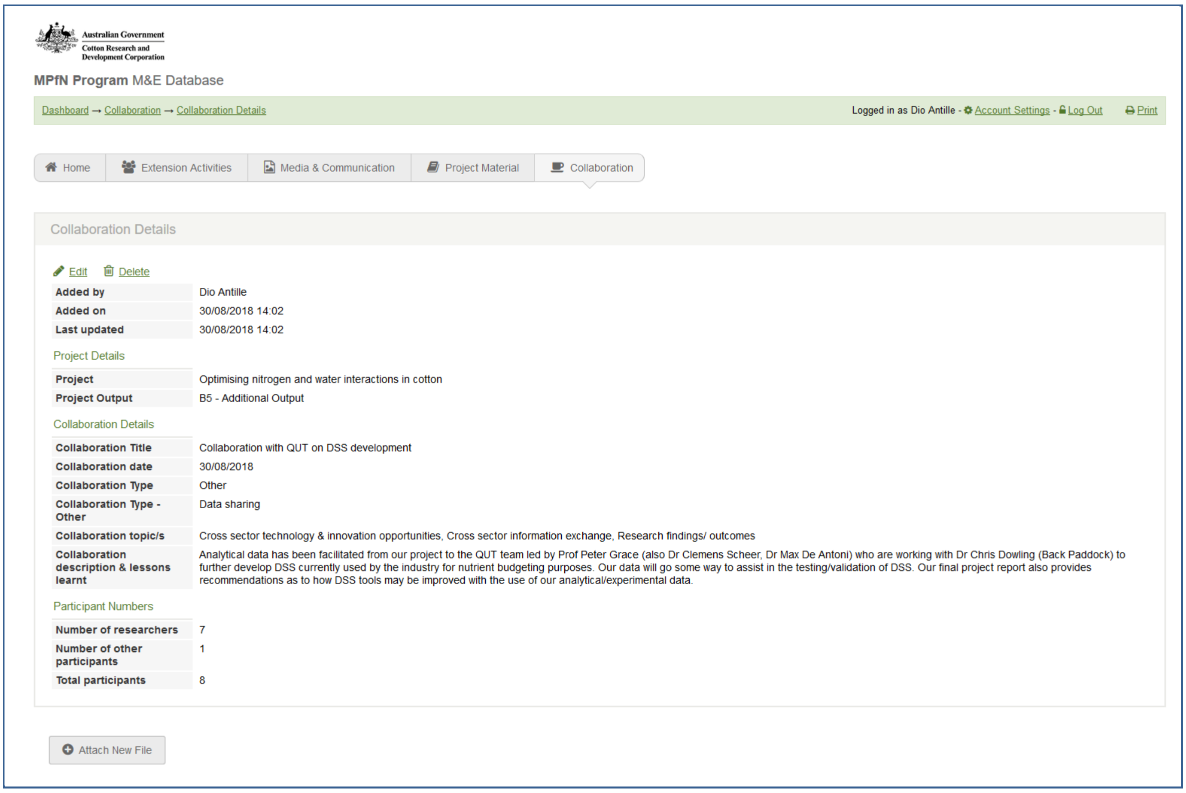
Discussions with Dr Chris Dowling (Back Paddock) were held on 24 October 2017. Dr Chris Dowling provided expert advice to the project by critically reviewing season 1 results derived from the season 1 field experiments, and by assisting with interpretation of analytical data. The meeting was attended by the project team only. This collaboration continued through data sharing with QUT (Prof Peter Grace and Dr Max De Antoni (QUT), and Dr Chris Dowling as part of the Project Milestone 3.1 ('Contribute to the development of BMP recommendations and recommendations for N fertiliser DSS enhancements'). This collaboration will inform ongoing research into improved nutrient management DSS.

The activities described above are documented in the MPfN database:



Recent Collaborations

Added on	Added by	Collaboration Title	Project	Output	KPI	Collaboration date	Collaboration Type	Participants	Attachments	View	Edit	Delete
Cotton												
25/06/2018 01:40	Dio Antille	Development of BMP/DSS	Optimising nitrogen and water interactions in cotton	B3		16/07/2018	Meeting discussion	7	0	view	edit	delete
25/05/2018 14:52	Dio Antille	Collaboration with Dr Phil Moody (Department of Environment and Science)	Optimising nitrogen and water interactions in cotton	B3	B3	12/04/2018	Other	5	2	view	edit	delete
30/11/2017 16:20	Dio Antille	Meeting with Dr Chris Dowling (Back Paddock)	Optimising nitrogen and water interactions in cotton	6(a)	3.2	24/10/2017	Meeting discussion	3	0	view	edit	delete



Collaboration Details

Added by	Dio Antille
Added on	30/08/2018 14:02
Last updated	30/08/2018 14:02

Project Details

Project	Optimising nitrogen and water interactions in cotton
Project Output	B5 - Additional Output

Collaboration Details

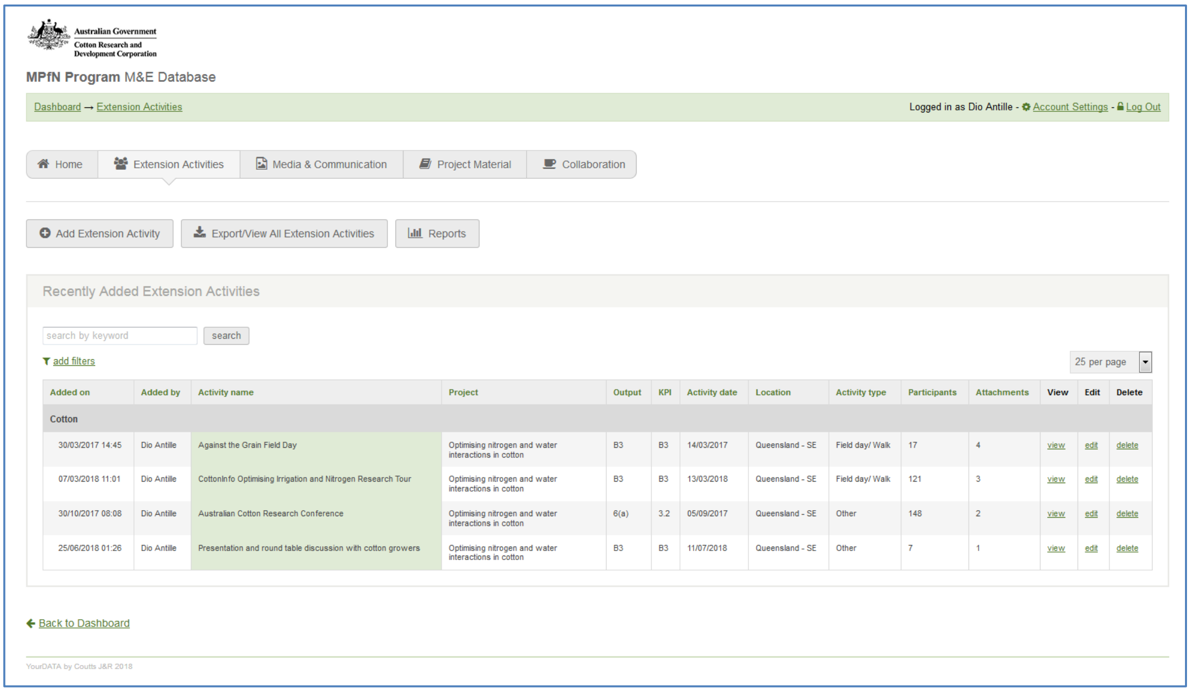
Collaboration Title	Collaboration with QUT on DSS development
Collaboration date	30/08/2018
Collaboration Type	Other
Collaboration Type - Other	Data sharing
Collaboration topic/s	Cross sector technology & innovation opportunities, Cross sector information exchange, Research findings/ outcomes
Collaboration description & lessons learnt	Analytical data has been facilitated from our project to the QUT team led by Prof Peter Grace (also Dr Clemens Scheer, Dr Max De Antoni) who are working with Dr Chris Dowling (Back Paddock) to further develop DSS currently used by the industry for nutrient budgeting purposes. Our data will go some way to assist in the testing/validation of DSS. Our final project report also provides recommendations as to how DSS tools may be improved with the use of our analytical/experimental data.

