



Rural R&D for Profit Program

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More Profit from Nitrogen:

enhancing the nutrient use efficiency of intensive
cropping and pasture systems

Final Report

30 September 2021

Cotton Research and Development Corporation

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Visit: www.crdc.com.au/more-profit-nitrogen

A research collaboration between the Australian agricultural sectors of cotton, dairy, sugar and horticulture with the support of the Australian Government Department of Agriculture, Water and the Environment as part of its Rural R&D for Profit program.



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Plain English summary

Achievement of MPfN Program aim and objectives

The More Profit from Nitrogen: enhancing the nutrient use efficiency of intensive cropping and pasture systems program (MPfN Program) was a five-year research collaboration between Australia's four most intensive users of nitrogen (N) fertiliser: cotton, dairy, sugar and horticulture. The Program was led by the Cotton Research and Development Corporation (CRDC) in partnership with Dairy Australia Ltd (DA), Sugar Research Australia Ltd (SRA) and Horticulture Innovation Australia Ltd (Hort Innovation). There were ten primary research projects, conducted over varying timeframes, delivered through the collaborative effort: 2 cotton, 3 dairy, 3 sugar and 2 horticulture (cherry & mango tree crops).

The individual final reports of these projects can be viewed on the MPfN Program website:

<https://www.crdc.com.au/more-profit-nitrogen> .

The aim of the MPfN Program was to deliver research that would provide necessary step-change knowledge and understanding sought by each of the industries to reduce the amount of applied N required to produce a unit of product. By developing improved in-depth understanding of the interacting influence of a broad range of factors on N use efficiency (NUE) in farming systems, the MPfN Program expertly delivered upon its core objectives to:

- Generate greater knowledge and understanding of the interplay of factors to optimise N formulation, rate and timing across industries, farming regions and irrigated/ non-irrigated situations;
- Generate greater knowledge and understanding of the contribution (quantifying rate and timing) of mineralisation to crop or pasture N budgets; and
- Generate greater knowledge and understanding of how Enhanced Efficiency Fertiliser (EEF) formulations can better match a crop or pasture specific N requirements.

Drivers for improved NUE

The industries involved in the MPfN Program each share common markets that have growing expectations for producers to adopt sustainable farming practices and environmental risk management systems. Additionally, most sugarcane producing regions of Queensland are located within regulated catchments of the Great Barrier Reef and therefore economical and tactical N strategies needed to focus upon improved water quality leaving the farm.

Through unprecedented collaboration between industries and research institutions, the MPfN Program provided NUE improvement strategies that have been demonstrated to deliver immediate and longer-term economical gains for farmers. In contrast to a standardised 'one size fits all' regulatory approach, proactive industry engagement in development of scientifically robust N Best Management Practices (BMPs) and supporting Decision Support Systems (DSS), provides ongoing malleability for the implementation of appropriate NUE solutions, adapted to localised conditions and farming systems.

Method

The ten primary projects were delivered by eight leading government and university research agencies, together with a further 22 collaborating partners, encompassing 93 interacting research, technical and student positions (Masters and PhD).

The MPfN Program, and its stakeholder involvement, was far reaching. Research activity was located from Darwin in the north, to Hobart in the south of Australia. Forty-five (45) fully replicated and randomised research trials were conducted on both commercial and research farms, with a further 49 sites used in deep soil sampling campaigns. Trials were conducted for one to four years. Thirteen (13) research facilities were also used for glasshouse, simulation, modelling and laboratory analysis activities.

A major coup for the MPfN Program was its significant success in supporting cross-program collaboration activities, largely beyond the original scope of program works. The results of cooperative efforts assisted in:

- Testing and refining a standardised approach to soil N mineralisation measurement methods and analysis of potentially mineralisable N (PMN) for predictive purposes;
- Providing agreement on potential NUE indicators and model parameters for Australian agricultural sectors, assisting to form a common language more easily understood by multi-disciplinary research teams and markets;
- Establishing agreement on a minimum data-set for MPfN Program research projects and proposed for future NUE research in Australian agriculture;
- Expediting understanding of the potential use of remote sensing technology in NUE research measurement and future on-farm applications; and
- Preparing economic case studies to demonstrate benefit to farm profitability and sustainability in adopting researched NUE strategy recommendations for each industry, as well as potential legacy impacts across all industries.

In parallel with research activities, the MPfN Program delivered a comprehensive extension and communication program of activities.

Outcomes/ Outputs

The MPfN Program successfully achieved its overall aim of delivering scientifically robust research findings for each sector that informed the development of BMPs and DSS to optimise NUE on farm. It also demonstrated benefit to farm business profitability and environment sustainability of adopting recommended strategies and realised the potential for each sector to significantly reduce the amount of N required to produce each unit of product (crop or pasture yield), without production loss and with improved crop/pasture quality. The key achievements for each industry are:

Cotton

- Increased understanding of the intricate relationship between N supplied through soil mineralised and fertiliser sources, phosphorus (P) supply, fertiliser placement & timing, and irrigation strategy to achieve greater NUE and improve P soil nutrition.

- Recommendations integrated onto the *Australian Cotton Production Manual* (Chapter 8- Nutrition), including demonstrated improved practices relating to:
 - Considering residual soil mineral N from previous seasons and in-season soil organics matter (SOM) mineralisation in calculation of N fertiliser requirements;
 - **Timing of urea fertiliser applications**- split N application considerations and P application benefits prior to cover cropping;
 - **Application strategies**- improvements using side-dressed urea V broadcast and water-run urea, and improvements in using P mixed into the bedding vs. banding.
 - **Rates of N application** reduced to within the *myBMP* guidelines, to adequately meet crop needs and decrease risk of environmental and profit loss;
 - Irrigation strategies to avoid loss via N runoff and denitrification, as well as mitigating excessive vegetative growth at the expense of lint production; and
 - **Sources of N**- the benefits of using of Polymer Coated Urea (PCU) to reduce losses, when compared with urea, in the first two irrigations and economic considerations in the use of PCU; and
 - Combined N/P/irrigation interaction considerations to optimise yield and quality outcomes.

Dairy

- Increased understanding of the interactions between N application (including EEFs), soil mineralised N and irrigation in sub-tropical dairy pasture systems of Australia;
- Increased understanding, and quantified, seasonal N supplied through mineralisation to irrigated and non-irrigated dairy pasture systems of south-eastern Australia, including the role of EEFs;
- Greater knowledge of the use of remote sensing technologies to determine pasture N requirements and measure/predict N plant content and yield;
- Development of an industry nutrient calculator that accounts for mineralised available N, specifically for south-west Victoria's dairy region. The concept is transferable for use in other regions, with localised data;
- The Australian dairy industry's *DairyMod* used to test and validate industry Fert\$mart N BMPs across most dairy farming regions of Australia;
- Production and economic benefits determined in adopting a seasonally modified N application approach, based on seasonal conditions and local growth potential, rather than a fixed N rate. A calculated return of an additional \$162-\$226/ha/year, dependent upon dairy region; and
- Updated *Fert\$mart nitrogen guidelines* and a new *Fert\$mart nitrogen pocket guide* developed, published and extended to the Australian dairy industry, including farmers, extension personnel and farm nutrient and business advisors. These resources have used the 4Rs principles of right rate, right place, right time and right source, with consideration of mineralised soil N contributions and managing losses (ammonia volatilisation, nitrate leaching, denitrification and run-off) in rain-fed and irrigation systems across all dairying regions of Australia.

Sugar

- Targeted formulation and management technique options developed, trialled and evaluated to better match N release to cane crop demand by controlling N transformation and solubility;

- Assessment of N stores in soils of the NSW growing region to improve understanding of N supplied from mineralisation and determination of optimal economic and seasonal use of EEFs to better match crop N demand and reduce environmental losses;
- Determination of optimal blending ratios of EEFs with conventional urea to better match sugarcane crop N dynamics and reduce environmental losses; and
- Recommendations prepared on opportunities to refine the industry nutrient guidelines, the Six-East-Steps, by testing for mineral N and potentially mineralisable N (PMN) and integrating use of the developed decision tree for selecting an EEF based upon possible agronomic, environmental and economic benefit.

Horticulture

- Determination of plant N uptake and cycling through the soil-plant-atmosphere system of cherry and mango tree crops, including distribution and storage of N within the tree, using the ¹⁵N stable isotope and undertaking litter, mulch and prune material studies;
- Determination and quantification of the contribution of soil mineralised N to the overall tree crop N budget;
- Improved understanding of the relationship between N supply and fruit yield and quality (skin colour, firmness and taste);
- Preparation of recommendations, to inform new N use guidelines, on N application timing, rate, placement and source, including biological (cherries) and EEF (mangoes) options; and
- Publication of new N use guidelines for cherry tree crops.

Program Achievements

Extension Activities

- 173 events delivered: field days, workshops, technical training, discussion groups and conferences (industry & research)).
- 16,044 people directly engaged in the MPfN Program via these events.

Media, Communications & Project Materials

- 249 outputs: industry/ research agency publications (eNewsletters/socials/magazines), intra-program partner newsletter (*Nitrogen Natters*), agriculture media printed and web articles, websites, conference presentations/ proceedings, research papers and journal publications.
- 477,674 distributions

Formal Collaborations

- 77 activities: intra-program, inter-industry and intra-industry forums, meetings and cooperative research activities.
- 1,462 people directly involved in intra and external program additional collaboration initiatives.

Benefits to industry/ primary producers

The MPfN Program has supported each industry to update or develop new guidance to primary producers on N (and P for cotton) fertiliser BMPs to increase NUE. The short-term outcome for farm business profit is reduced input costs through improved strategic use of N fertiliser using the right rate, in the right place (spatially and within crop), at the right time (according to seasons, crop stage and daily weather), using the right source (N fertiliser type/ mix, use of advanced technologies) for

localised conditions and farming systems, resulting in optimal plant uptake and reduced loss to the environment. Increased profit margin potential has also been demonstrated through improvements to yield and product quality, increasing overall farm income.

Each of the industries can be confident that the soil can supply much of the crop/ pasture N requirements, often dependent upon time of year and seasonal climatic conditions and should be including soil supplied N in budgeting BMPs and tools. Primary producers can be more confident that they can decrease N application rates and overall farm N inputs by using industry tools that account for mineralised soil N sources.

By better understanding the influence of certain management practices upon available N to the plant across seasons/ crop stage, such as soil moisture, supply of organic matter or vigour control, the MPfN Program has also demonstrated ways that farmers can further optimise plant growth or food/ fibre yield and quality other than through N fertiliser alone. Managing soil health is key to maximising N contribution from the soil.

The MPfN Program has delivered new soil function, plant physiology, measurement techniques and remote sensing knowledge, not only to the four contributing sectors, but more broadly to the benefit of Australian agriculture. Future research will draw-upon not only the findings, but the methods and agreed benchmarks and datasets used to undertake the MPfN Program.

Future research and adoption by industry/primary producers

Cumulatively, the projects of the MPfN Program agree that future research on the influence of changing climatic conditions and weather events on N soil dynamics and losses will be needed. Moreover, the common recommendation across all industries, that seasonally modified and climate-responsive N management strategies should be adopted, signifies that annual, seasonal and weekly weather forecasting models need to deliver increased accuracy and these should be embedded seamlessly into N budget calculators/ DSS.

The MPfN Program has demonstrated how important the breakdown of organic material, such as harvest/ tree litter residues and soil organic matter (SOM), is to releasing plant available N to a crop/ pasture. Although it has succeeded in determining N contribution amounts, more is needed on building confidence in predictive measurement methods, across more soil types, regional climate zones and individual farming systems before incorporating into N budget calculators/ DSS with categoric confidence for the entire geographic diversity of an industry.

Advancements in technologies to aid in NUE have been investigated by several projects, though not as core activities. The use of remote sensing technologies to measure and predict soil N contributions and plant N uptake/ demand at varying crop and seasonal phases has potential to improve real-time decision making by farmers and will assist to address both considerations above. Further focused collaborative research is needed, especially development of remote sensing capabilities for areas with challenging climates that decrease the confidence in data outputs.

A coordinated and comprehensive review, analysis and modelling of all data collected in completed and current EEf experiments in Australian agricultural systems has been recommended by projects who conducted work in this area. This will assist to improve understanding of the factors, processes and complex interactions needed to determine the agronomic, economic and environmental

benefits of EEFs, and more accurately identify where, when, what, and how EEFs should be used across multiple Australian agricultural sectors.

Whilst there were challenges highlighted in the first four years of the MPfN Program on broad-scale adoption of improved NUE strategies, due to urea N being a relatively cheap “insurance”, the price of urea has doubled since September 2020. This means that the profitability outcomes of the MPfN Program have become more enticing to primary producers of late and has prepared them for more expensive N costs in the future. Additionally, the MPfN Program has demonstrated the longer-term benefits of NUE BMP adoption through future participation of industry and producers in sustainability incentive programs, carbon markets or premium green labelling schemes. A case study developed by the MPfN Program modelled the economic impact of participation in a theoretical N BMP certification scheme. It showed that a 1% product premium can be achieved with significant economic returns and immediate payback, including consideration of set-up and on-going audit costs, particularly in high-value (per ha) crops such as cotton and cherries. Further detailed work should be completed to demonstrate how N BMP adoption provides longer-term economic outcomes for farmers.

Abbreviations and glossary

Ammonia (NH_3)

Best Management Practices (BMPs)

Cotton Research and Development Corporation (CRDC)

Dairy Australia Ltd (DA)

Decision Support Systems (DSS)

Dimethylpyrazole phosphate, a nitrification inhibitor (DMPP)

Dinitrogen gas (N_2)

Dissolved Organic Matter (DOM)

Dry matter (DM)

Enhanced Efficiency Fertiliser (EEF)

Fert\$mart (Dairy industry nutrient management program)

fNUE (fertiliser nitrogen use efficiency)

Horticulture Innovation Australia Ltd (Hort Innovation)

More Profit from Nitrogen: enhancing the nutrient use efficiency of intensive cropping and pasture systems program (MPfN Program)

myBMP- Cotton industry voluntary farm and environmental management system, including a Soil Health module.

Nitrogen (N)

Nitrogen Use Efficiency (NUE)

Nitrous oxide (N_2O)

Polymer Coated Urea (PCU)

Potentially mineralisable nitrogen (PMN)

Six Easy Steps (6ES- Sugar industry nutrient management program)

Soil Organic Matter (SOM)

Sugar Research Australia Ltd (SRA)

1. Introduction to the MPfN Program

1.1 Delivery

The *More Profit from Nitrogen: enhancing the nutrient use efficiency of intensive cropping and pasture systems program* (MPfN Program) was a five-year research collaboration between Australia's four most intensive users of nitrogen (N) fertiliser: cotton, dairy, sugar and horticulture. The Program was led by the Cotton Research and Development Corporation (CRDC) in partnership with Dairy Australia Ltd (DA), Sugar Research Australia Ltd (SRA) and Horticulture Innovation Australia Ltd (Hort Innovation). There were ten primary research projects, conducted over varying timeframes, delivered through the collaborative effort. The projects were:

Cotton

- **RRDP12** *Enhancing nutrient use efficiency use in cotton*, led by the NSW Department of Primary Industries (2016-2021).
- **RRDP13** *Optimising nitrogen and water interactions in cotton*, led by the University of Southern Queensland (Centre for Engineering in Agriculture) (2016-2018).

Dairy

- **RRDP14** *Increasing nitrogen use efficiency in dairy pastures*, led by Queensland University of Technology (2016-2019).
- **RRDP15** *Improving dairy farm nitrogen efficiency using advanced technologies*, led by The University of Melbourne (2016-2019).
- **RRDP16** *Quantifying the whole farm systems impact of nitrogen best practice on dairy farms*, led by The University of Melbourne (2016-2020).

Sugar

- **RRDP17** *Improved nitrogen use efficiency through accounting for deep soil and mineralisable N supply, and deployment of Enhanced Efficiency Fertilisers to better match crop N demand*, led by NSW Department of Primary Industries (2016-2020)
- **RRDP18** *Smart blending of Enhanced Efficiency Fertilisers to maximise sugarcane profitability*, led by the Queensland Government Department of Environment and Science (2016-2020).
- **RRDP19** *New technologies and managements: transforming nitrogen use efficiency in cane production*, led by the Queensland Government Department of Agriculture and Fisheries (2016-2021).