Participant Numbers

Number of researchers	7
Number of other participants	1
Total participants	8

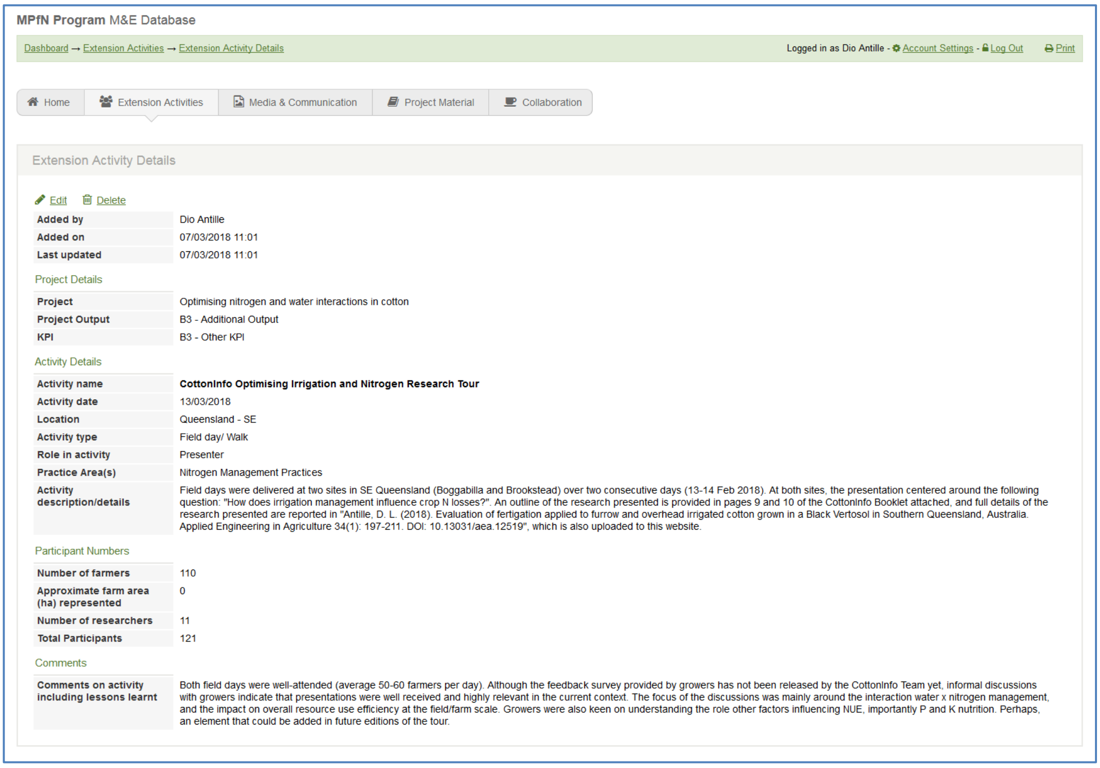
4 Extension and adoption activities

The image below is a screenshot taken from the MPfN Program M&E Database, which shows the extension activities conducted over the life of this project.



Added on	Added by	Activity name	Project	Output	KPI	Activity date	Location	Activity type	Participants	Attachments	View	Edit	Delete
Cotton													
30/03/2017 14:45	Dio Antille	Against the Grain Field Day	Optimising nitrogen and water interactions in cotton	B3	B3	14/03/2017	Queensland - SE	Field day/ Walk	17	4	view	edit	delete
07/03/2018 11:01	Dio Antille	CottonInfo Optimising Irrigation and Nitrogen Research Tour	Optimising nitrogen and water interactions in cotton	B3	B3	13/03/2018	Queensland - SE	Field day/ Walk	121	3	view	edit	delete
30/10/2017 08:08	Dio Antille	Australian Cotton Research Conference	Optimising nitrogen and water interactions in cotton	6(a)	3.2	05/09/2017	Queensland - SE	Other	148	2	view	edit	delete
25/06/2018 01:26	Dio Antille	Presentation and round table discussion with cotton growers	Optimising nitrogen and water interactions in cotton	B3	B3	11/07/2018	Queensland - SE	Other	7	1	view	edit	delete

The first activity listed on the table above comprises information about the presentations and field days that took place during the 2018 edition of the CottonInfo Researchers Tour. The following information was recorded in the database:



Added by	Dio Antille
Added on	07/03/2018 11:01
Last updated	07/03/2018 11:01

Project Details

Project	Optimising nitrogen and water interactions in cotton
Project Output	B3 - Additional Output
KPI	B3 - Other KPI

Activity Details

Activity name	**CottonInfo Optimising Irrigation and Nitrogen Research Tour**
Activity date	13/03/2018
Location	Queensland - SE
Activity type	Field day/ Walk
Role in activity	Presenter
Practice Area(s)	Nitrogen Management Practices
Activity description/details	Field days were delivered at two sites in SE Queensland (Boggabilla and Brookstead) over two consecutive days (13-14 Feb 2018). At both sites, the presentation centered around the following question: "How does irrigation management influence crop N losses?". An outline of the research presented is provided in pages 9 and 10 of the CottonInfo Booklet attached, and full details of the research presented are reported in "Antille, D. L. (2018). Evaluation of fertigation applied to furrow and overhead irrigated cotton grown in a Black Vertosol in Southern Queensland, Australia. Applied Engineering in Agriculture 34(1): 197-211. DOI: 10.13031/aea.12519", which is also uploaded to this website.