Horticulture

- **RRDP20** *Optimising nutrient management for improved productivity and fruit quality in mangoes*, led by the Northern Territory Government Department of Industry, Tourism and Trade (2016-2021).
- **RRDP21** *Optimising nutrient management for improved productivity and fruit quality in cherries*, led by the University of Tasmania-Tasmanian Institute of Agriculture (2016-2020).

The individual final reports of these projects can be viewed on the MPfN Program website:

<https://www.crdc.com.au/more-profit-nitrogen> .

1.2 MPfN Program aim and objectives

The aim of the MPfN Program was to deliver research that would provide necessary step-change knowledge and understanding sought by each of the industries to reduce the amount of applied N required to produce a unit of product. By developing improved in-depth understanding of the interacting influence of a broad range of factors on N use efficiency (NUE) in farming systems, the MPfN Program objectives were to:

- Generate greater knowledge and understanding of the interplay of factors to optimise N formulation, rate and timing across industries, farming regions and irrigated/ non-irrigated situations;
- Generate greater knowledge and understanding of the contribution (quantifying rate and timing) of mineralisation to crop or pasture N budgets; and
- Generate greater knowledge and understanding of how Enhanced Efficiency Fertiliser (EEF) formulations can better match a crop or pasture specific N requirements.

Through improvements in knowledge and understanding, the MPfN Program strived to bring about profitability improvement through the testing and adoption of amended and new proposed practices and technologies that provided the greatest potential to deliver improved NUE.

The MPfN Program was operated under three key focus areas for improving productivity and profitability of N use. Each of the ten projects conducted research under one, two or three of these:

- Activity B4- Extracting value from enhanced efficiency fertilisers (EEFs).
- Activity B5- Optimising NUE in irrigated systems.
- Activity B6- Understanding N supply through mineralisation.

The activities of research were supported by program planning and management (Activity B1 and B2). A Science Coordinator was engaged to develop and implement the project plan, communications and extension plan (Activity B3) and monitoring and evaluation plan. The role was also responsible for preparing and coordinating collaboration activities across the program, as well as supporting external collaborations with stakeholder groups who needed to be engaged due to their significant role in the extension and adoption of the MPfN Program outcomes. These included industry extension programs (e.g., Cotton Info, DA and SRA extension programs), industry groups (e.g., Fertiliser Australia, Cherry Growers, Australian Mango Industry Association, Sugarcane Productivity Services), private consultancies and government service providers (e.g., regional NRM organisations, state government departments).

A Program Management Committee (PMC) was established and met at least twice annually under agreed Terms of Reference. The PMC was comprised of the Science Coordinator, project management representative (CRDC- Allan Williams), representatives from each of the partnering research and development corporations (RDCs) and research organisation and/or project leader representatives.

1.3 MPfN Program rationale

The industries involved in the MPfN Program each share common markets that have growing expectations for producers to adopt sustainable farming practices and environmental risk management systems. Additionally, most sugarcane producing regions of Queensland are located within regulated catchments of the Great Barrier Reef and therefore economical and tactical N

strategies need to focus upon improved water quality leaving the farm. The outcomes of the MPfN Program sought to provide opportunity for the industries to demonstrate what they are doing to produce high quality food and fibre with the lowest environmental impact, most profitably for the economic sustainability of Australian agriculture.

Nitrogen is essential for plant growth and it is a key profit driver for the four MPfN Program agricultural industries. However, the N cycle is complex and N availability for plant growth is affected by a series of inter-connected, often location specific, factors such as climatic and weather conditions, soil type and condition, historical paddock/field N management, irrigation management, and source, placement, timing and rate of applied N fertiliser within season/crop.

The use of N intensified Australian agriculture over many years, enabling increased production from each hectare (ha) of farmed land. Urea, the most common source of N fertiliser used in Australia, has increased in its economic viability for farmers more recently, but increased use has not necessarily equated to relative production gains. Oversupply of N above what can be readily taken-up by a plant reduces NUE, increasing the risk of loss to the environment through known pathways (ammonia volatilisation, nitrate leaching, denitrification and run-off), reducing the quality of product produced (e.g., producing excessive vegetative growth at the expense of cotton lint, mango fruit maintaining green skin while ripening) and causing plant disease and animal health issues (e.g., nitrate poisoning in dairy herds).

Previous research had identified high level information on the importance of soil mineralisation processes in contributing N to pastures and crops. Wet/dry cycles between rainfall and/or irrigation events were known to have a major impact on N mineralisation patterns, conversion of N in fertiliser into nitrate, the risk of N being leached or lost via gaseous emissions and resulting NUE. Similarly, dissolved organic N (DON) was known to constitute a large N pool in the soil for microbial mineralisation and subsequent plant uptake or loss via leaching or gaseous emission pathways. However, how different farming practices, N fertiliser formulations (including EEFs), and the rate and timing of fertiliser and irrigation applications affect the rate at which microbes degrade soil organic matter, and release nitrate and dissolved organic N was unknown and needed further exploration across the industries.

On the technology front, the MPfN Program provided a conduit to prepare intensive users of N for a future where improved sensor technologies and communication networks allow for real-time monitoring of a crop or pasture's N status, and therefore near real-time decision making on how to most efficiently and effectively supply N for optimal plant uptake under current climatic and weather conditions.

The MPfN Program was developed by the partner organisations to assist primary producers, and their advisors, to increase knowledge and understanding around the influence of the integrated factors on NUE and provide them with the tools and decision frameworks needed to increase their confidence to apply N using the right source, at the right time, placed in the right location (in-paddock and in-crop) at the right rate to match crop and pasture requirements. The long-term outcome for the four industries is a producer base that has adopted practices to improve yield and product quality, from reduced N input costs, whilst minimising loss to the environment

The MPfN Program sought to address existing gaps in knowledge and understanding by:

1. Improving the accuracy of industry guidelines and decision support systems (DSS), in particular with respect to the contribution of mineralisation (one of the largest sources of uncertainty and therefore confidence);
2. By working closely with producers to ensure potential solutions were practical and effective; and
3. Analysing results from a whole-farm economics perspective to identify the most cost-efficient fertiliser N management strategies for each industry based upon results of trialed strategies.

Therefore, the research questions that the MPfN Program sought to answer through using localised field trials, to maximise engagement with local producers were:

- How can N be managed most effectively to make the most of available water and soil-N, to maximise productivity and quality, minimise losses to the environment and provide economic benefits to the producer?
- Can sensing technologies be used to predict soil mineralisable N and how effective is it compared to current 'soil C' based methods for estimating N mineralisation for soils?
- What tools can producers use to access better information regarding N dynamics and seasonal availability to inform their decisions for a better economic outcome?
- How can N and irrigation management be modified to minimise losses and maintain or improve productivity?
- How effective are current BMPs for N management in improving NUE, productivity, profitability and environmental impact on farm?
- Can EEFs or blending of EEFs result in improved synchronicity between plant demand and N release to mitigate losses to the environment and increase NUE?
- What is the cost effectiveness of EEFs, under a range of soil and climatic conditions, and product blends?
- Can improved EEF technologies be developed that release N to better match changing plant demand over crop development stages or respond to variations in seasonal conditions?
- Can polymer and / or sorber technology be used to improve the ability of vegetative buffer strips to remove nutrients and sediment from farm water run-off?

In summary, the research of the MPfN Program was needed collectively by the four industries to:

1. Remove uncertainties surrounding the contribution of mineralisation to N budgets;
2. Investigate losses of N from the farming system to ensure that the most significant pathways were understood and targeted for improved NUE management;
3. Undertake a significant proportion of the research activities under commercial farming regimes to enhance the relevance of outcomes for producers;
4. Investigate the potential for new sensor and precision technologies to improve the management of N; and
5. Focus on the potential for new EEFs, and combinations of existing EEFs to better match N supply to crop demand.

2. Method and project locations

The ten core research projects of the MPfN Program were delivered by eight leading government and university research agencies, together with a further 22 collaborating partners, encompassing 93 interacting research, technical and student positions (Masters and PhD). Appendix 1 provides a comprehensive list of the people, roles and organisations involved.

Research activity was located from Darwin in the north, to Hobart in the south of Australia. Forty-five (45) fully replicated and randomised research trials were conducted on both commercial and research farms, with a further 49 sites used in deep soil sampling campaigns. Trials were conducted for one to four years. Thirteen (13) research facilities were also used for glasshouse, simulation, modelling and laboratory analysis activities.

Research methodology across all research projects focused on investigating the potential of amended or new fertiliser source, placement, timing and rate NUE management practices for the industry. “Usual farmer practice” and/ or “Above current N BMP”, “Current N BMP”, “0” N treatments (control), and “new/amended strategies” (fertiliser rates (kg/ha), fertiliser source (blends, EEFs, biologicals), fertiliser placement (broadcast, banding, in-bed, fertigation), fertiliser timing (pre-mid-post primary & cover crop, within season and daily applications) and irrigation management (application in relations to soil moisture content and timing)” were trialled adjacently in randomised, replicated plots at field/paddock, small field or pot scale. Trials were conducted for timeframes specific to the industry: annual ratoon/crop length, annual ryegrass/kikuyu seasons (subtropical dairy system) or all-year-round perennial ryegrass phases (southern dairy systems).

This suite of trials provided both researchers and producers opportunity to compare yield and quality product results, losses to the environment and the overall NUE of all treatments, as well as economical considerations. They also provided an opportunity to demonstrate the practical pros and cons of managing each of the treatments.

Importantly, field trials were established to provide a cross-section of seasonal conditions, soil properties and farming systems within the key farming regions of each industry. Research organisations worked in collaboration with the RDCs to locate the sites in representative regions, soil types and farming systems to increase the applicability of the outcomes for their farmer and service provider base. Across these, both research and commercial trial locations provided a greater understanding of the potential benefits of management strategies, including timing of fertiliser application, balancing seasonal N cycling with productivity, timing of irrigation and the conditions under which of EEFs are effective from a whole of farm perspective. Different blends of a variety of commercially available fertiliser formulations (conventional urea, controlled-release urea, and/or nitrification-inhibitor-coated urea) provided assessment of the normal recommended or industry BMP compared to reduced total N application rates with different blending ratios.

Isotopically labelled N fertiliser (^{15}N) was used in selected trials to closely monitor the fate of N as it cycled through soil-plant-atmosphere processes, including loss pathways, enabling researchers to quantify the NUE of the crop/pasture. For the tree crop industries of mango and cherry, these treatments required complete excavation of whole orchards trees, destruction of trees to determine within tree fate of N, and litter studies of leaf and pruned branches.

Soil and plant samples were taken to monitor ammonium and nitrate N dynamics in soil and crop N uptake at various stages in relation to biomass production. The interactive effects of seasonal conditions and soil physical/chemical properties on the performance of different fertilisation scenarios was analysed.

Quantifying how much N is provided by the soil organic N pool, via mineralisation, and how this changes seasonally at a paddock scale was investigated by eight of the projects and was important in determining the overall NUE. By determining the source of N taken-up by the crop/pasture over crop stages/ seasons, the substantial contribution of soil N supplied to the crop/annual N budget was determined. Importantly, research methods enabled projects to determine the influence of previous field/paddock N management (previous crop or cover crop/ previous season residual N) on the following crop/ seasonal pasture N budget requirements.

Whilst each of the projects prepared trial protocols or work plans that were internally reviewed to ensure scientific rigour, the MPfN Program conducted initial meetings for project leaders to collaborate on trial design and research methods. This cross-project and cross-sector cooperation led to commonalities across methods used to measure, analyse and interpret soil, nutrient and biomass samples.

Extension activities conducted in the field or in collaboration with industry programs, armed the research projects with progressive insights into how farmers were responding to current seasonal conditions. From El Nino drought and fire to La Nina flooding and extreme weather events, and pandemic restrictions causing agricultural supply issues, the 2016 to 2021 program timeframes covered many bases on which to consider the practicalities of amended/ new N management strategies, often adjusting treatments to provide seasonal answers to local farmer questions.

The outcomes of research findings were developed into industry recommendations (sugar, mango) or fully prepared NUE BMP guidelines (dairy, cherry, cotton (integrated into the Australian Cotton Production Manual) as well as DSS calculators/ trees.

The MPfN Program deployed significant methods to support cross-program collaboration. These included annual partner forums, bi-annual PMC meetings, intra-industry meetings and a quarterly partner newsletter to update on research. The results of cooperative efforts assisted by:

- Testing and refining a standardised approach to soil N mineralisation measurement methods and analysis of potentially mineralisable N (PMN) for predictive purposes;
- Providing agreement on potential NUE indicators and model parameters for Australian agricultural sectors, assisting to form a common language more easily understood by multi-disciplinary research teams and markets;
- Establishing agreement on a minimum data-set for MPfN Program research projects and proposed for future NUE research in Australian agriculture;
- Expediting understanding of the potential use of remote sensing technology in NUE research measurement and future on-farm applications; and
- Preparing economic case studies to demonstrate benefit to farm profitability and sustainability in adopting researched NUE strategy recommendations for each industry, as well as potential legacy impacts across all industries.

Appendix 2 provides a comprehensive table of research activity locations, including research site type and GPS coordinates. A mapped depiction of the location of the core research sites is also provided along-side each of the project final reports and presentations on the MPfN Program website: <https://www.crdc.com.au/more-profit-nitrogen> .

Each of the project final reports and presentation recordings provides extensive detail on trial design, treatments applied and the measurement methodologies used to collect, store, analyse and interpret resultant data.

3. Outputs and Outcomes

3.1 Program level achievements

The MPfN Program delivered upon all outputs and achieved all key performance indicators (KPI) as specified in sections B and C of the Deed of Variation (Department of Agriculture and Water Resources, December 2017). Progress against KPI was reported in milestone reports 1-9, with the final KPI to be reported for milestone 10 outlined in Appendix 3.

The *More Profit from Nitrogen Final Evaluation Report (AgEcon, June 2021)* ([Link to Report on CRDC Website](#)) assessed whole-of-program activities and project level deliverables against the outputs, milestones and performance indicators of the three MPfN Program plans:

- The Program Management Plan (PMP)
- The Communication and extension Plan (CEP)
- The Monitoring and Evaluation Plan (MEP).

Stakeholder feedback on program delivery, planning, reporting and internal communications was captured.

Delivery was evaluated as strong overall. Across the three plans, an average 91% of planned outputs, milestones and performance indicators were evaluated as strongly delivered (Table 1).

Table 1. Summary of evaluation of program delivery against the MPfN plans

MPfN plan	Elements rated as strong	Overall evaluation
Overall evaluation of delivery against the MPfN PMP	132/133 (99%)	Strong
Overall evaluation of delivery against the MPfN CEP	22/24 (92%)	Strong
Overall evaluation of delivery against the MPfN MEP	35/42 (83%)	Strong
Overall stakeholder rating of planning, monitoring and reporting	4.2 (n=34)	Strong
Overall evaluation of delivery against the MPfN plans (average rating)	91%	Strong

(Source: MPfN Final Evaluation Report, AgEcon, June 2021)

The MPfN Program delivered more than 150% of planned activities and outputs across collaboration, communication, and extension. Internal stakeholders rated the project planning, monitoring and delivery as highly effective (average 4.2/5), and the administrative support provided as highly effective (average 4.2/5), with generally positive comments supporting these ratings.

Delivery against the MPfN Program PMP

Delivery of the program against the PMP was evaluated as strong (Table 2). All activities were successfully completed according to the Deed of Variation (December 2017), except for activity B4 where one KPI was partially achieved and carried through to the following milestone where it was subsequently reported as achieved. A full list of the MPfN Program activities, outputs, KPIs and

milestones, including status as determined through the evaluation process, is included in the evaluation report.

Table 2. Evaluation of delivery against MPfN PMP activities

Activity	Description	KPI delivery assessed as strong	Overall evaluation
B1	Project initiation	5/5 (100%)	Strong
B2	Project planning and management	5/5 (100%)	Strong
B3	Communication and extension	34/34 (100%)	Strong
B4	Extracting value from enhanced efficiency fertilisers (EEF)	22/23 (95%)	Strong
B5	Optimising nitrogen use efficiency (NUE) in irrigated systems	31/31 (100%)	Strong
B6	Better understanding N supply through mineralisation (quantifying rate and timing)	34/34 (100%)	Strong
Overall evaluation of delivery against the MPfN PMP		132/133 (99%)	Strong

(Source: MPfN Final Evaluation Report, AgEcon, June 2021)

Everything in the program is planned from the very beginning. Whole program meetings with collaboration researchers and representatives from fertiliser groups and Sugar Research Australia (Sugar)

In terms of program facilitation; online database, templates for reports, all very well managed. Have a look at how this program was managed and use that as a benchmark for how others should be managed (dairy)

It has been excellent and well-coordinated (cotton)

Overall, delivery of the MPfN against the three program objectives was evaluated as strong (Table 3).

Table 3. Summary of evaluation of program delivery against the MPfN objectives

Evaluation of successful delivery against the project objectives		Average stakeholder rating	Overall evaluation
Primary objectives	Generate knowledge and understanding	3.9 (n=62)	Strong
	Inform NUE resources	3.6 (n=60)	Moderate
Secondary objectives	Support collaboration (internal stakeholders only)	4.0 (n=33)	Strong
	Support extension pathways	3.6 (n=61)	Moderate
Overall evaluation of delivery against the MPfN objectives (average rating)		3.8	Strong

(Source: MPfN Final Evaluation Report, AgEcon, June 2021)

Across the MPfN Program objectives, the perceived effectiveness against research level outcomes (research level knowledge and fostering collaboration) was strong, reflecting the delivery of a high level of research outcomes for what was fundamentally a research program. While the perceived effectiveness against industry level outcomes (contribution to industry level resources, extension, and changes in industry level knowledge) was moderate, the lower ratings were consistent with these primarily being secondary objectives or later phase outputs of the program, hence the resources had been only recently prepared by the projects/ industry but not yet fully communicated or extended to primary producers or service providers. It is important to note that the timeframe for practice change within an agricultural R&D context can take years (or decades). It is rare for industry

adoption of R&D to occur rapidly following the completion of the underlying research, but rather, adoption occurs in stages depending on the overlapping of a range of underlying factors including risk and underlying market conditions relating to the commodity and the innovation.

Comments recognised that while the MPfN Program delivered clear R&D outputs to inform industry resources (a primary objective), responsibility for integrating the findings into industry resources and extending these to growers lay primarily with the individual industries and would continue beyond the completion of the MPfN Program. In addition, while all industries had begun to integrate the MPfN Program recommendations into industry resources, or had plans to do so, the comments indicated that service providers and producers were not as aware of this ongoing process.

The evaluation concluded (Table 4) that the MPfN Program had:

1. Made a strong contribution to generating NUE knowledge and understanding;
2. Identified NUE strategies or technologies that were made available for inclusion (and in some cases already included) in industry NUE resources; and
3. Moderately (almost strongly) built industry confidence to adopt the NUE strategies.

Table 4. Summary of evaluation of immediate and legacy impact to improve on-farm NUE

Evaluation of immediate and legacy impact to improve on-farm NUE	Average stakeholder rating	Overall evaluation
Generate knowledge	3.9 (n=62)	Strong
Inform NUE resources	3.6 (n=60)	Moderate
Confidence to adopt MPfN strategies and recommendations	3.7 (n=65)	Moderate
Overall evaluation of immediate and legacy impact (average rating)	3.7	Strong

(Source: MPfN Final Evaluation Report, AgEcon, June 2021)

Collectively, the MPfN Program was evaluated as strong in generating immediate research impact and establishing a strong foundation to support potential future adoption of NUE practices resulting in improved profitability and reduced environmental impact (Table 4). Importantly, the evaluation report highlighted the important future role of individual industry research and extension bodies in converting this potential into realised NUE practice change and industry impact. It suggested that whilst the MPfN Program had delivered the necessary NUE knowledge, understanding and resources/tools for practice change, continuing the process of integrating the recommendations into industry resources and extension programs and/or extending the newly prepared resources, guidelines and DSS, and understanding specific barriers to NUE practice change, was an immediate role for each of the agricultural industries and the fertiliser industry.

3.2 Project level achievements for the cotton industry

The combined research outcomes of the MPfN Program cotton projects were integrated into the Nutrition chapter (Chapter 8) of the *Australian Cotton Production Manual 2021*. Members of the research team co-authored this chapter alongside other key nutrient researchers and advisors of the industry.

- [Link to Australian Cotton Production Manual 2021 on CRDC Website](#)

The research team also co-authored two economic case studies with AgEcon economists that provided demonstratable economic benefit in split N in-crop applications over all upfront applications, and whilst EEFs provided no measured cotton yield increases, the economic impact of reduced N loss via irrigation run-off was valued at \$12.17/ha.

- [Economic Case Study: Implications for timing of N fertiliser application on irrigated cotton yields: apply all N up-front or split?](#)
- [Economic Case Study: Matching N plant demand using Enhanced Efficiency Fertilisers and implications for N field run-off in irrigated cotton.](#)

3.2.1 RRD1712- NSW Department of Primary Industries

[Link to RRD1712 Final Report on CRDC Website](#)

[Link to RRD1712 Final Presentation on CRDC Website](#)

Recommendations delivered to industry from research findings

Nitrogen findings and recommendations

- Pre-season soil tests provide a clear benefit when estimating seasonal N fertiliser requirement. Application rates of N fertiliser can be reduced substantially or optimised when knowledge of existing soil fertility is accounted for and used to budget fertiliser application rates. Seasonal research at Narrabri found that when pre-season soil tests were conducted and mineral N was included as a base for crop N fertiliser budgets, the fNUE improved from 13 kg lint/kg N (2016/17) to 34 kg lint/kg N (2017/18).
- Pre-season soil N was high at all the commercial on-farm research studies, with available mineral N found to be up to and exceeding 500 kg N/ha. While this made it difficult for conducting on-farm research it does provide an opportunity for growers to utilise the native soil N from their cropping soil rather than applying high amounts of synthetic N fertilisers.
- The timing of N fertiliser is important, and growers should plan their N management with two goals in mind. Firstly, growers should apply N fertiliser to meet the demands of the growing crop, with the bulk of fertiliser N being available for the crop during the key flowering stage. Secondly, growers should avoid applying fertiliser N at times that promote large N losses from the field. The research found when all or the majority of N fertiliser was applied up-front, losses of N from the field were higher compared to when N was applied in-crop, meaning there is greater fertiliser N recovery potential when the bulk of the N fertiliser was applied in-crop.
- Split and all in-crop applications of N fertiliser resulted in increased post-season soil N, and the later the application the greater the amount of post season N. If growers use split fertiliser applications, then they should modify the farming system to utilise this carry over N in the following winter crop.
- While in-crop N applications can reduce fertiliser losses compared to pre-plant applications, growers should not over apply fertiliser N late in the developing crop. Two research field experiments and a commercial farm case study all showed that when fertiliser N was applied after cut-out there was a lint yield penalty and N uptake by the cotton was very low. There was no improvement in boll retention higher in the plant and no increase in boll weight compared to treatments where N fertiliser was applied earlier in-crop (by early bolls) or pre-plant.
- The choice of N fertiliser product and form has importance when evaluating methods for improving NUE on-farm. For instance, anhydrous ammonia has low N losses when applied

directly into the soil, either pre-plant or side-dressed in-crop, but application of ammonia via fertigation (water-run) is not recommended due to high N losses. The on-farm case study at Moree found ammonia when used as a water run product lost over 24% of the applied N compared to broadcasting urea N on the surface and irrigating immediately after. The study was conducted when plant height was 1m tall and complete canopy coverage—volatilisation losses from water-run ammonia would be greater if plant height was lower and more of the soil surface was exposed.

- The in-crop N application method has an influence on N losses from the field and the fertiliser availability to the plant. Side-dressing N (urea) gave the best N supply to the plant and lowest field losses of all methods and treatments studied within the project. The water-run products (urea, UAN, and ammonia) had higher runoff N losses from the field. Stopping the addition of N once runoff begins can reduce this loss dramatically and supply more N to the plant instead.
- Enhanced efficiency fertilisers including nitrification inhibitors and polymer coated urea were able to reduce N losses early in the growing season (first and second irrigation events) but did not improve plant N uptake or lint yield. However, these EEFs allow producers greater flexibility when applying N fertiliser, especially when the application of fertiliser N occurs early in the bed forming stage long before planting.
- While difficult to account for prior to the season, N fertiliser application should be aligned with yield potential and seasonal conditions. Application of N fertiliser late in-crop delayed plant maturity, increased trash load of picked samples and reduced lint fibre quality. In some cases, application of late fertiliser N resulted in similar plant immaturity as the application of excessive N fertiliser rates (>300 kg N/ha).
- N fertiliser applications will not solve constraints to production caused by other nutrient deficiencies, compaction, poor drainage, agronomic factors, etc. Both industry survey and field experiment data has shown that N fertiliser rates in excess of 200–240 kg N/ha are not further increasing cotton lint yield. Other constraints can often be limiting production and should be investigated before increasing N rates.
- Pre-season N should be applied towards the irrigated furrow side of the hill to increase retention of fertiliser N within the plant hill. The ¹⁵N study conducted in 2018/19 showed that fertiliser N applied at a depth of 30 cm under the plant line had moved up towards the soil surface and across towards the non-irrigated furrow, with little distribution of applied N into the irrigated side of the plant hill. To counter this biased movement, growers can offset the application to the irrigated side hill which would increase fertiliser N dispersion within the plant hill.
- Cotton systems incorporating intensive irrigation (50–60 mm deficit) and high N application rates (>250 kg N/ha) are at risk of increased disease pressure. An observed implication of these treatments in the 2019/20 growing season was that the greater plant growth led to a yield disadvantage, partly due to high disease pressure (in this instance *Alternaria* leaf spot – *A. macrospora* and *A. alterata*). The experiment found greater yield for treatments applied with growth hormones (mepiquat chloride) and/or treatments with a higher soil water deficit (90 mm).

Phosphorus findings and recommendations

- Minimum tillage practices over the long term resulted in more available P (Colwell P) levels in soil. Considering other associated soil health benefits of minimising traffic, it is recommended to minimise the tillage required and consider applying P fertiliser every 3–5 years.
- Factors other than critical soil Colwell P levels are determining the P response. Sporadic P responses were observed in Northern NSW soils with Colwell P levels ranging from 20–40 mg P/kg and this supports the previous suggestion by Brendon Griffith that the critical Colwell P levels for cotton is likely around 25 mg P/kg.
- P application before a cover crop improved the lint yield in a soil with subsoil sodicity (ESP = 8%, below 30 cm). Therefore, it is recommended to apply P before a rotation crop to improve the P response in subsequent cotton.
- Replace P from seed P export every few seasons to prevent decline (match the crop removal). Mixing rather than banding provides more root interception opportunities for the cotton plant to acquire P. However, the suggestion to mix the P conflicts with sustainable soil management of minimising the tillage, so the P replacement timing with mixing operation needs to be maximised to minimise the tillage.
- There is clear interaction of N application timing with P response. More ratio of N at pre-planting resulted in cotton plants responding to applied P with improved yield. N fertiliser has the potential for priming effect on soil microbes and immobilises P as evidenced by low reactive P runoff. Therefore, excessive N rate should be avoided.
- Late N application was counterproductive for P response and should be avoided.
- Improvement in P use efficiency can be achieved by maximising the opportunity for cotton plant roots to explore more soil volume. This could be achieved by enriching more volume of soil by mixing P, N application timing, improving irrigation frequency in years with low in-crop rainfall, improved soil management such as minimum tillage, using crop rotation to mitigate soil constraints such as compaction and sodicity.

3.2.2 RRDP1713- University of Southern Queensland- Centre for Engineering in Agriculture

[Link to RRDP1713 Final Report on CRDC Website](#)

[Link to RRDP1712 Final Presentation on CRDC Website](#)

Recommendations delivered to industry from research findings

Patterns of within-season soil and fertiliser N supply

- 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.

Fertiliser leaching (May 2018 to July 2018)

- 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.

Findings to improve N DSS

- 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;
- 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; and
- 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.

3.3 Project level achievements for the dairy industry

The combined research outcomes of the MPfN Program dairy projects resulted in the preparation of two new nitrogen management resources for the dairy industry. These resources are now published on the industry’s *Fert\$mart Program* webpage and have been extended by the researchers, in collaboration with Dairy Australia, throughout 2020-2021, to Dairy Australia extension personnel, government service providers, private farm consultants and farmers via webinars conducted for all dairy regions of Australia. Importantly, the industry is also working with Fertilizer Australia in developing a *Fert\$mart N FertCare®* module for dairy agronomists, resellers and spreaders undertaking the fertiliser industry’s certification scheme. An extract from the pocket guide (Figure 1) is provided below as an example of the clear guidance provided to farmers through these collaborative resources of the dairy projects.

- [Fert\\$mart Nitrogen Pocket Guide](#)
- [Fert\\$mart Nitrogen Guidelines- Best Management Practice](#)

*The 4Rs are a nutrient stewardship framework: use the **right** fertiliser source, at the **right** rate, at the **right** time, and in the **right** place.*

- ***Urea is currently the cheapest pure SOURCE of N.** If P fertiliser is also needed at the same time, di-ammonium phosphate (DAP) is cost-effective source of N. Assuming soil moisture is adequate for pasture growth, N losses from urea applications, via volatilisation, are usually not large enough to justify using other N sources.*
- ***Apply N at RATES of 20 to 50kg N/ha per application, no closer than 21 to 28 days apart.***

It can also be useful to combine the daily equivalent rate by the interval between N applications (e.g., 1.5kg N/ha per day by 21 days = 32kg N/ha applied). During the peak growth period, with good soil fertility and newer cultivars, it may be justified to increase the rate to 2kg N/ha per day, limited to a maximum of 60kg N/ha in a single application.

Figure 1. Extract from the Fert\$mart Nitrogen Pocket Guide for dairy farmers

The research team also co-authored four economic case studies with AgEcon economists. Three of these demonstrated the economic benefit of adopting a seasonally modified N application approach, based on seasonal conditions and local growth potential in the three major dairy regions of Tasmania, South-west Victoria and NSW. Combining the change in the cost of applied N and the change in the value of dry-matter production (modelled over 18-years) generated a financial return of an additional \$253/ha/year (Irrigated- Elliott, Tasmania), \$226/ha/year (Rain-fed, Terang, Vic) and \$162/ha/year (Irrigated-Taree, NSW). The fourth case study demonstrated the economic benefit of using soil moisture monitoring to optimise N applications at the RRDP1715 commercial rain-fed site. It showed that an additional \$29/ha/year could be generated, considering purchase and ongoing costs.

- [NSW case study: Quantifying the whole farm systems impact of nitrogen: best practice on an irrigated dairy farm \(NSW\)](#)
- [TAS case study: Quantifying the whole farm systems impact of nitrogen: best practice on an irrigated dairy farm \(TAS\)](#)
- [VIC case study 1: Quantifying the whole farm systems impact of nitrogen: best practice on a rainfed dairy farm \(VIC\)](#)
- [VIC case study 2: Improving dairy farm nitrogen use efficiency: using soil moisture monitoring \(VIC\)](#)

3.3.1 RRDP1714- Queensland University of Technology

[Link to RRDP1714 Final Report on CRDC Website](#)

[Link to RRDP1714 Final Presentation on CRDC Website](#)

Recommendations delivered to industry from research findings

Agronomic, NUE, losses and economic indicators of N fertiliser application to dairy pastures

The research findings highlight the potential to grow large quantities of pasture feed under well managed conditions with adequate water supply in sandy soils. There was only a minor decrease in marginal dry matter production with increasing N rate and the DM production rates per unit of N were high under non-moisture limiting conditions.

- Under paddock conditions even with irrigation, the N response trials demonstrated mostly the classic plateauing response to N application rates across sites, with the benefit of additional N applications declining at the higher N rates.