Participant Numbers

Number of farmers	110
Approximate farm area (ha) represented	0
Number of researchers	11
Total Participants	121

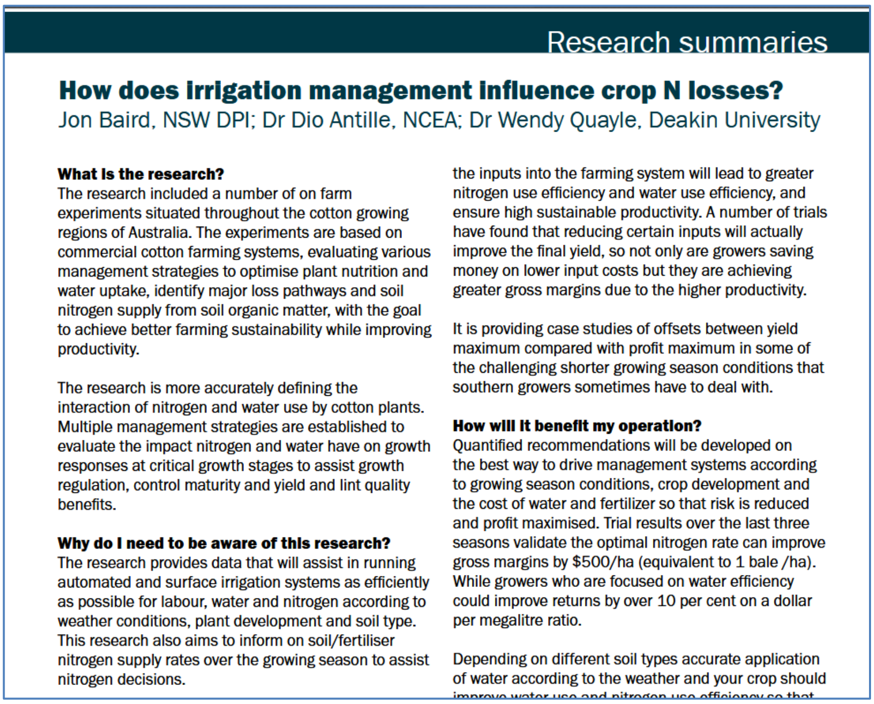
Comments

Comments on activity including lessons learnt	Both field days were well-attended (average 50-60 farmers per day). Although the feedback survey provided by growers has not been released by the CottonInfo Team yet, informal discussions with growers indicate that presentations were well received and highly relevant in the current context. The focus of the discussions was mainly around the interaction water x nitrogen management, and the impact on overall resource use efficiency at the field/farm scale. Growers were also keen on understanding the role other factors influencing NUE, importantly P and K nutrition. Perhaps, an element that could be added in future editions of the tour.

The activity described above carries the following documents, which are stored in the database:

- Antille, D. L., Nguyen-Ky, T., Aikins, K. A., Hussein, M. A. H., Singh, S., Luhaib, A. A. A., Singh, A. (2018). Evaluation of NEXEN™ stabilized nitrogen applied to overhead irrigated cotton (*Gossypium hirsutum* L.). ASABE Paper No.: 1800252. St. Joseph, MI.: American Society of Agricultural and Biological Engineers. DOI: 10.13031/aim.201800252.
- Antille, D. L. (2018). Evaluation of fertigation applied to furrow and overhead irrigated cotton grown in a Black Vertosol in Southern Queensland, Australia. *Applied Engineering in Agriculture, 34*(1): 197-211. DOI: 10.13031/aea.12519. Available here: [Open].
- Baird, J., Antille, D., Quayle, W. (2018). How does irrigation management influence crop N losses? In: Chaffey, A., Smith, J.: 2018 Optimising Irrigation and Nitrogen Research Tour. Tour Booklet, pp. 9-10. CottonInfo Team (www.cottoninfo.com.au) and CRDC (Australian Government). Available here: [Booklet] and [Open].

A screenshot of the CottonInfo booklet is shown below:



Research summaries

How does irrigation management influence crop N losses?

Jon Baird, NSW DPI; Dr Dio Antille, NCEA; Dr Wendy Quayle, Deakin University

What is the research?

The research included a number of on farm experiments situated throughout the cotton growing regions of Australia. The experiments are based on commercial cotton farming systems, evaluating various management strategies to optimise plant nutrition and water uptake, identify major loss pathways and soil nitrogen supply from soil organic matter, with the goal to achieve better farming sustainability while improving productivity.

The research is more accurately defining the interaction of nitrogen and water use by cotton plants. Multiple management strategies are established to evaluate the impact nitrogen and water have on growth responses at critical growth stages to assist growth regulation, control maturity and yield and lint quality benefits.

Why do I need to be aware of this research?

The research provides data that will assist in running automated and surface irrigation systems as efficiently as possible for labour, water and nitrogen according to weather conditions, plant development and soil type. This research also aims to inform on soil/fertiliser nitrogen supply rates over the growing season to assist nitrogen decisions.

the inputs into the farming system will lead to greater nitrogen use efficiency and water use efficiency, and ensure high sustainable productivity. A number of trials have found that reducing certain inputs will actually improve the final yield, so not only are growers saving money on lower input costs but they are achieving greater gross margins due to the higher productivity.

It is providing case studies of offsets between yield maximum compared with profit maximum in some of the challenging shorter growing season conditions that southern growers sometimes have to deal with.

How will it benefit my operation?