- Smaller, frequent applications are much more effective than larger, less frequent applications in clay soils but this is less important in sandier soils.
- Application of N fertiliser can still be profitable even at high rates under optimal conditions, particularly when feed costs are high (i.e., drought). Applying N above the optimum in terms of pasture response however decreases NUE and increases N loss to the environment.
- However, a substantial amount of applied N (30-40%) is still lost from the soil-pasture system, more when urine is considered.
- The overapplication of N fertiliser above the optimum should be avoided because (a) the accumulation of nitrates in the pasture biomass can have a detrimental effect on herd health and milk production; and (b) losses of applied N from dairy systems (30-40%)

Predicting and accounting for mineralisation and timing of N fertiliser application to match plant demand

- N mineralisation in high carbon dairy pastures (i.e., uncultivated) ranges from 100 kg N annually in duplex soils to over 170 kg N in heavier textured soils and represents a key resource. However, this resource typically only becomes available under warm and wet summer conditions and is easily lost via denitrification.
- Plant demand is highest during the peak rye grass growing period (Sept-December) and lowest just after rye establishment (low plant demand) and in late summer (high mineralisation)
- Applied fertiliser N is immobilised during periods of high plant N demand (spring rye)
- Immobilised N is released during low plant N demand periods over the summer/early autumn. These findings are confirmed by the results of the ¹⁵N recovery tracing the fate of applied N fertiliser over three grazing cycles.

Impact of different irrigation frequencies on denitrification losses from dairy pastures

- Results from the irrigation and denitrification trials demonstrated that only small, but significant N losses (1-5 kg or 3-15% of applied N per grazing cycle) occur under irrigation regardless of irrigation amount/frequency, up to irrigations of 80 mm per application.
- However, losses increase exponentially the longer soils stay saturated under large (>100 mm) rain events, when losses can exceed 20 kg N ha⁻¹ or equivalent to >60% of applied N. Casino has averaged over five, >100mm rain events per year so this represents the dominant N loss pathway.
- The effect of soil type on the magnitude of denitrification was less than expected, with similar losses observed from the sandy Camden site and the heavy clay Casino soil. This is most likely due to the good soil structure from the permanent pasture at Casino allowing rapid infiltration, and losses would be higher in cultivated, low organic matter, compacted or sodic soils.
- Denitrification losses from urine patches can exceed 30 kg N in the first 2 months, relatively minor compared to the >700 kg N inputted. However, more losses are likely following large rainfall events
- Improved pasture N management should aim to maximise soil aeration to minimise conditions conducive for denitrification and the formation of excess mineral N in the soil. Management options include improved irrigation, minimising compaction while ensuring adequate water supply for plant growth.
- More frequent irrigation (~every 4 days) saved water and increased irrigation use efficiency from 25 kg per mm of irrigation to 45 kg per mm of irrigation by simply allowing more flexibility

in scheduling irrigation in relation to rain events and reducing the reliance on rainfall predictions.

- Less frequent irrigation, utilising stored moisture (and potentially nitrogen) in the soil profile is better, with water utilisation recorded down to 70 cm compared when irrigation was applied in one event per grazing cycle compared to only 30 cm if applied over 4 events.

Potential of enhanced efficiency fertiliser to improve NUE and pasture productivity

- Climatic conditions during the winter/spring annual rye grass fertilisation period rarely produce conditions conducive for N loss of surface spread urea.
- Urease inhibitors therefore have limited potential under normal conditions
- The exception to this is occasional hot and windy conditions following cold fronts in late October/early November when application of urea should be avoided.
- Nitrification inhibitor (DMPP) shows good potential during winter/spring annual rye grass
- DMPP has been shown to reduce direct losses of N via denitrification during large rainfall events, increase immobilisation of N into the organic matter and increase pasture productivity during the winter/spring rye grass period.
- as a **rule of thumb** that **DMPP application always be applied at a 15-30% reduction to the optimal N rate of standard urea.**

3.3.2 RRD1715- The University of Melbourne (Advanced Technologies)

[Link to RRD1715 Final Report on CRDC Website](#)

[Link to RRD1715 Final Presentation on CRDC Website](#)

Recommendations delivered to industry from research findings

- Seasonal responses to N were clear, with generally little response in autumn due to limited water availability under both dryland and irrigated systems. Where irrigation management led to greater autumn soil profile water, a good response to N was seen. Improved irrigation management at the edges of the dryland growing season (early irrigation start-up in spring when soils are drying, and longer irrigation in autumn) could improve pasture productivity and NUE.
- Mineralisation contributed substantial amounts of plant available N in the soil, particularly under dryland conditions and following the summer where pasture uptake of N was limited.
- The recovery of fertiliser N in the plant was low (19-30%) following each fertilisation event, and most of the N taken up by the plant came from the soil (>70%). We assume that the N from applied fertiliser not recovered in the plant was immobilised and then released from the soil organic matter pool over time for plant uptake. This leads to good recovery of N unless there are major losses as ammonia, from denitrification, or via leaching of nitrate, which we predict were minimal at our site. After 8-12 months, around 33-49 % of the applied fertiliser had been utilised by the pasture 26-78% was recovered in the soil and roots and up to 41% was unaccounted for.
- Variations NUE occurred between seasons and indicate that the fertilisation rates should be variable to match the seasonal N response. NUE was higher with lower N inputs, but the reduced

pasture productivity at these lower N rates, and the impact on farm feed requirements needs to be considered.

- A modelling approach is a viable tool for predicting mineralisation and the seasonal pattern in mineralisation rates under dryland and irrigated conditions was identified. The key drivers of mineralisation were identified as future temperature and N rate. The mineralisation calculator was viewed as a useful tool to educate advisors on the drivers of mineralisation, however its usefulness will depend on its ability to cope with the high level of climate variability.
- Using remote sensing approaches to predict pasture production and N content are valid. Complications in pasture systems exist due to the variety of species and leaf architecture. Measurements prior to 3-leaf stage are considered most useful. Climate conditions experienced in southwest Victoria made use of the remote sensing approach challenging as cloud cover varied dramatically over the course of a day.
- Overall, the use of currently available EEF had limited impact on pasture dry matter production and nutrient cycling, which is partly due to climate and water management, although productivity benefits were seen for one winter period, where reduced inputs were possible with use of DMPP coated urea, compared to granular urea. Limited ammonia loss is expected to occur under well managed irrigated pastures, and the dryland site was limited to one year of data, plus N fertiliser was only applied to the dryland site when there was good active pasture growth and the growth responses were likely to be reliable.
- Reducing N inputs during seasons where soil stored N levels are high, such as at the autumn break on dryland pastures, will benefit the industry by reducing the input cost of fertiliser, and the potential off-site environmental impacts, supporting the commitments of the Australian dairy industry to improve the efficiency of N use for pasture production.

3.3.3 RRD1716- The University of Melbourne (Whole farm systems modelling)

[Link to RRD1716 Final Report on CRDC Website](#)

[Link to RRD1716 Final Presentation on CRDC Website](#)

Recommendations delivered to industry from research findings

- The existing BMPs for N fertiliser use on dairy pastures were largely validated as being widely applicable and appropriate.
- There were instances identified where these BMPs could be further refined. These included:
 - Accounting for soil moisture in determining the rate and timing of N fertiliser applications. In particular, the research identified the risk of autumn N applications in Victoria resulting in either low or no N response in most years.
 - That the ideal rate of N fertiliser to apply (to achieve 90% of maximum potential yield) varies by site, season and year. Conversely that exceeding this recommended upper limit leads to significantly increased risk of N loss.
- For most sites (Ellinbank, Elliott, Mt Gambier, Taree and Terang) and seasons, current BMPs of applying between 20 and 50 kg N/ha post grazing will ensure efficient use of N applied, assuming soil moisture is not first limiting growth, notwithstanding the high variability between years. However, this research has refined these recommendations across all sites and seasons.

- At Elliott in Tasmania, an irrigated site, there was merit in increasing N fertiliser rates above the current recommendation of 50 kg N/ ha post grazing during spring and summer.
- In contrast, at the rainfed sites of Ellinbank and Terang in Victoria, the recommendation would be to not apply N fertiliser during autumn and only in selected wetter summers.
- The reduction in N fertiliser inputs required to achieve 90% of relative yield (Y90), relative to maximum pasture production (Ymax), was > 50% across all sites and seasons.
- The associated reduction in total N loss when fertiliser was reduced from Ymax to Y90, varied between 34% and 74%, depending on site and season.
- Nitrate leaching risk was highest in winter for the four temperate sites and autumn at the subtropical site.
- Strategic approaches to N fertiliser were shown to be more efficient in N use and lower both N inputs and N losses with little impact of pasture production, with the greatest improvement in N use efficiency from moving from a flat rate of N to one based on the BMPs. This was shown across all seasons and locations studied. Strategies that used increasing levels of precision improved NUE marginally again – this may mean that soil moisture sensors, coupled with rainfall data, are more valuable in improving N decisions than soil or plant sensors in the first instance.
- Applying N fertiliser to sub-tropical pasture all year round lifted pasture productivity of both the kikuyu and annual ryegrass. However, much of the extra kikuyu grown could not be utilised by grazing cows. The study showed it was more profitable to address deficiencies in the metabolisable energy of kikuyu with supplementary grain feeding, rather than using N fertiliser.
- Across 18 dairy locations throughout Australia, modelled annual volatilisation was 51 % greater from urine than from the fertiliser N, which was 22 % greater than from soil N sources.
- Substituting grass silage with lower protein maize silage reduced overall diet N concentration from 3.0% to 2.4%, which in turn reduced ammonia volatilisation by 47% (56 to 30 kg N/ha/year), improved whole farm N use efficiency by 65% (31 to 60 g milk MS/g N-NH3) without impact on milk production.
- Despite considerable variation in model sophistication in the three models compared (APSIM, DairyMod and DayCent), no model consistently outperformed the other models with respect to simulation of soil N, shoot biomass or soil water.
- While tactical N application had immediate effects on NO3, NH4, N mineralisation and pasture growth, no long-term relationship between mineralisation and pasture growth could be discerned. These results suggest that while N application in excess of plant requirements generally stimulates immobilisation and a pulse of N2O emissions, subsequent effects through N mineralisation on pasture growth are variable. Further controlled environment soil incubation research may help separate successive and overlapping cycles of mineralisation and immobilisation that make it difficult to diagnose long-term implications for (and associations with) pasture growth.
- This study demonstrated the benefits of developing site and seasonal-specific N fertiliser BMP guidelines that are both economical and environmentally beneficial.

The BMPs for N fertiliser use on dairy pastures were updated based on the above new knowledge, together with research from the parallel MPfN dairy projects (Led by Dr Helen Suter and Dr David

Rowlings). These BMPs were published as the *Fert\$mart Nitrogen Guidelines- Best Management Practice* and *Fert\$mart Nitrogen Pocket Guide* (Links provided in Section 3.2).

The project recommended that Dairy Australia continue to promote the new *Fert\$mart* BMPs for N fertiliser use on dairy pastures through hosting the guidelines on the Dairy Australia website and also *actively* promoting these to the industry through the regional extension networks and through Fertilizer Australia's FertCare® program.

3.4 Project level achievements for the sugar industry

The combined research outcomes of the MPfN Program sugar projects have resulted in a suite of recommendations that are under consideration of the industry's Six Easy Steps® nutrient program advisory panel.

The outcomes and outputs of the MPfN Program will assist Sugar Research Australia to work with industry partners to make updates to the following resources, hosted by the Six Easy Steps® Toolbox (<https://sugarresearch.com.au/growers-and-millers/nutrient-management/six-easy-steps-toolbox/>):

- FertFinder- an excel format DSS to assist in fertiliser product decisions at a regional level;
- NutriCalc™ - A web-based nutrient management DSS using the SIX EASY STEPS approach to determine nutrient requirements; and the
- *Guidance for refining nutrient inputs in specific situations* resource.

The research teams also co-authored two economic case studies with AgEcon economists. The first study demonstrates that by testing for PMN, and considering these results in crop N budgets, growers can reduce N rate. Using a Mackay (QLD) site as an example, the economic benefit was \$26/ha in CO₂e abatement and an upper range of \$98.60/ha in reduced N fertiliser costs.

The second study demonstrated that, under certain climatic conditions, the environmental and economic costs associated with N losses/ ha can be substantial. Using seasonal forecasting, simultaneously with nutrient budgets, can present opportunities to better match fertiliser N with plant demand, particularly in years of high precipitation.

While soil mineral N contents declined to very low levels early in-season, after the application of urea following high rainfall events, the PCU products consistently sustained higher mineral N content in soil. PCU benefits are primarily about mitigating N losses from leaching, rather than increased crop yield. Economic sensitivity testing demonstrated that these losses can be as high as \$93.72/ha when straight urea is used. At this higher range, the cost of using a PCU 75%/Urea 25% blend versus Urea 100% is economically viable at \$29.55/t sugar/ha versus \$14.90/ t sugar/ha. This relates to a high rainfall scenario at Lannercost (QLD).

- [Economic Case Study: Accounting for mineralised nitrogen \(N\) in crop budgets to improve N use efficiency and profit](#)
- [Economic Case Study: Smart blending of Enhanced Efficiency Fertilisers to maximise sugarcane profitability](#)

3.4.1 RRDP1717- NSW Department of Primary Industries

[Link to RRDP1717 Final Report on CRDC Website](#)

[Link to RRDP1717 Final Presentation on CRDC Website](#)

Recommendations delivered to industry from research findings

PCU (an N EEF) in NSW sugarcane field trials

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

Recommendations

- While the PCU products protected N from potential loss pathways by slowly releasing N, this did not influence yield in the four field trials. It should be noted that all four field trials had particularly dry starts to the seasons limiting N loss pathways. Therefore, under the conditions where the field trials were conducted (i.e., dry Spring and Summer), the use of PCU cannot be recommended;
- The slow-release pattern of PCUs would be likely to minimise N loss pathways in wet seasons, particularly where N fertiliser is applied directly before heavy rain, therefore it is recommended that industry develop better climate forecasting and use a modelling approach to refine decisions on the seasons where EENFs are likely to have a benefit on lowering N loss pathways;
- At some sites, lower doses of N fertiliser result in greater fertiliser N recovery in the crop and improved apparent N use efficiency. However, at other sites, yields continued to increase with increasing N dose. It is therefore recommended to maintain current recommendations within the 6ES to maximise yield.

Soil supply of N: Opportunities to refine decision support tools

- A detailed assessment of soil mineral N to 1 m (0-20, 20-40, 40-60, 60-80 and 80-100cm) from 27 sugarcane paddocks in 2016/17 revealed that several sites had considerable mineral N stores to depth. Nitrate stores were in all cases below a total of 50 kg N/ Ha, while ammonium stores were up to 250 kg N/ Ha. The high ammonium stores occurred on the Tweed Valley Hydrosols;
- A further assessment and refinement of the methodology has aggregated the data from the initial 27 sites, with a further assessment of 14 paddocks in the Tweed Valley. The additional assessment was limited to sampling from the 0-20 and 20-40cm soil layer. This has refined the mineral N stores to generally under 100 kg N/ Ha;

- PMN was conducted on the 0-20 and 20-40cm layer from all sites, and it was revealed that there was a large variability in 14-day PMN between soils. PMN ranged from 25 through to 225 kg N/ Ha;
- Summing mineral N and 14-day PMN, the soil was shown to provide between 50 and 400 kg N/ Ha, with most sites providing between 75-175 kg N/ Ha;
- The 14-day PMN can significantly underrepresent the soil supply of mineralizable N, as assays on soils that were conducted to 456 days show between a 2-5-fold increase in PMN across this period;
- MIR has provided a reasonable calibration to both 14-day and 300-day PMN, enabling an 'overnight' laboratory assessment of PMN. For example, a correlation of 0.81 (Pearson R² of 0.65) between a 300-day laboratory PMN measurement and the MIR prediction was obtained; and
- The MIR calibration is suitable for NSW sugarcane soils.

Recommendations

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

Key recommendations for the Six Easy Steps advisory panel

- Existing soil N stocks, including nitrate NO₃⁻ and NH₄⁺ in the 0-40cm layer, as well as PMN should be considered in making decisions on the most appropriate N fertiliser rate (i.e., informing the 6ES);
- While no benefits to yield were observed across four biometrically designed field trials with the use of PCU versus urea application, it must be noted that the field trials all experienced particularly dry starts to the season, where loss pathways of N were low. The use of PCU (being a more expensive product than urea) should be considered when N loss pathways are deemed important- i.e., average or higher than average rainfall is expected following N fertiliser application. This would require a modelling approach detailed location specific climate forecasting;
- Mid-infrared spectroscopy (MIR) provides a useful prediction for mineralisable N (especially long term mineralisable N) for NSW soils collected at sowing, which along with available mineral N can be used to refine fertiliser N recommendations for growers. Opportunities exist to offer this test as a service to the NSW sugarcane industry, allowing refined fertiliser N decisions.

Key messages for the NSW sugarcane industry

- Careful consideration needs to be given in selecting N EEFs, as their efficacy compared to the less expensive urea products did not justify their expense in the current testing seasons, which experienced very dry or drought conditions.
- Improved location specific seasonal climate forecasting is required, in conjunction with a modelling approach, to determine when N EEFs would be of benefit, and which N release pattern from PCU would be optimal for the given season;

- Some soils can provide a significant quantity of plant available N from existing mineral N stores and PMN. The project team will work with local industry to further validate the potential of the MIR test for PMN, and how this could inform the 6ES.

3.4.2 RRDP1718- Queensland Government Department of Environment and Science

[Link to RRDP1718 Final Report on CRDC Website](#)

[Link to RRDP1718 Final Presentation on CRDC Website](#)

Recommendations delivered to industry from research findings

Summary of project findings

- Soil mineral N (NH_4^+ and NO_3^-) contents generally declined to very low levels within 2-3 months following application of the conventional urea. This demonstrated the risk of substantial N loss from the main root zone in the early crop growing season, particularly for late harvested crops in the wet tropics which are subject to high rainfall events in summer.
- Use of PCU consistently sustained higher mineral N contents in soil during the mid- to late season compared to normal urea and nitrification inhibitor (DMPP)-coated urea treatments.
- Substantial movement of fertiliser N into deep soil occurred following high rainfall events but was significantly lower in the PCU treatments than in urea-only or NI+U treatments.
- Sugarcane biomass N accumulation followed sigmoidal dynamics, with slow N uptake rates during the first 50-60 days after harvest (DAH), then increased rapidly and peaked until approximately 200 DAH, followed by minor N uptake until harvest.
- To best match sugarcane N uptake dynamics, an ideal PCU fertiliser or its blend with normal urea should maintain sufficient, but not excessive, N supply during the 50-200 DAH. All the PCU products tested were able to release N rapidly enough to meet the crop N requirements during the early stages. Therefore, the primary benefit of blending PCU with urea is cost savings, rather than improved N supply, if N release from the PCU fertiliser is not overly slow.
- The N release dynamics for same PCU products applied from late September to December did not differ significantly at the different sites studied. Therefore, N supply from PCU to crops at different stages of the crop-growing season can be defined and predicted accurately.
- Different PCU products have significantly different N release patterns. It appeared that the 2017 Agromaster Tropical (41 %N) and the 2018 Agromaster Tropical (44 %N) matched sugarcane crop N uptake dynamics more closely than Agromaster Standard (45 %N) and Yates Meister-15 (42 %N). A product with an N release rate between those of the first two products would be more desirable if used alone.
- Nitrification inhibitor-coated urea slowed down conversion of mineral N from NH_4^+ (more stable) to NO_3^- (more susceptible to loss) in most circumstances, which is in line with findings in previous studies that nitrification inhibitor-coated urea significantly reduced emissions of nitrous oxide (N_2O , a potent greenhouse gas) from sugarcane cropping soils.
- Reducing the application rate of the conventional urea from the 6ES rates by 25% or 40% resulted in yield loss in only 1 out of the 18 trials. Applying N fertiliser in excess of the recommended 6ES rate by 25% or 40% increased yield in only 2 out of 18 trials.
- Yield responses to EEFs and different blending ratios of PCU to urea, and thus the consequent profitability, varied between sites and years. A decision tree was developed to assist in selection of EEFs (Figure 2.). Improved understanding of key drivers for such variability and their interactions is required.

Key recommendations for the Six Easy Steps advisory panel

EEFs have the potential to offer considerable environmental benefits compared to normal urea, but their yield benefits varied substantially between different sites and from year to year at the same site. From a combined agronomic, economic and environmental perspective, EEFs are recommended for paddocks with high N loss risks only.

The decision tree developed by the project can be used to assist in fertiliser selection based on site and seasonal conditions as well as farm management practices and should be considered in a review of the 6ES FertFinder DSS. The project recommends a coordinated and comprehensive review, analysis and modelling of all data collected in the completed and current EEF experiments in Australian sugarcane cropping systems. This would help improve our understanding of key factors and processes driving the agronomic, economic and environmental benefits of EEFs and more accurately identify where, when, what, and how EEFs should be used.

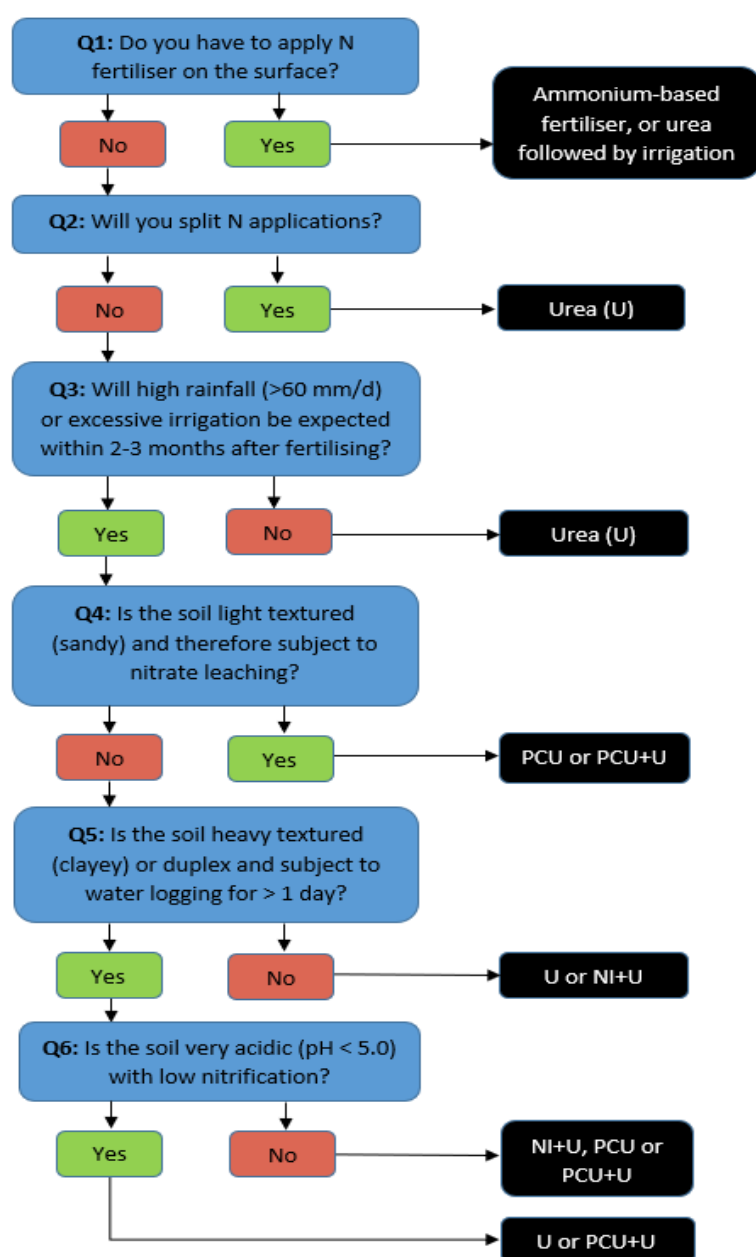


Figure 2. A decision tree for selection of nitrogen fertilisers based on possible agronomic and environmental benefits and costs. U: urea; PCU: polymer-coated urea; PCU+U: blended PCU and urea; NI+U: nitrification inhibitor-coated urea.

3.4.3 RRDP1719- Queensland Government Department Agriculture and Fisheries

Link to RRDP1719 Final Report on CRDC Website (*coming-* undergoing legal IP review)

[Link to RRDP1719 Final Presentation on CRDC Website](#)

Recommendations delivered to industry from research findings

- Matrix encapsulation of nitrification inhibitors can extend the efficacy of the inhibitor in soils. For example, encapsulation of DMPP in the matrix of Formulas 1 and 2 (F1/DMPP and F2/DMPP; currently confidential), extended the efficacy of DMPP by >20 days in the Macknade sugar cane soil, to over 68 days at soil temperatures reflective of the Herbert Catchment. In a black clay soil, polymer B/DMPP was the best performer, a formulation that did not perform as well in several other soils. In a red clay soil, F1/DMPP exceeded the performance of solution DMPP. These inhibitor formulations and solution DMPP also tended to decrease nitrous oxide emission relative to urea alone (red clay soil). Solution DMPP, which tended not to exhibit the same benefit as F1/DMPP in the red clay soil, was nevertheless more effective in eliminating N₂O emission in that soil, as those emissions tended to occur within the initial two weeks after treatment addition – making a sparing release of the inhibitor irrelevant.
- Important additional observations regarding DMPP behaviour and impact in soil included:
 1. DMPP was found to leach in the soil profile and had separated from the peak mineral N concentration at the end of Pot Trial 1; and
 2. DMPP addition did not suppress all microbial respiration from the soils, suggesting that the agri-chemical has a more specific microbial effect.
- Growth accelerator trial 1 (sugar cane), where the two sugar cane soils were leached prior to solution DMPP losing efficacy, indicated that solution DMPP, F1/DMPP and F2/DMPP increased N uptake and reduced leaching losses very significantly. A second pot trial has explored lower DMPP application rates and allowed a longer period for solution DMPP efficacy to decline to mimic the reaction vessel trials.
- The rainfall simulation results failed to provide a significant N runoff signal from the N-source only treatment. It did not demonstrate a significant impact of a sorbent and inhibitor combination on N runoff losses close to the fertiliser source. A previous related rainfall simulation trial conducted by the research team suggested that DMPP would significantly decrease runoff N losses. However, DMPP and encapsulated formulations were demonstrated to have an impact in decreasing leaching losses in growth accelerator trials.
- Only one inhibitor treatment employed in the small plot field trial resulted in a significant increase in N uptake – F2/DMPP at a rate equivalent to 0.81 kg DMPP ha⁻¹ resulted in a 19% increase in N uptake relative to the equivalent rate of urea alone. While mean uptake of some other treatments (including other rates of F2/DMPP) resulted in values higher than the control, these increases not significant.
- The F2/DMPP treatment also performed well in the single-season sugar cane field trial in the Burdekin. In particular, sugar and cane yields for the ENTEC and high F2/DMPP (both at the 0.5 X 6ES; 105 kg N ha⁻¹) were not significantly different from those of the full 6ES treatment (210

kg N ha⁻¹). Relaxing the statistical criteria (from $P < 0.05$ to $P < 0.10$) it was also evident that the high F2/DMPP treatment is likely to be delivering higher cane yield than the 0.5 6ES urea treatment. No other novel or existing treatment met this criterion.

- During the conduct of the growth accelerator trials, we finalised the robotic gantry and 3D plant scanning apparatus, honing a novel method of non-destructively profiling nutrient uptake daily. This technique is a considerable advance in the team's capability in fertiliser screening and nutrient cycling in agriculture.
- Research conducted for this project was able to demonstrate it was possible to tailor delivery of an inhibitor to match a specific requirement. Adjusting these formulation characteristics to optimise formulations for specific production systems, is the recommended next step in development.

Benefits of the research for industry

The project developed prototype, controlled delivery formulations of the inhibitor DMPP that can extend the efficacy of this agri-chemical in soil and can be further optimised to match specific requirements. The encapsulants used are biodegradable, thereby eliminating the potential for microplastic contamination of adjacent sensitive environments. Manufacture is relatively simple and uses widely available industrial techniques. A key success has been that the products developed are easily handled by conventional fertiliser spreading equipment and were favourably regarded by the fertiliser contractors who handled them for our northern trials. Successes of these materials were observed in the laboratory, small plot field trials, and at the field scale. Since the field scale results were only collected across a single season, these results should be considered positive, but preliminary.

Key recommendations for the industry

The project recommends further investigation of the F2/DMPP formulation, based on the positive results collected within the project. The initial step in this process should be the continuation of the Burdekin trial.

It is also recommended optimising the F2/DMPP formulation to maximise its benefits and applying these in multi-season field trials (minimum of 3 growing seasons). These studies should seek to optimise the materials for the production system via adjustment of the range of influential formulation parameters, as revealed in the project. If agronomic benefits continue to be demonstrated, strategies need to be pursued to make these products available to growers.

Performance of DMPP (or potentially any nitrification inhibitor) is dependent on soil conditions. Efficacy in improving N retention is dependent on ammonia volatilisation being prevented, the soil having significant nitrification potential, and ammonium adsorption capacity. Given these limitations on the conditions under which nitrifications will effectively improve nitrogen use efficiency (NUE), a multi-pronged approach to NUE improvement is required. It is recommended investigating a combination of nitrification inhibitors in conjunction with mill mud, waste-derived fertilisers (circular nutrient economy products) and managing the nitrogen mineralisation potential (PMN) of sugar cane soil profiles. Many of the beneficial characteristics of controlled release or polymer coated urea products can be achieved via the use of waste-derived fertiliser formulations, without generating

potential micro-plastics concerns, and with greater benefit in terms of developing the N mineralisation potential of the soil profile.

These managements should be developed to be readily incorporated and promoted as part of 6ES.

Encapsulated DMPP formulations have application beyond sugar cane production and may have comparable or greater benefits in broad-acre agriculture or horticulture. Research across industries may provide a strategy and resources to complete product optimisation.

3.5 Project level achievements for the horticulture industry

The two tree crops of mango and cherry are quite different in their physiological functions due to mangoes being an ever-green tropical fruit, and cherry a deciduous temperate fruit. Nevertheless, the two separate research teams worked cooperatively.

For the cherry tree crops, the MPfN Program has delivered the first NUE BMP guidelines for the industry- [Optimising nitrogen management in cherry orchards](#). In addition to being made available on the MPfN Program webpage, they are also available to growers through the Tasmanian Institute of Agriculture extension website. This 9-page resource provides a comprehensive explanation of the research findings to support the BMPs, and includes tables, graphs, photos and diagrams.

For mango tree crops, the finding and recommendations have been provided to the NT DITT extension team for development of the NUE BMP guidelines in 2022, through an industry-based extension project for Northern Territory growers.

The research teams also co-authored two economic case studies with AgEcon economists:

[Mango Economic Case Study](#)

The study outlined that N uptake efficiency can be as high as 75 % but reduces with excess N applied. For a crop of 15 t/ha with 11 kg of recycled biomass N, fertiliser application of 13 kg N/ha would meet the orchard requirements. Compared to a current practice of 50 kg N/ha, this has the potential to save \$140/ha in N inputs, as well as reducing N losses to the environment. Applied N above 25 kg N/ha increases the risk of “stay green” skin, which could lead to a 10–20 % decrease in price received.

[Cherry Economic Case Study](#)

For an orchard density of 1330 trees per ha, and a two-year average crop of 12 t/ ha, the project calculated an annual N application of 91 kg/h is required to replace N removed by fruit harvest and to replenish N in storage organs. When compared to a current practice of 120 kg/ ha this has the potential to save \$205/ha in N input costs, as well as reducing N losses to the environment.

3.5.1 RRDP1720- Northern Territory Department of Industry, Tourism and Trade (Mango)

[Link to RRDP1720 Final Report on CRDC Website](#)

[Link to RRDP1720 Final Presentation on CRDC Website](#)

Recommendations delivered to industry from research findings

Summary of project findings



Figure 3. Developed project diagram of the quantified inputs and outputs of nitrogen in a commercial mango orchard.