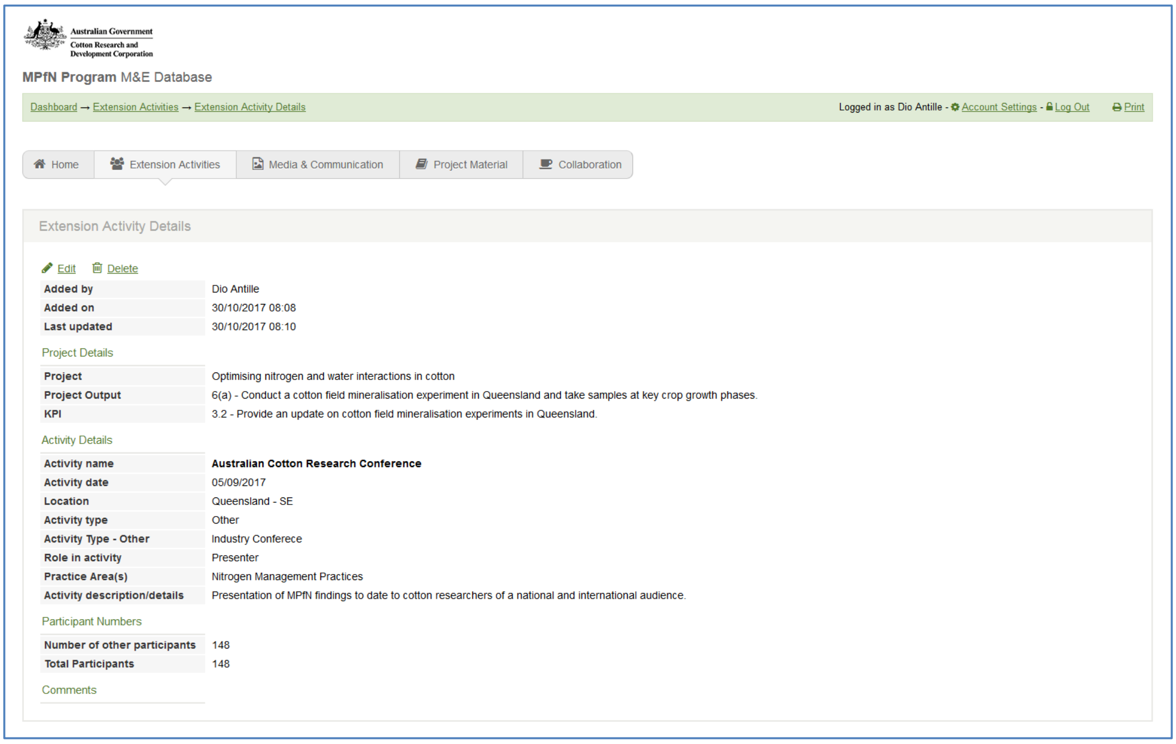
Quantified recommendations will be developed on the best way to drive management systems according to growing season conditions, crop development and the cost of water and fertilizer so that risk is reduced and profit maximised. Trial results over the last three seasons validate the optimal nitrogen rate can improve gross margins by $500/ha (equivalent to 1 bale /ha). While growers who are focused on water efficiency could improve returns by over 10 per cent on a dollar per megalitre ratio.

Depending on different soil types accurate application of water according to the weather and your crop should

A presentation was delivered at the 2017 edition of the Australian Association of Cotton Scientists (AACS) Conference in Canberra:

- Pittaway, P., Antille, D. L., Melland, A. R. (2017). Fertiliser N in root exclusion tubes monitored over a cotton growing season. Proc. of the Australian Cotton Research Conference 'SciCott2017: Cotton science delivering impact'. 5-7 Sept. 2017, CSIRO Discovery Centre, Canberra, ACT, Australia: The Association of Australian Cotton Scientists. Available here: [Open].

Both the paper and presentation submitted for presentation at the 2017 AACS Conference are stored in the database.



Added by	Dio Antille
Added on	30/10/2017 08:08
Last updated	30/10/2017 08:10

Project Details

Project	Optimising nitrogen and water interactions in cotton
Project Output	6(a) - Conduct a cotton field mineralisation experiment in Queensland and take samples at key crop growth phases.
KPI	3.2 - Provide an update on cotton field mineralisation experiments in Queensland.

Activity Details

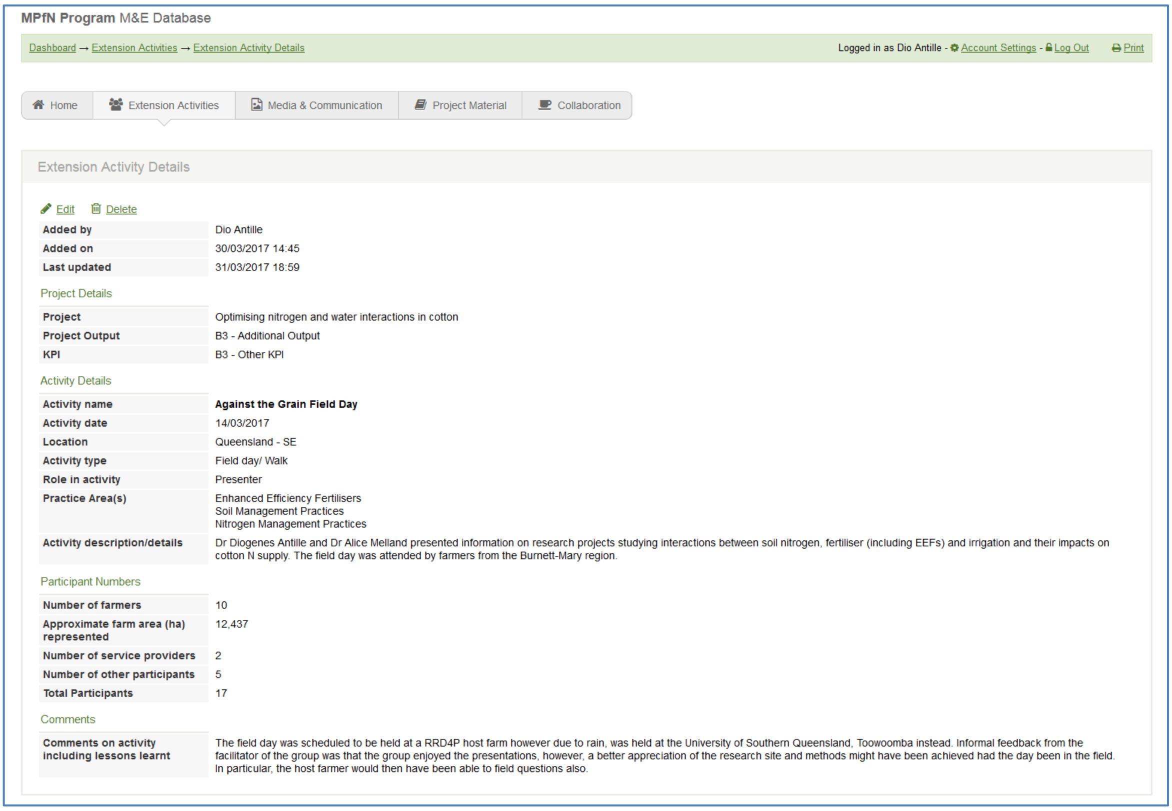
Activity name	**Australian Cotton Research Conference**
Activity date	05/09/2017
Location	Queensland - SE
Activity type	Other
Activity Type - Other	Industry Conferece
Role in activity	Presenter
Practice Area(s)	Nitrogen Management Practices
Activity description/details	Presentation of MPfN findings to date to cotton researchers of a national and international audience.