- The N uptake efficiency of soil-applied fertiliser of mature mango trees decreases as the quantities applied increase.
- Spraying a dilute solution of N onto mango tree leaves is a comparatively efficient way to supplement N into trees. Any N not taken up can be recycled within the orchard.
- Nitrogen in mango trees is highly mobile and is transported around trees rapidly via xylem and phloem, including leaves to roots.
- In a mature orchard, litter and pruned material contains about 20 kg N/ha. This decomposes annually (100 % in Darwin and 85 % in Katherine). The litter N becomes available in the top 20 cm of soil during the build-up and wet season (~11 kg N/ha in Darwin and 17 kg N/ha in Katherine). It is a short-term N bank for trees to access. What is not used, is lost each year.
- Emissions of the greenhouse gas nitrous oxide (N₂O) from litter and fertiliser are well below the Tier 2 Intergovernmental Panel on Climate Change (IPCC) limits for intensive horticulture in Australia.
- Harvested fruit takes about 0.8 to 1.0 kg N per tonne as it leaves the orchard. Supplying too much N for a particular harvest yield causes the skin of mango fruit to stay green when ripe. Fruit from trees receiving no applied N contain 0.4 kg N per tonne.
- Soils in NT mango orchards have minimal texture and structure, with a low capacity to store N or carbon over the medium or long term.

Key recommendations for the industry

This work directly quantifies, for the first time, N uptake and cycling in NT mango orchards so N inputs can be refined in terms of quantity and timing. Recommendations to the industry are made in the four R context as set out below.

Right time

Fertiliser should be applied to soils post-harvest, during the active growth phase of trees, and approaching the monsoon period. This coincides with the reactivation of soil macro and microfauna as moisture levels increase with break of season rains. Avoid applying N to soils or via fertigation (dissolved fertiliser delivered to trees through the watering system) when soils are waterlogged during the wet season, and during the dormant or quiescent period as trees approach flower induction. Foliar application of N (a solution of dissolved fertiliser applied to leaves as a spray) can occur at any time when rain is not expected.

Right form

Commercially available fertilisers are recommended. Minimal N₂O emissions were measured from decomposing litter and urea. Enhanced efficiency fertilisers show limited economic or environmental benefit in NT weather conditions. Soil amendments such as zeolite or biochar mixed into topsoil show some potential to retain nutrients over time but are currently cost prohibitive.

Right place

Placement of fertiliser depends on the type being applied. Soil-applied fertiliser should be placed under the drip line of the canopy, where tree feeder roots can easily access it. Avoid placing close to tree stems. Fertigation will depend on the orchard irrigation in place, pressure in the system and the radius of the sprinkler throw. Foliar applications should be made using spray equipment that is correctly calibrated to deliver the desired volume of N to the canopy of each tree.

Right amount

This will vary according to location, soils, leaf and soil analysis results, seasonal conditions and yield history. Soil-applied N uptake efficiency decreases markedly as the quantities of applied N increase. Extra or 'insurance' N is washed beyond tree roots during the wet season but may still impact on fruit quality. For each orchard, growers need to know the relationship between excess N supply, yield and 'stay green' skin when ripe. Consider how much N left the orchard in fruit, how much N is cycling in litter and available in the top 20 cm of soil during active growth and predicted yield for the next season. Fertigation and foliar application are efficient ways to add N in orchards when soils are not waterlogged. Monitor soil and tree health as usual to avoid nutrient mining or a negative nutrient balance in orchards over time.

This research provides new evidence for when and where N is available in soils for uptake and when it is lost, how much N is taken up by foliar application, and how much N and other nutrients are cycling annually in orchards. This information can now be developed further for the industry and a calculator constructed to help growers reconsider what are necessary and economic N inputs.

3.5.2 RRDP1721- University of Tasmania- Tasmanian Institute of Agriculture (Cherry)

[Link to RRDP1721 Final Report](#)

[Link to RRDP1721 Final Presentations](#)

Recommendations delivered to industry from research findings

Summary of project findings

Figure 4 below details the inputs and outputs of N over a season in a commercial cherry orchard developed by the project. The research achieved its aim of developing recommendations to industry and service providers on how best to manage N resources to reduce the N footprint of cherry production whilst maintaining and even improving sweet cherry fruit quality to an export quality standard.

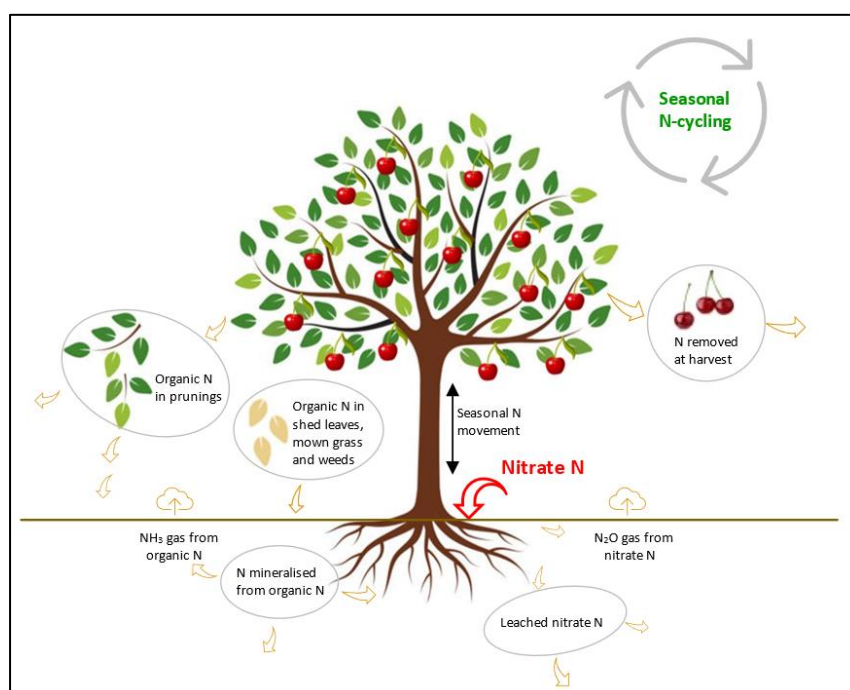


Figure 4. Developed project diagram of the elements of seasonal N-cycling for orchard cherry trees, including nitrate- N, ammonia (NH₃) and nitrous oxide (N₂O)

- The uptake of N fertiliser as determined by ¹⁵N whole tree recovery trials was measured at approximately 35%. Lower uptake of fertiliser applied at the higher rate did suggest a lower NUE, yet the rate of N applied did not affect its relative distribution amongst tree organs. As expected, the amounts of fertiliser N allocated to tree organs were for the most part substantially higher with the higher rate of N applied.
- The trials showed that pre-harvest N application can result in a wasteful amount being lost in fruit. Post-harvest application could increase NUE, but if excessive, can result in unnecessary N being removed in pruned material. Therefore, applying most annual N post-harvest is recommended, but the balance of pre- and post-harvest application might vary from season to season depending on yield and regional climatic factors.
- To best inform N management, testing of fruitlet and fruit N concentrations, and that of N in plant tissue and soil, is recommended. Efficiency of N uptake can be further enhanced by applying N frequently in smaller doses, and without excessive water where possible, to avoid

the loss of excess N through leaching and denitrification emissions. These losses can be further minimised by restricting N application if substantial rainfall is imminent in the week ahead.

- Research data suggests that 76.5 g N/tree is likely to be a reasonable seasonable 'replenishment' quantity of N (from harvested fruit and pruning material) that would provide adequate N for optimum yield of quality fruit and healthy, but not excessive, vegetative development. Attempts to improve NUE would be a preferable way to replenish tree N than increased N application.
- Taking the above value of 76.5 g N/tree as an annual replenishment quantity of N required by mature trees, at an uptake efficiency of 40% at best, would require the application of approximately 190 g N/tree if no other inputs were considered and/or uptake efficiency improved. One additional input to the 'N cycle' to be considered is N suitable for uptake that might be supplied by the mineralisation of pruned material and shed leaves. The trials demonstrated the breakdown of leaves into mineralised N of between 3.5 kg N/ha to 5.6 kg N/ha over a 12-month period. The breakdown of stems sufficient to release N for potential mineralisation and recycling would be expected to occur over a considerably longer timeframe than for leaves. Some orchards leave long lengths of pruned stems within the tree rows. The breakdown of stems to release their considerable organic N content for potential mineralisation is very slow. The removal of all pruned material for composting, as already practiced in some orchards, is worthy of consideration. At the least, much more substantial pulverisation of pruned stems before they are replied to tree rows would seem advisable.
- Alternative biological based fertiliser treatments at the N rate applied (45 kg N/ha) performed in general, comparably to the conventional calcium nitrate-based fertiliser applied at the same rate over the three seasons trialed. The feedlot waste was a relatively cheap and simple source of biologically based N, and fruit quality and yield outcomes were satisfactory over the three-year period. There is likely to be some variation in N rate between batches of feedlot waste so regular monitoring of source material is required. Certainly, this form of N could be complimentary to either conventional forms of N, or the Organic N which is significantly more expensive, yet comparatively easier to apply. The liquid based Organic N can be directly applied through existing fertigation infrastructure, however for growers considering this source of N as a viable alternative, longer-term studies investigating the soil health benefits of this form, on top of fruit quality outcomes, would be necessary given the high input cost.
- Complementing the conventional N and feedlot waste forms with a nutrient uptake facilitator showed some early evidence of being beneficial, however the positive effect wasn't repeated in seasons 2 and 3. The biological based forms of N tested clearly provide an effective alternative to conventional based fertilisers, yet based on ¹⁵N recovery trials, the project would recommend applying at a greater rate than the 45 kg N/ha trialed for ongoing tree health and adequate nutrition. This additional cost would need to be offset by further evidence of improved long-term soil and orchard health to encourage industry to adopt these N management approaches.
- Management of fertigated N application in small, regular doses is certainly constrained by the irrigation/fertigation infrastructure of each orchard. However, improvements in NUE to higher levels than those found should be possible. Regular soil testing would be necessary to improve NUE in cherry cropping systems. Another vital tool to improving NUE in cherry orchards, already undertaken in many, would be real-time monitoring of soil moisture, including that

below the root zone, to prevent application of excessive irrigation water. Pursuing such a suite of improvements might well result in improvements in NUE to over 50%, with benefits to return on investment and the environment. To determine changes in NUE, regular monitoring of N forms in soil, and N contents of fruit, leaves and pruned material would be necessary. Such testing would also act as a safeguard for orchard managers aiming to decrease their applications of N, which understandably would need to proceed with a degree of caution.

Key recommendations for the industry

- **Rate and timing:** N application rate and timing had no effect on fruit yield or quality.
- **N use efficiency:** The timing of N application to mature trees, pre-harvest, post-harvest or split application (50:50) made no difference to the efficiency of its uptake (average of 38%) but did affect its distribution within the tree.
- **Distribution:** Trees directed more pre-harvest N to fruit and more post-harvest N to vegetative growth.
- **Storage:** Only a small proportion of total tree N (19%) came from annual fertiliser application, emphasising the importance of N storage in the tree and soil.
- **Remobilisation:** The production of cherry flowers is totally dependent on the remobilisation of stored N, as is the early spring growth of leaves, stems and fine roots, with root uptake beginning about 30 days after full bloom.
- **N form:** Young trees grew equally well whether N was applied in mineral form (calcium nitrate) or organic forms, when measured over 3 years.
- **Decomposition:** N derived from leaf litter residue can provide 3-5% of tree N requirements within 12 months, with release of N from stems considerably slower.
- **Leaching:** More nitrate leaching below the root zone occurred at higher rates of nitrate N application, with 14.4, 20.5 and 30.2 kg N/ha leached in one year from respective applications of 0, 150 and 300 kg N/ha.
- **Nitrous oxide emissions:** A heavy rainfall event resulted in the loss of 2% of applied nitrate fertiliser as the potent greenhouse gas nitrous oxide. Irrigation had little influence on nitrous oxide emissions.
- **Monitoring:** Ongoing monitoring of plant and soil N, with regular application of limited N doses and avoidance of excessive irrigation, is the key to efficient N use and preventing losses through leaching and nitrous oxide emissions.

3.6 Contribution to Rural R&D for profit program objectives

3.6.1 Productivity and profitability improvements for primary producers

The MPfN Program has increased knowledge and understanding of soil and fertiliser N processes, in the context of other influencing management practices, across diverse Australian farming regions, climatic zones, soil types and farming systems. An important means to articulate the impact of research outcomes upon production measures (yield & quality) and business profit was the deployment of an economic case study approach. By improving knowledge and understanding, the research projects were able to propose new and/or amended NUE BMP strategy recommendations to industry. The economic case studies developed by the MPfN Program explore the likely economic implications for farmers of adopting these NUE strategies compared to current industry practice and/or the farmer case typical practice. This component of the project evaluated the question for each industry: Will a primary producer generate more profit from N should they adopt the NUE strategy recommendations of research?

Common across findings of the MPfN Program was the key message that the potential of generating “more profit from nitrogen” comes from a combination of strategies: total N application and rates reduced without impact to production and decreases in losses by accounting for mineralised or carry-over soil sources (cost savings); production gains from standard practice N inputs that are better timed with crop/ pasture uptake or seasonal availability of soil mineralised N sources (increased income); N inputs optimised regarding their impact on product quality (improved fruit colour/taste marketable at higher prices); and the use of more costly EEFs under certain climatic/ seasonality conditions to reduce the risk of N loss and release N when plant uptake is more certain (reduced production impacts in moist/saturated soil conditions).

Across industries, the pathway to improved profitability and the economic metric used varied dependent upon the industry measure of the biomass produced and/or market economic expression.

3.6.2 Seamless extension of results of R&D

The MPfN Program was established and delivered upon a strong foundation of collaboration that has seen industry stakeholders (RDCs, primary producers and service providers (agency and private advisors)) engaged in the research process. Although primarily developed as a research effort, project leaders have worked cooperatively with industry extension programs and commercial companies, many through the program’s relationship with Fertiliser Australia, to conduct research in local regions and hold/ be involved in location extension events.

Importantly, the research projects have worked cooperatively within their industries to translate research outcomes into “extension ready” resources or have authored updates in industry production manuals. These resources are available, now, on the MPfN Program webpage, as well as extension program websites of each of the industries. Moreover, research teams have been actively involved in the extension effort during the latter part of their projects. Primarily using webinars and videos during Covid-19 restrictions, they have upskilled both extension providers and farmers in the

new/amended strategies, including communicating the key messages on production, profit and reduced environmental impact outcomes of adoption.

Many respondents highlighted the importance of effectively communicating and extending project research, with the issue of grower and industry resistance to change reinforcing the importance of demonstrating the value proposition and benefits of nitrogen use efficiency practices. Some of the strategies suggested to address these challenges included: aligning messages with profitability; clearly communicating the benefits/savings of using nitrogen more efficiently; involving more producers in trials; better engaging service providers in the research; and disseminating information through multiple sources and using alternative extension methods.

In the MPfN Program final evaluation process, stakeholders were asked to rate the extent to which the MPfN Program has resulted, or will result, in greater producer confidence to adopt the strategies and recommendations relating to the three NUE research areas. Overall, stakeholders rated the MPfN Program moderately for influencing producer confidence to adopt the NUE strategies (Table 5) (average rating 3.7, n=65). Across the three individual research areas, stakeholders singled out the program for being the most effective at increasing producer confidence to adopt NUE strategies relating to N mineralisation. The lower rating for confidence to adopt the research findings on EEF products reflects the many uncertainties that remain around when EEF use is economically viable across varying seasonal scenarios and limited DSS to assist in this process.

Table 5. Stakeholder rating of the extent to which the MPfN Program will result in greater confidence to adopt NUE strategies across the three research areas

Average score by stakeholder group				
Stakeholder group	EEFs (activity B4)	Interplay of N factors (activity B5)	Mineralisation and N budgets (activity B6)	Average
RDC	4.0 (n=4)	3.2 (n=5)	3.0 (n=5)	3.4 (n=5)
Research leader	3.3 (n=9)	4.1 (n=10)	4.0 (n=12)	3.8 (n=12)
Research team member	3.4 (n=18)	3.5 (n=19)	3.9 (n=20)	3.6 (n=22)
Research partner	4.0 (n=5)	2.8 (n=4)	4.2 (n=5)	3.7 (n=5)
Industry service provider	3.5 (n=10)	3.7 (n=11)	4.0 (n=11)	3.7 (n=11)
Producer / grower	3.5 (n=6)	3.7 (n=7)	3.8 (n=8)	3.6 (n=8)
Industry group				
Sugarcane	3.6 (n=19)	2.8 (n=12)	3.6 (n=17)	3.3 (n=19)
Dairy	3.7 (n=15)	3.8 (n=17)	4.1 (n=18)	3.8 (n=18)
Cotton	3.5 (n=13)	3.9 (n=15)	3.8 (n=13)	3.7 (n=15)
Mango	2.3 (n=3)	3.6 (n=9)	3.7 (n=10)	3.2 (n=10)
Cherry	3.3 (n=6)	3.4 (n=8)	3.5 (n=8)	3.4 (n=8)
Stakeholder average	3.5 (n=52)	3.6 (n=56)	3.8 (n=61)	3.7 (n=65)

(Source: MPfN Final Evaluation Report, AgEcon, June 2021)

In support of the ratings on producer confidence to adopt the MPfN recommendation, stakeholders also provided comments on the extent to which adoption was already taking place, was likely to occur, or was unlikely or unknown (Table 19). Across all industries the comments were net positive (adoption has already occurred or is likely to occur with time).

While stakeholders rated producer confidence to adopt as moderate; it is important to note that the timeframe for practice change within an agricultural R&D context can take years (or decades). It is rare for industry adoption of R&D to occur rapidly following the completion of the underlying

research, but rather, adoption occurs in stages depending on the overlapping of a range of underlying factors including the strength of extension pathways and stakeholders' appetite for risk and change (social aspects), and underlying market conditions relating to the commodity and the innovation (economic aspects). A wide range of social and economic barriers have been identified by MPfN Program stakeholders, with the primary impediments being the perceived risk of missing out on lost productivity with reduced N application, combined with the low cost of traditional N sources such as urea. Together, these factors support a culture in many industries where N has been applied as a form of cheap "insurance" to maximise productivity, though recent significant increases in urea price will likely have an impact upon this attitude and recommendations of the MPfN Program means that primary producers will be well-prepared for future price rises.

While research has been extensively supported with communication and extension throughout the process, it's success is ultimately dependent on extension of the final research results in the longer term, with this responsibility falling to the industry research organisations (RDCs) and supporting industry extension programs and industry body professional development/ certification organisations e.g., Fertilizer Australia's FertCare® program for agronomists and resellers.

Importantly, the significance of this ongoing process was clearly signalled by stakeholders through their feedback in the final evaluation process. Adoption was considered likely to occur over time as the MPfN Program recommendations are integrated into industry resources and extension programs, especially in the sugar industry that has yet to stipulate how the outcomes will be embedded into the Six Easy Steps. Promisingly, stakeholders commented that adoption was already evident in all industries, with demonstrated potential for economic and environmental benefits including yield or quality improvements, reduced N inputs, and reduced losses of N to the environment.

Considering the above, the MPfN Program's 1) strong contribution to generating knowledge and understanding; 2) identification of NUE strategies or technologies that were made available for inclusion (and in some cases already included) in industry NUE BMP resources; and 3) contribution to a moderate (borderline high) industry confidence to adopt the NUE strategies, are together assessed to generate a strong immediate research impact, and a strong foundation supporting potential future adoption of NUE practices resulting in improved profitability and reduced environmental impact (Table 4, Section 3.1).

Importantly, it is up to individual industry research and extension bodies to convert this potential into realised NUE practice change and industry impact by continuing the process of integrating the MPfN Program recommendations into industry resources and extension programs and understanding and addressing industry specific barriers to NUE practice change.

3.6.3 Industry and research collaborations forming the basis for ongoing innovation and growth of Australian agriculture.

The cooperative nature in which the MPfN Program was originally scoped between the industry RDCs and research partners, and the ongoing collaborations developed and fostered throughout delivery with industry stakeholders and the private sector, has strongly contributed to a new way of thinking about agricultural research in Australia.

A significant level of research has been published in the public domain through peer reviewed papers, conference papers and industry publications and guidelines. All intellectual property is therefore deemed to have been placed in the public domain and is readily available to future research, reducing the likelihood of inefficiencies. This enables those components of MPfN Program research that have been recommended for future ongoing research to be expedited to the next phase without duplication of effort.

Historically, advancements in innovation have been impeded by siloed research and a reluctance by researchers to release findings until project completion. The MPfN Program partners delivered research activities with “extension and adoption” as a priority outcome, and never wavered from their focus upon delivering results that were practical and resulted in multi-benefits to primary producers. As such, they fully embraced interaction and involvement with primary producers and their trusted advisors, including the fertiliser industry, to progressively divulge findings, seeking input and feedback to ensure they were addressing industry needs and responding to seasonal conditions and market drivers. Furthermore, each of the research projects made remarkable efforts to collaborate with extension and communication programs to deliver key messages as they unfolded, ensuring that the outcomes and final resources developed were more understood by the target audience, reducing the lag time between extension and adoption.

The science community of Australian agriculture has benefited from a strong presence by the MPfN Program researchers at both national and international conferences. Whilst intra-program collaboration has certainly encouraged research organisations to embrace future partnerships with co-partners of the program, they have also been sought by potential collaborators based upon the presentation of their research in the broader context of the MPfN Program. The organisations involved have demonstrated to the research community their capabilities and capacity to work collaboratively with other research agencies as part of a broader research effort, and their skills in engaging the end-users in the process, for the betterment of overall research outcomes. Whilst not all research organisations/ team members joined the MPfN Program with a mindset of improving their own primary producer and industry engagement skills, they have certainly completed their work with this a strong professional development outcome.

For each of the individual industries and projects there are specific technical knowledge and understandings, as well as prototype DSS, identified as foundational outcomes and needing further investment and research to elevate to the next level of innovation. These are explained in the individual project final reports available on the MPfN Program webpage.

4. Supporting Collaboration

4.1 Overview of MPfN Program collaborations

The MPfN Program delivered 77 formal collaboration activities (refer Appendix 4) covering a breadth of intra-program, inter-industry and intra-industry forums, meetings and cooperative research activities. 1,462 people directly involved in intra and external program collaboration initiatives.

The MPfN Program evaluation reported that the program strongly supported collaborative research across all participating industries. It highlighted the important role in program leadership and coordination of the program to develop and implement cross-sector and cross-project opportunities to exchange on research methods and findings, as well as work cooperatively to deliver additional research outputs.

Each of the subprojects, the researchers have done excellent work. The level of reporting has been very good and good collaboration contributing largely to the larger group. The willingness to engage with others and the science and reporting is outstanding. (Sugar Industry)

The MPfN program has been very productive, and the national coordination provides great opportunities for collaboration and information exchange. Grouping the industry teams together also strengthens industry specific research collaboration. (dairy)

You can piggy-back on what other researchers are doing and learn a lot. (Mango).

There are enough commonalities between the different industries and the underlying science. Having the workshops and formats have enabled me to avoid some pitfalls based on other industry research. (sugar)

Feedback was sought from internal stakeholders as part of the final evaluation process, to assess how effectively the MPfN Program had supported research collaboration. Across nine collaboration activities (Figure 5), on average, stakeholders rated the MPfN Program activities highly for supporting collaboration (average rating 4.0, n=33).

Stakeholders focussed on the overall effectiveness of MPfN activities in supporting inter and intra-industry collaboration and singled out the *Annual MPfN Program Partner Forums* and *Nitrogen Natters* quarterly partner newsletter, prepared by the Science Coordinator with contributions from all sub-projects, as being particularly effective.

A small number of sugar and cotton industry stakeholder commented that more could have been done by individual industries to support collaboration, to facilitate integrated research objectives and synthesis of results, within sectors. Stakeholders saw this as a role for RDCs in the development of the initial program and then fostering more integration with other aligned industry research being financially supported by those RDCs, not necessarily just within the MPfN Program (e.g., SRA's EEF60 project).

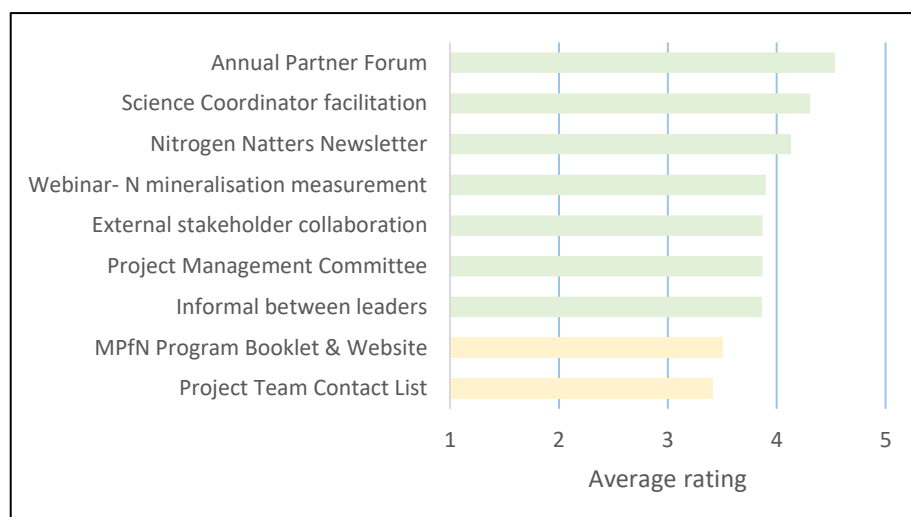


Figure 5. Rating of the effectiveness of MPfN activities in supporting collaboration

(Source: MPfN Final Evaluation Report, AgEcon, June 2021)

4.2 MPfN Program Partner Forums (2016-2021)

Annual partner forums were rated at 4.5/5 as the most effective collaboration activity of the MPfN Program by the research and industry stakeholders (MPfN Final Evaluation Report, June 2021).

Collaborations with the fertiliser Australia very good/ Annual meetings very effective / Partner Forum worked really well / Great opportunity to interact with MPfN community / Forums were a great opportunity to share/ Forums have been important and people are aware of what others are doing/ You get to interact with people from other industry - would not have happened naturally/ Able to look at the data from other projects and talk about it scientifically/ Stimulating that type of activity and knowledge sharing that is useful for all industries/ Really enjoyed the partner forums and being able to have conceptual discussion about NUE and mineralisation and how to present that.

Partners: Projects of the MPfN Program

Project Leader: Marguerite White, Science Coordinator

Five annual *MPfN Program Partner Forums* were conducted in Melbourne (Vic, 4th December 2016), Coolangatta (Qld, 8th-9th August 2017), Darwin (NT, 2nd-4th July 2018), Benowa (Qld, 4th-6th September 2019), via Zoom (22nd& 23rd April 2020) and Cairns (Qld, 27th June 2021).

These ranged from one to three-day events. The 2020 forum was to be held in Hobart, however, due to the Covid-19 pandemic, changes were made to deliver two four-hour “exchange” sessions via Zoom webinar and videos were made and distributed. The forums were highly valued by all team members, collaborators and industry/ research stakeholders because of the opportunity they provided to come together to update on research activities, share ideas on methodology and interpretation, and plan for future cooperative research, communication and extension activities.

The **2017 MPfN Program Partner Forum** resulted in agreed collaboration activities for the program which were later delivered upon:

1. Development of an agreed minimum/ common data-set for the MPfN Program:
 - a. Stock-take of the ten research projects- data collection & monitoring equipment in use
 - b. Commonalities and gaps identified- potential to standardise determined

- c. Agreed data-set established, if deemed appropriate.
- 2. Development of a set of core principles in N mineralisation measurement methodologies:
 - a. Stock-take to be undertaken of the ten research projects- mineralisation method
 - b. Collaborate with Dr Phil Moody on webinar content to explore potential commonalities across projects- conduct webinar.
 - c. Potentially scope additional project to establish core principles on mineralisation measurement.
- 3. Remote sensing technology use:
 - a. Conduct a webinar with Andrew Robson- options, benefits & outcomes for NUE.

The August meeting was considered extremely worthwhile for the mango team. Being part of a large, busy research group relies on high quality communications to keep the projects coordinated and achieving the milestones on schedule. Establishing relationships face to face at an early stage makes this easier and more effective, therefore improving the outcomes of the projects.

(NT DITT November 2017 Milestone Report)

The **2018 MPfN Program Partner Forum** evaluation revealed that over 90% of the 45 participants rated the event as very effective or extremely effective at fostering beneficial information exchange and increasing understanding between the four industries involved.

When asked about what they liked about the event, these examples are representative of responses:

Great to come together and share research and thinking/ Opportunity to discuss findings with other teams/ That so many of my colleagues across sectors took the time to participate and share/ Presentations and discussion cross- industry and cross-environments about common issues/As a sub-contractor on a project, I was previously unaware of most of the other activities occurring on the projects. It was extremely valuable for me to be involved in the discussions, and to see what activities are occurring in the other projects. I now feel much more involved in the overall project, and more motivated about the project.

The **2019 MPfN Program Partner Forum** was strategically planned in collaboration with Fertilizer Australia to coincide with the dates and venue of the **Australian Fertilizer Industry Conference**. This brought the MPfN Program team members together with a key target audience for adoption of the outcomes of the program, industry agronomists and fertiliser advisors. A joint field day and information session (Figure 6) was conducted for participants of both events, including a session where each of the ten MPfN projects delivered “snapshot” presentations to the captured audience. This partnership event resulted in a formal request from Fertilizer Australia to continue



Figure 6. Australian Fertilizer Industry Conference and 2019 MPfN Program joint presentations & field day.

the relationship and ensure outputs delivered by MPfN are disseminated via their FertCare® Program. Example of comments provided in the event evaluation:

...Thanks for suggesting the concept of a shared conference between MPfN and Fertilizer Australia. I appreciate your help and co-operation in planning and delivering the Field Tour and joint session. I received a number of very positive comments from AFIC delegates about Friday's Field Tour and joint session.....As you heard expressed on Friday, a number of delegates are keen to go back over some of the MPfN material that was presented. As further results and information from the MPfN Program come to hand, I would welcome the opportunity to help communicate relevant information and key learnings to Fertcare participants via email and newsletters etc- Fertilizer Australia Program Manager, Mr Jeff Kraak

The session was great. It's good to know that the different industries are working together as it makes a lot of sense and today has given us the opportunity to get an insider look- fertiliser resale business operator, SW Victoria.

Thank-you for the MPfN Program session at the conference. It was refreshing to see all the researchers working together and I think they did an impressive job at pulling some very complex work together into short presentations, especially as much of the research is still under way- major fertiliser manufacturer & laboratory services representative, Western Australia.

The presentation to fertiliser industry representatives indicates these people are eager for new technologies in this area. If we can prove a product, several parties will be interested in discussions- Dr Matthew Redding, QDAF (MPfN Sugar Project).

The relationship with Fertilizer Australia continued for the **2020 MPfN Program Research Update and Exchange**, conducted via Zoom in lieu of the forum due to Covid-19 border restrictions. Heavily promoted by partners and Fertilizer Australia, this alternative platform resulted in **99** registered bookings for Session 1 (Dairy & Cotton), and **89** for Session 2 (Sugar & Horticulture). There was a good variation of stakeholder groups represented from research, agronomy/ fertiliser industry, extension, technical and private farm consulting roles.

The recordings of both sessions were made available via You Tube [Session 1 Recording \(Dairy & Cotton\)](#) and [Session 2 Recording \(Sugar & Horticulture\)](#) (187 views in addition to attendees).

The two morning sessions held via Zoom to update teams and interested stakeholders in MPfN research activities and outcomes since the September 2020 forum was considered highly worthwhile attending, with an average score of 4.6/ 5 from 52 respondents.