Participant Numbers

Number of other participants	148
Total Participants	148

Comments

The information provided below describes a field day activity organised by the Burnett Mary Regional Group on 15th March 2017 at which we presented information derived from this project. The information stored in the database includes the booklet, photographs taken on the day and a list of attendees.



Added by	Dio Antille
Added on	30/03/2017 14:45
Last updated	31/03/2017 18:59

Project Details

Project	Optimising nitrogen and water interactions in cotton
Project Output	B3 - Additional Output
KPI	B3 - Other KPI

Activity Details

Activity name	**Against the Grain Field Day**
Activity date	14/03/2017
Location	Queensland - SE
Activity type	Field day/ Walk
Role in activity	Presenter
Practice Area(s)	Enhanced Efficiency Fertilisers Soil Management Practices Nitrogen Management Practices
Activity description/details	Dr Diogenes Antille and Dr Alice Melland presented information on research projects studying interactions between soil nitrogen, fertiliser (including EEFs) and irrigation and their impacts on cotton N supply. The field day was attended by farmers from the Burnett-Mary region.

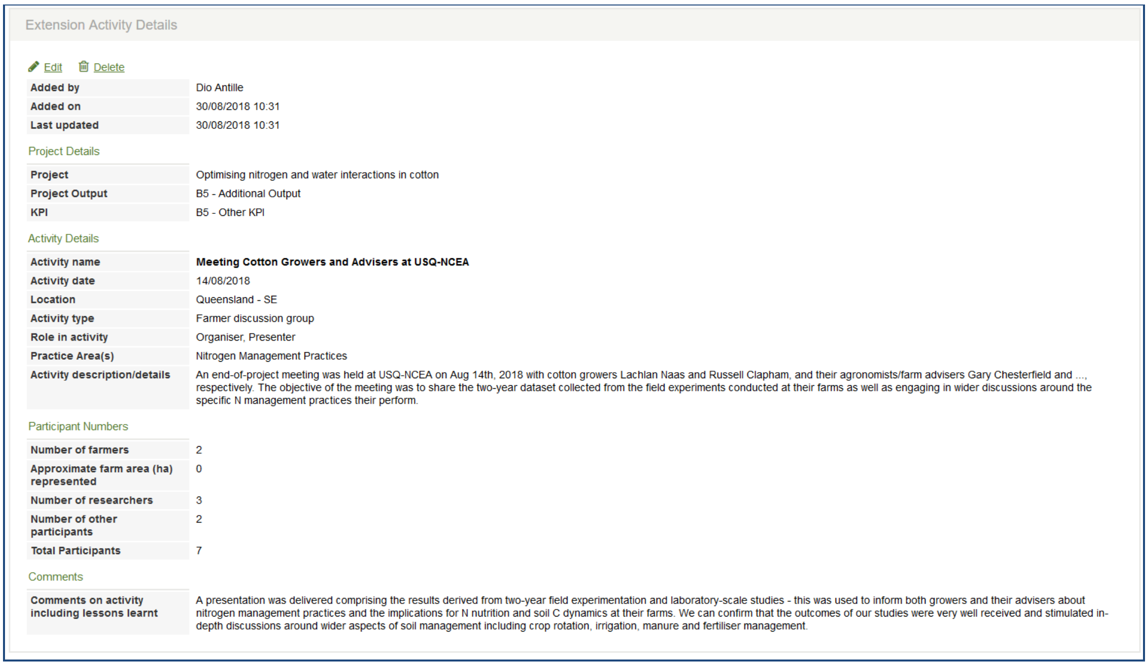
Participant Numbers

Number of farmers	10
Approximate farm area (ha) represented	12,437
Number of service providers	2
Number of other participants	5
Total Participants	17

Comments

Comments on activity including lessons learnt	The field day was scheduled to be held at a RRD4P host farm however due to rain, was held at the University of Southern Queensland, Toowoomba instead. Informal feedback from the facilitator of the group was that the group enjoyed the presentations, however, a better appreciation of the research site and methods might have been achieved had the day been in the field. In particular, the host farmer would then have been able to field questions also.

A round table discussion was held at USQ-CAE on 14th Aug 2018 with growers Lachlan Naas (Jondaryan, QLD), and Russell Clapham (Pittsworth, QLD) and both their agronomy advisers (Gary Chesterfield and Robert Boulton, respectively), who collaborated with us on this project by enabling access to their properties to establish the field experiments, and through several technical discussions around N management on-farm. We are able to report that the results derived from our work were very well received and that this end-of-project meeting provided a valuable opportunity to communicate the outcomes of this work to growers and technical advisers. The information stored in the database contains a copy of the presentation delivered at the meeting in USQ-CAE. Growers were also provided with a 1-page summary of key results and take-home message, and copies of publications by Antille (2018, *Applied Engineering in Agriculture*) and Antille et al. (2018, ASABE Paper No.: 1800252). Both these publications are stored in the MPfN database.



Extension Activity Details

Added by	Dio Antille
Added on	30/08/2018 10:31
Last updated	30/08/2018 10:31

Project Details

Project	Optimising nitrogen and water interactions in cotton
Project Output	B5 - Additional Output
KPI	B5 - Other KPI

Activity Details

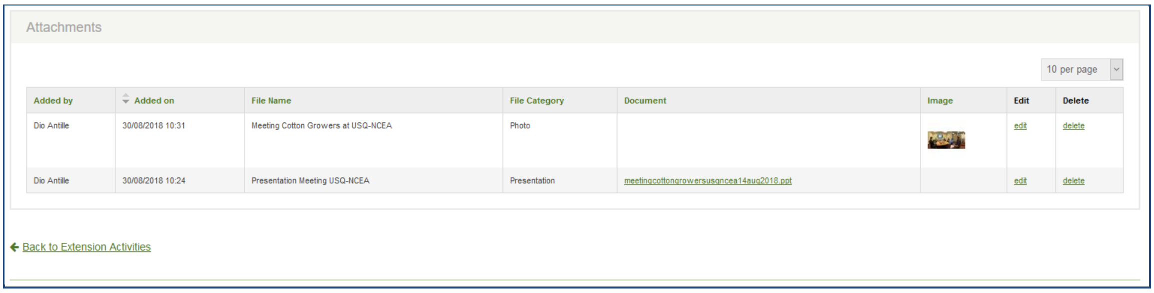
Activity name	**Meeting Cotton Growers and Advisers at USQ-NCEA**
Activity date	14/08/2018
Location	Queensland - SE
Activity type	Farmer discussion group
Role in activity	Organiser, Presenter
Practice Area(s)	Nitrogen Management Practices
Activity description/details	An end-of-project meeting was held at USQ-NCEA on Aug 14th, 2018 with cotton growers Lachlan Naas and Russell Clapham, and their agronomists/farm advisers Gary Chesterfield and ..., respectively. The objective of the meeting was to share the two-year dataset collected from the field experiments conducted at their farms as well as engaging in wider discussions around the specific N management practices their perform.

Participant Numbers

Number of farmers	2
Approximate farm area (ha) represented	0
Number of researchers	3
Number of other participants	2
Total Participants	7

Comments

Comments on activity including lessons learnt	A presentation was delivered comprising the results derived from two-year field experimentation and laboratory-scale studies - this was used to inform both growers and their advisers about nitrogen management practices and the implications for N nutrition and soil C dynamics at their farms. We can confirm that the outcomes of our studies were very well received and stimulated in-depth discussions around wider aspects of soil management including crop rotation, irrigation, manure and fertiliser management.



Attachments

Added by	Added on	File Name	File Category	Document	Image	Edit	Delete
Dio Antille	30/08/2018 10:31	Meeting Cotton Growers at USQ-NCEA	Photo			edit	delete
Dio Antille	30/08/2018 10:24	Presentation Meeting USQ-NCEA	Presentation	meetingcottongrowersusqncea14aug2018.ppt		edit	delete

5 Lessons learnt

Key lessons

- Field trials over two successive cotton seasons were successfully established and experiments completed with the help of highly collaborative growers and agronomy advisers.

- Even with highly collaborative growers, obtaining regular updates on irrigation volumes applied to fields was difficult. Soil moisture sensing in all experimental fields is therefore recommended for future research.

- The replacement of the Pittsworth site by a second site at Jondaryan had significant operational advantages in day-to-day running and monitoring of the experiments. This facilitated exchange of scientific outcomes with a closely related project led by QUT (AOTG-0008), which was seated at the same site. Sharing of analytical and experimental data derived from this work with the QUT team led by Prof Peter Grace is documented both in this report and the MPfN data base.

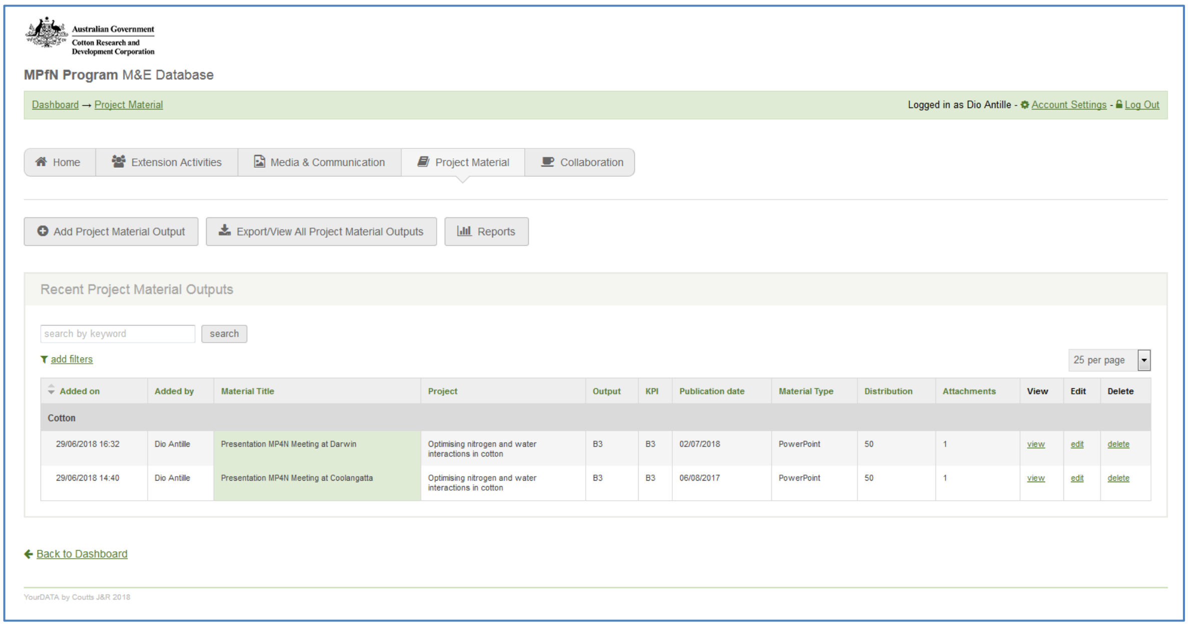
- Reliance on single laboratories for analytical work is beneficial for consistency of results, but this proved risky because one laboratory became unavailable for reasons outside the project's control and therefore an alternative laboratory was required. Comparative cross-laboratory analyses may be needed to evaluate any impacts of changing laboratories on interpretation of the results (specifically, different methods of analysis of soil water-extractable total N).

- Our data indicates that soil application of nitrogenous fertilisers can enhance the desorption of microbially-protected soil organic carbon fractions. This process can lead to increased dissolved organic carbon, which can have implications for N losses through denitrification, particularly around irrigation or rainfall events and also in situations where water-run urea (or fertigation) is practiced. Cropping systems that rely on high N inputs may therefore experience a more/less significant but progressive run-down in soil organic C stocks (long-term process), and as a result, reduced (long-term) N fertiliser use efficiency. Ongoing laboratory-scale investigations (leaching study) assisted in the understanding of these mechanisms.

6 Appendix

6.1 Project material and intellectual property

The following information is stored in the MPfN database:



Added on	Added by	Material Title	Project	Output	KPI	Publication date	Material Type	Distribution	Attachments	View	Edit	Delete
Cotton												
29/06/2018 16:32	Dio Antille	Presentation MP4N Meeting at Darwin	Optimising nitrogen and water interactions in cotton	B3	B3	02/07/2018	PowerPoint	50	1	view	edit	delete
29/06/2018 14:40	Dio Antille	Presentation MP4N Meeting at Coolangatta	Optimising nitrogen and water interactions in cotton	B3	B3	06/08/2017	PowerPoint	50	1	view	edit	delete

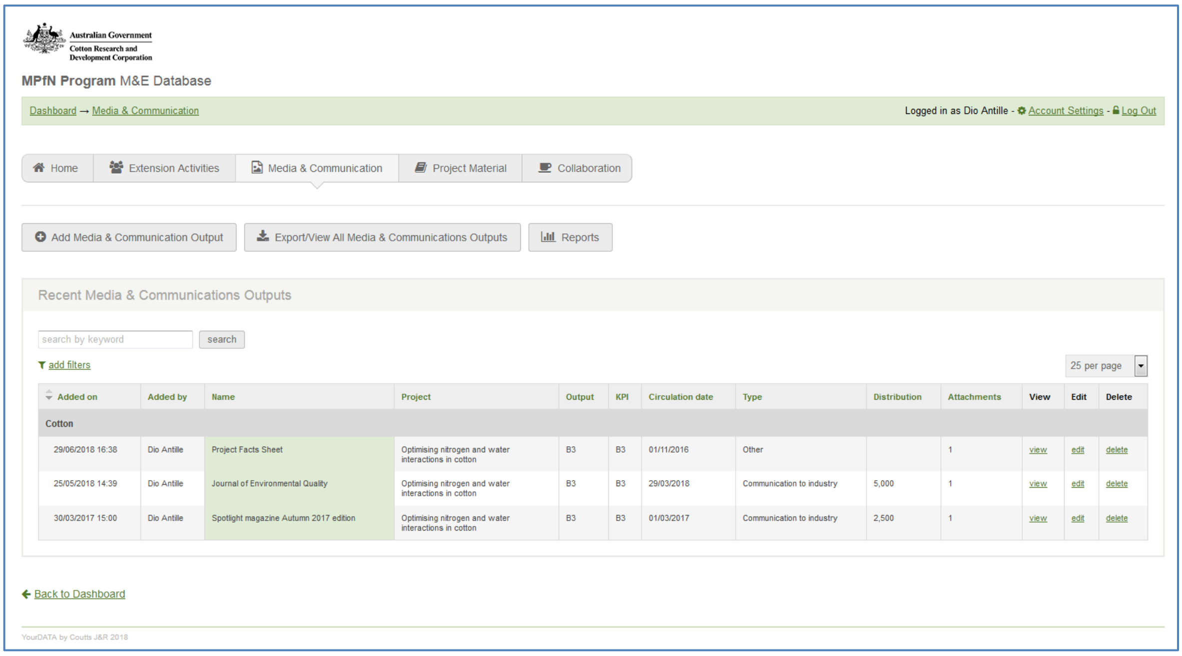
The presentations delivered at the meetings in Coolangatta in August 2017, Darwin in July 2018 and the workshop held at USQ-CAE with growers and advisers comprise a summary of the key experimental results derived from this project, along with an overview of the leaching study. We anticipate that at least one article will be produced after the completion of this project for publication in a scientific journal. Other project material was mentioned earlier and included the paper presented at the 2017 AACS.

6.2 Equipment and assets

The project acquired a digital 20-L Shaking Water Bath, which was used to incubate samples while maintaining a constant temperature. The desired temperature and speed range for this equipment are 5-99°C and 20-200 rpm, respectively. The cost was $4215.

6.3 Media and communications material

The following media and communications material is stored in the MPfN database:



Recent Media & Communications Outputs

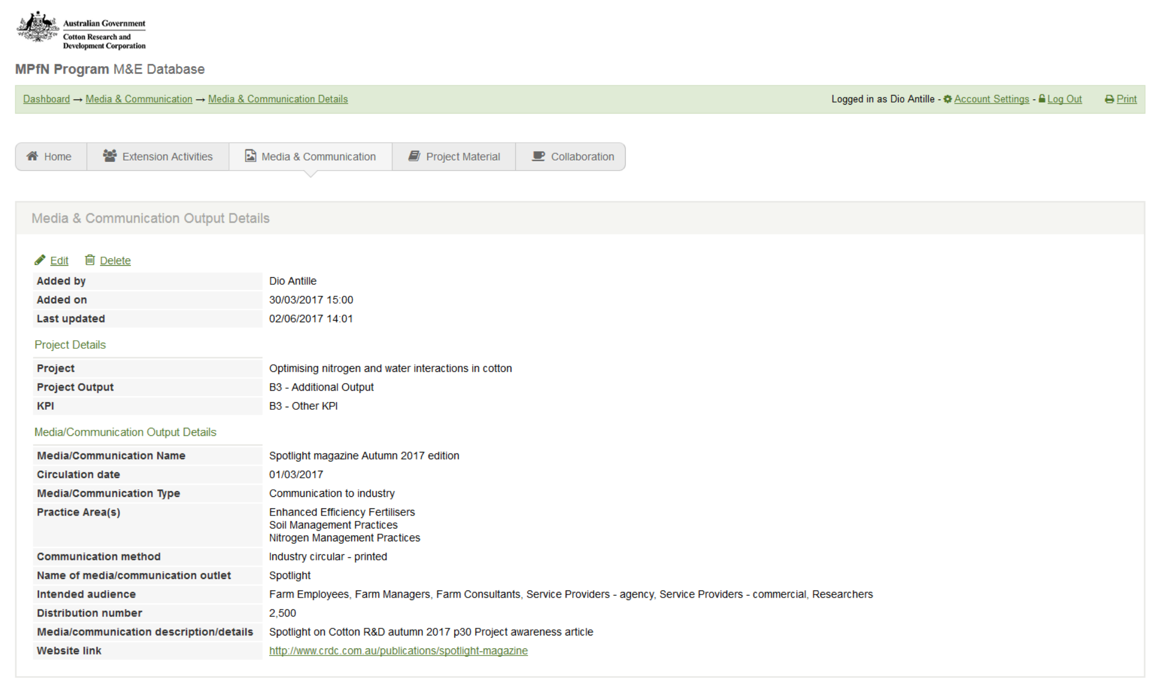
Added on	Added by	Name	Project	Output	KPI	Circulation date	Type	Distribution	Attachments	View	Edit	Delete
Cotton												
29/06/2018 16:38	Dio Antille	Project Facts Sheet	Optimising nitrogen and water interactions in cotton	B3	B3	01/11/2016	Other		1	view	edit	delete
25/05/2018 14:39	Dio Antille	Journal of Environmental Quality	Optimising nitrogen and water interactions in cotton	B3	B3	29/03/2018	Communication to industry	5,000	1	view	edit	delete
30/03/2017 15:00	Dio Antille	Spotlight magazine Autumn 2017 edition	Optimising nitrogen and water interactions in cotton	B3	B3	01/03/2017	Communication to industry	2,500	1	view	edit	delete

A 1-pager project fact sheet was produced incorporated to the Programme Overview Booklet produced and distributed by the programme.

The scientific article published in the Journal of Environmental Quality by Pittaway et al. (2018) was not derived from this project, but it was used to inform the project, and specifically the leaching study. Full details of this publication are given below:

- Pittaway, P. A., Melland, A. R., Antille, D. L., Marchuk, S. 2018. Dissolved organic carbon in leachate after application of granular and liquid N-P-K fertilizers to a sugarcane soil. *Journal of Environmental Quality* (Section: Vadose Zone Processes and Chemical Transport) 47(3): 522-529. DOI: 10.2134/jeq2017.11.0433. Available here: [Open].

A short communication article was published in the Spotlight Magazine in March 2017. The information stored in the database contains the following:



Media & Communication Output Details

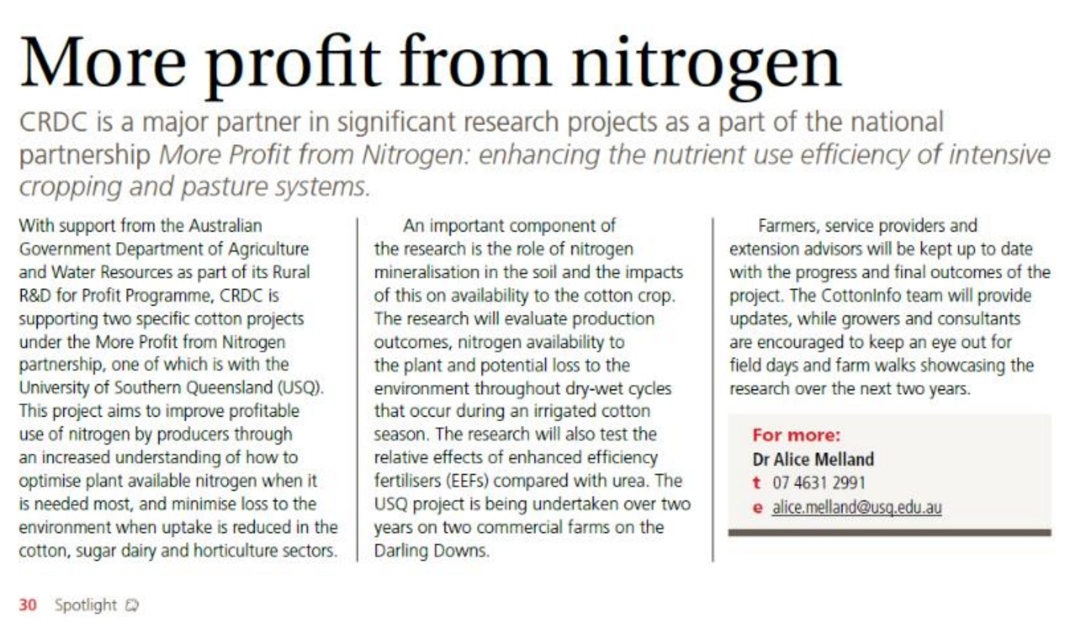
Added by	Dio Antille
Added on	30/03/2017 15:00
Last updated	02/06/2017 14:01

Project Details

Project	Optimising nitrogen and water interactions in cotton
Project Output	B3 - Additional Output
KPI	B3 - Other KPI

Media/Communication Output Details

Media/Communication Name	Spotlight magazine Autumn 2017 edition
Circulation date	01/03/2017
Media/Communication Type	Communication to industry
Practice Area(s)	Enhanced Efficiency Fertilisers Soil Management Practices Nitrogen Management Practices
Communication method	Industry circular - printed
Name of media/communication outlet	Spotlight
Intended audience	Farm Employees, Farm Managers, Farm Consultants, Service Providers - agency, Service Providers - commercial, Researchers
Distribution number	2,500
Media/communication description/details	Spotlight on Cotton R&D autumn 2017 p30 Project awareness article
Website link	http://www.crdc.com.au/publications/spotlight-magazine



More profit from nitrogen

CRDC is a major partner in significant research projects as a part of the national partnership *More Profit from Nitrogen: enhancing the nutrient use efficiency of intensive cropping and pasture systems.*

With support from the Australian Government Department of Agriculture and Water Resources as part of its Rural R&D for Profit Programme, CRDC is supporting two specific cotton projects under the More Profit from Nitrogen partnership, one of which is with the University of Southern Queensland (USQ). This project aims to improve profitable use of nitrogen by producers through an increased understanding of how to optimise plant available nitrogen when it is needed most, and minimise loss to the environment when uptake is reduced in the cotton, sugar dairy and horticulture sectors.

An important component of the research is the role of nitrogen mineralisation in the soil and the impacts of this on availability to the cotton crop. The research will evaluate production outcomes, nitrogen availability to the plant and potential loss to the environment throughout dry-wet cycles that occur during an irrigated cotton season. The research will also test the relative effects of enhanced efficiency fertilisers (EEFs) compared with urea. The USQ project is being undertaken over two years on two commercial farms on the Darling Downs.

Farmers, service providers and extension advisors will be kept up to date with the progress and final outcomes of the project. The CottonInfo team will provide updates, while growers and consultants are encouraged to keep an eye out for field days and farm walks showcasing the research over the next two years.

For more:
Dr Alice Melland
t 07 4631 2991
e alice.melland@usq.edu.au

30 Spotlight

6.4 Budget

The 2017-18 budget acquittal was submitted by 31st July 2018. A final Statement of Expenditure & Receipts was submitted on Monday 17th December 2018.

6.5 Contribution from this project to the work led by QUT on DSS

The QUT Team led by Prof Peter Grace has undertaken work to perform a DSS inter-comparison. Experimental data collected from across sites in SE QLD, including NAS and CPL, over three cotton seasons are being used to assess N fertiliser recommendations provided by the following tools:

- NutriLOGIC (CottASSIST),
- N-$mart (COOLER COTTON)
- SoilMate (Backpaddock)
- CotNPlan (Backpaddock)

The assessment is in three stages: The first two stages aim at assessing, for each calculator, how close N recommendations derived from the DSS compare with N used on-farm for given target yields. The third stage will consist of a sensitivity analysis that aims to identify how much N recommendations varied between-DSSs depending on the amount of soil N present prior to crop establishment. During the first stage the calculators are run for each site using a dataset that included:

- Field location
- Soil physico-chemical properties (texture, organic matter, pH, bulk density)
- Pre-season soil mineral N content measured each year in September/October
- Cotton variety
- Irrigation amount
- Rotation/Cropping history
- Target yield

Cottonseed N will be also used as an input parameter at a later stage in the assessment. This approach was adopted because some models such as SoilMate and CropNPlan estimate the crop N requirements using cottonseed N as a proxy for the crop N uptake, and therefore seasonal N requirements. The final inter-comparison of the four calculators will determine the fertiliser N recommendations depending on pre-season soil mineral N levels and cropping history. Each calculator will be run 20 times using the soil characteristics of the site with the highest crop response to different N rates. Each run consisted of a combination of four cropping sequences (cotton-cotton, cotton-cereal, cotton-fallow, cotton-legume), and five mineral N levels in the top 30 cm of soil (i.e., 10, 20, 40, 60, and 80 kg N ha^{-1}).

Our project (MPfN Project No.: RRDP1713) has contributed with data from both the Jondaryan and Pittsworth sites in SE QLD to help parameterise the DSS being tested. Data supplied to QUT included: soil physico-chemical properties, irrigation and rainfall records and crop rotation history.