Great to see work from other regions...All presentations, I thought, were excellent...Good presentations, well thought through. A credit to the presenters...Excellent info. Well prepared, relevant info. Grateful that I could attend these sessions from my office...The ability to keep abreast of the latest findings is awesome.

Importantly, the average rating of 4.2/5 was achieved for belief that the MPfN Program research outcomes and outputs will provide opportunities for industries to increase NUE. This was a great indication that, whilst not yet at project end, there was confidence that MPfN Program would provide opportunity to make changes to current practices.

The presented strategies/ tools that were considered to make a difference included:

Industry guidelines, understanding of in-season N mineralisation and how to link this back to N application adjustments, predictive tools of when EEFs are most likely to result in a favourable response (NUE/ profitability), relationship between mineralised N rate, moisture and temperature, new formulation encapsulated DMPP, budgeting and reducing N inputs and use of nitrogen inhibitors and EEF with decreased N application.

The final **2021 MPfN Program Partner Forum** was strategically scheduled to align with the 2021 Joint Soil Science Australia & New Zealand Soils Science Society “Soils, Investing in Our Future” Conference. Again, impacted by Covid-19 border restrictions, the forum was held as a hybrid event, with 45 attendees in person, and 33 online. Promoted through Fertilizer Australia’s FertCare® program, there was a strong representation of delegates from fertiliser manufacturers and reseller companies. The variation of stakeholder groups represented, included: 1/3 of attendees from research (teams and collaborators), 1/3 from the agronomy/ fertiliser industry (e.g., Incitec Pivot Fertilisers, Agripower, EcoGrowth, Webber & Chivell Fertilisers, Browns Fertilisers, Liquaforce, Nutrien Ag Solutions), and the remainder from extension, technical and private farm consulting roles (Farmacist, Back Paddock, Soils and Solutions, Thomas Elder Consulting, Tropecrop Pty Ltd, BioAg, AgroBest, Graham Mussell Consulting, NSW DPI) and sector manufacturers (MSF Sugar, Sunshine Sugar, Norco Milk, Suputo). The recordings made of all final presentations made by the project leaders have been produced into videos, made available alongside each project final report on the MPfN Program webpage (Links provided in Section 3).



Figure 7. 2021 MPfN Program Forum was a hybrid event with 78 registered attendees.

4.3 Nitrogen Natters partner newsletter

Partners: Projects of the MPfN Program

Project Leader: Marguerite White

The *Nitrogen Natters* quarterly partner newsletter was rated at 4.1/5 as an effective collaboration activity of the MPfN Program by the research and industry stakeholders (MPfN Final Evaluation Report, June 2021). The initiative came from the inaugural 2016 MPfN Program Partner Forum, with the desire to foster ongoing information exchange between all team members, not just the leadership group. It provided a platform for sharing the extension and communication activities across the program each quarter. The newsletter was distributed to stakeholders of the program, including the Australian Fertiliser Industry’s certified Fertcare® agronomists, and was further shared onwards within industry and the research community. Fifteen editions of *Nitrogen Natters* were published and distributed. They are an invaluable resource for future researchers, industry and stakeholder groups, and as such have been made available on the MPfN Program webpage.

[Link to Nitrogen Natters Editions on the CRDC Website](#)

The newsletter is effective and useful and shares information across trials and across the industries/Exposure to the research from other fields of cotton and horticulture adds to a bit more than just one industry/ Nitrogen Natters has been my go-to cross industry read/ Marguerite makes it interesting with the industry newsletter.

4.4 Characterising the soil organic carbon and N pools, and the PMN at MPfN Program field trial sites

Lead Partner: Queensland Government of Environment and Science

Partner: Projects of the MPfN Program

Project Leader: Dr. Phillip Moody

[Link to Final Report on the CRDC Website](#)

As an agreed action of the 2017 MPfN Program Partner Forum, this additional project capitalised on the large geographical spread of MPfN projects. The program's diversity provided an opportunity to benchmark the soil N mineralisation potential of agricultural soils under different management systems, and to benchmark the lability of the soil organic carbon and soil organic nitrogen pool in these soils.

Surface soil samples were submitted from the research sites of the individual projects from nil applied N treatment, with the aim to undertake the following soil analyses: potentially mineralisable N (PMN); particulate organic C (POC) and N (PON); and permanganate oxidisable (labile) organic C (POxC). This additional output of the MPfN Program would not have been possible without the outstanding cooperation of all project teams.

4.5 Nitrogen use efficiency indicators for the Australian cotton, grains, sugar, dairy and horticulture industries

Lead Partner: CSIRO

Partners: The University of Queensland and the projects of the MPfN Program

Project Leader: Dr. Diogenes Antille & Dr. Phillip Moody

[Link to Final Report on the CRDC Website](#)

[Link to journal publication- Environment and Sustainability Indicators \(Volume 10, June 2021, 100099\)](#)

As an agreed action of the 2018 MPfN Program Partner Forum, this additional project reviewed current metrics used to measure NUE in Australian agricultural systems to reflect productivity, profitability and environmental aspects. A suite of NUE indicators were then identified that had relevance across sectors to communicate research findings from the MPfN Program. The proposed NUE indicators were applied to data derived from the MPfN Program, provided by MPfN Project Leaders, which enabled industry-specific NUE values to be determined. These values were used to compare NUE between industries and identify opportunities where NUE could be potentially improved. An NUE indicator framework was adapted for the Australian cotton industry, as an

example, based on a generic framework developed by the EU Nitrogen Expert Panel (2015). This additional output of the MPfN Program would not have been possible without the outstanding cooperation of all project teams.

4.6 MPfN Program economic case studies across sectors

[Cross-sector Case Study: Assessment of the relationship between the most economic rate of N and N use efficiency: testing specific cotton, sugar, dairy and horticulture scenarios](#)

[Cross-sector Case Study: Long-term costs and benefits of best practice Nitrogen Use Efficiency: market access and environmental considerations for increased profit](#)

Lead Partner: AgEcon

Partners: CSIRO and the projects of the MPfN Program

Project Leader: Jon Walsh

As a joint decision of the March 2021 PMC Meeting, this additional project sought to draw-upon research findings and historical industry data to determine the legacy impact of implementing outcomes of the MPfN Program, and future use of the NUE indicators developed through the program. Consultants, AgEcon and CSIRO researchers, Dr Diogenes Antille and Dr Ben MacDonald, collaboratively scoped and delivered this project, with significant input from each of the research projects. The case study results provide some level of insight into the potential longer-term gains primary producers can hope to obtain through participating in certification schemes and demanding at least a 1% premium.

4.7 Targeted Conference Special Sessions - 2018 & 2021

Partners: Projects of the MPfN Program

Project Leader: Marguerite White

Whilst there was a very strong presence of MPfN Program team members extending and communicating research activities and outcomes across a breadth of industry and soil/agronomy science conferences (Section 5), the MPfN Program Science Coordinator submitted abstracts to secure *special sessions* at both the 2018 National Soils Science Conference ([Proceedings of the National Soils Conference, 2018](#)) and the 2021 Joint SSA & NZSSS “Soils, Investing in Our Future” Conference (postponed due to Covid-19 restrictions from September 2020 ([Conference Program](#) , [Oral Abstracts Booklet](#))).

Six presentations and one poster were accepted in 2018, and 13 presentations and two posters in 2021 from the MPfN Program team members. The significant presence of the MPfN Program would not have been possible without the collaboration with Soil Science Australia organisers, and a willingness by the MPfN Program team members to collaborate on abstract/ presentation content and use MPfN Program templates to collectively promote the outcomes of the research effort.

2021 Joint SSA & NZSSS MPfN Program Special Session Recordings shared on the MPfN Program website:

Session 1: Chaired by Dr Guna Nachimuthu (NSW DPI)

- Valuing soil organic matter for effective nutrient management in high input dairy pastures - Helen Suter, *The University of Melbourne*
- N₂O losses from urine patches following application of DMPP coated urea in dairy pastures - Johannes Friedl, *Queensland University of Technology*
- NUE indicators for the Australian cotton, grains, dairy and horticulture industries - Diogenes Antille, *CSIRO Agriculture and Food*
- Controlled Release N versus Potentially Mineralisable N: The Showdown - Lukas Van Zwieten, *NSW DPI*
- Quantifying the lateral leaching of Nitrogen fertiliser in an irrigated cotton using ¹⁵N - Jon Baird, *NSW DPI*
- Does excess nitrogen fertiliser affect in-crop nitrogen mineralisation in irrigated cotton soils? - Graeme Schwenke, *NSW DPI*
- Irrigation deficit effects on soil inorganic nitrogen in alternate-furrow flood irrigated Australian cotton production systems - Ben MacDonald, *CSIRO Agriculture and Food*

Session 2: Chaired by Dr Graeme Schwenke (NSW DPI)

- Selecting controlled-release urea for sugarcane based on fertiliser nitrogen release and crop nitrogen uptake dynamics - Weijin Wang, *Queensland Department of Environment and Science*
- Cotton roots respond to phosphorus and nitrogen fertiliser and irrigation management - Clarence Mercer, *NSW DPI*
- Dissolved phosphorus movement and balance within cotton fields - Gunasekhar Nachimuthu, *NSW DPI*
- New Techniques to increase the throughput of fertiliser product screening: machine vision and microdialysis - Matt Redding *Queensland Department of Agriculture and Fisheries*
- DMPP coated urea increases pasture yields after long-term (3 years) application in a subtropical dairy pasture - David Rowlings, *Queensland University of Technology*
- The influence of soil moisture on N₂ and N₂O emissions from an intensive dairy pasture - Arjun Pandey, *The University of Melbourne*

4.8 MPfN Program Science Coordinator

The *Science Coordinator* was rated at 4.4/5 as an effective collaboration activity of the MPfN Program by the research and industry stakeholders (second to the MPfN Program forums organised by the position) and 4.7/5 in support of project planning monitoring and reporting, (MPfN Final Evaluation Report, June 2021). This role was responsible for planning and delivering activities that fostered active collaboration between partners, and with key external organisations, over the five-year program. It delivered cross-industry and cross-program outputs- 9 extension events, 41 communication outputs, 15 project materials and 27 formal collaborations (refer Appendix 4).

It is efficiently coordinated and managed well, Marguerite is excellent at her job/ Really good role and proactive program manager and coordinator / Always responsive and helpful - she is excellent value/ Worked hard to bring the leaders together and to engage more broadly/ Very helpful and helped me contact those who are the most helpful through that contact list/ Good to be reminded we are part of a bigger project, to stay on track, help in writing-up outcomes and impacts for industry (we get lost in

the science)/ Has been a real asset to the program. An excellent communicator and organiser in terms of program facilitation/ Online database, templates, all very well managed so we appear as a program.

Have a look at how this program was managed and use that as a benchmark for how others should be managed.

4.9 Cross institutional collaboration on publications & student research

The *Program Science Publications and Conference List* references 145 published or in review/ preparation journal articles, conference proceedings/ presentations, Masters thesis and PhD thesis delivered by the MPfN Program. This publication can be found on the MPfN Program webpage:

[Link to MPfN Program Science Publications and Conference List on CRDC website](#)

Partners of the MPfN Program collaborated across projects, industries and organisations, as well as across disciplines within organisations, to prepare journal publications and provide opportunities for student positions- the future of innovative research for Australian agriculture.

For cotton, collaboration between NSW DPI, CSIRO and The University of Melbourne delivered two published articles, and support of a PhD position. A further PhD position was supported by a collaboration between NSW DPI and The University of Queensland.

As a result of dairy collaborations, the combined dairy projects (The University of Melbourne and QUT) team were able to attract an international masters student, a post-doctoral fellow and an exchange student:

- A masters student from Wageningen University, United Kingdom, joined the project team in 2018 and 2019. The student's project developed a model to predict the effect of excess dietary N on milk production and its implications for reducing N inputs on pasture-based dairy farms. This study was led by Esmee de Loof and published as a Masters thesis through Wageningen University. The project team have established on-going collaboration with Esmee, now employed by Meridian Agriculture in Victoria for the dairy industry and are developing a peer reviewed journal paper from the thesis. The model developed is now used by selected farm consultants and is being used by DairyNZ.
- A *Horizon 2020 Marie Curie* (UN supported scholarship) post-doctoral fellowship was secured in partnership with Bangor University (UK). Dr Karina Marsen joined the project team for 2019 and 2020. Karina was able to value-add to all 3 dairy projects under MPfN by working at the Allansford and Casino sites as well as on the modelling. This collaboration with Bangor University will continue until the end of the Marie Curie fellowship in 2021, but a UK Research Innovation, Future Leader Fellowships proposal has been submitted to continue the collaboration with Dr Marsden and Prof Chadwick. Karina presented a poster at the 2021 ASS & NZSSS Soils Conference.
- As a result of the Marie Curie Fellowship, the dairy projects were able to secure a CLIFFS/GRAD PhD student from Brazil, Camila Dos Santos, to work for a short time on the Casino site, assisting Karina Marsden.

The dairy teams also worked collaboratively to collaborate on journal publications and continue to cooperatively prepare new papers. QUT researchers published two with the Tasmanian Institute of Agriculture, and the University of Melbourne Modelling project collaborated with Hunter Local Land Services (NSW), Norco Milk Cooperative, Tasmanian Institute of Agriculture and NSW DPI on four publications.

The University of Melbourne Advanced Technology project worked across disciplines with engineering departments of the university to deliver upon the remote sensing objectives of the project (potential of hyperspectral data) resulting in a publication and several approved conference abstracts.

The NSW DPI Sugar project has published two journal articles with Southern-Cross University and Sunshine Sugar. Importantly, linkages were developed with scientists at the Qld Department of Environment and Science (eg, Dr Dianne Allen), who provided feedback on the methodologies for PMN. This collaboration resulted in a further project funding request (not successful), but linkages exist for future opportunities. The QDAF project published and supported a PhD position with the University of Queensland.

In horticulture, the mango NT DITT team was supported extensively by the QUT team also responsible for the dairy (subtropical pastures) project. The partnership has resulted in one collaborative journal publication, and a PhD and Masters thesis. This same QUT team partnered with the Tasmanian Institute of Agriculture cherry research team to prepare and publish a paper.

4.10 Commercial sector collaborations

Commercial partners were also an important part of both internal and external collaborations. NSW DPI (cotton) and QDES (sugar) both partnered with fertiliser manufacturers in the supply and testing of EEF products- these were Incitec Pivot Fertilisers Ltd (nitrification inhibitors – DMPs (NSW DPI) and Entec® with DMPP (QDES)) and ICL Specialty Fertilizers (Agromaster® PCU products (QDES)).

NSW DPI also collaborated Flurosats Pty Ltd software developers of the Flurosense platform. The cotton project provided field experimental plot information to use in conjunction with drone-sourced spectral imagery to assist in developing software for N management in cotton crops. Outputs from this work were presented in two papers at a spatial information conference.

Authored by FluroSat's remote sensing team, with Jon Baird of the NSW DPI cotton team, the paper is based on analysis of the nitrification inhibitor x N rate experiment near Moree in 2016–17. The research compared Vegetation Index (VI) maps and graphs generated from data acquired using both hyperspectral and multispectral sensors mounted on drones, as well as satellite multispectral data. The results demonstrated the potential of hyperspectral data to identify greater variability in crops, especially later in the season.

5. Extension and adoption activities

5.1 Overview of MPfN Program effective extension

A comprehensive account of the completed extension and communication activities for the five-year duration of the MPfN Program is provided in Appendix 4.

There were 173 extension activities achieved (Figure 8), engaging 16,044 people. A significant number of activities were delivered where researchers directly extended their research progress and outcomes to primary producers, service providers and private consultants through industry events either as the organisers or as guest speakers (workshops, field days, discussion groups, industry conferences, webinars and You Tube videos). Due to the geographic spread of the cotton, dairy and sugar industries, as well as Covid-19 restrictions later in the project, webinars, videos and podcasts were an effective means of extension. These webinars were overall organised through extension initiatives such as SRA's webinar series (Sugar), NSW DPIs Soils Network of Knowledge (SNoK) monthly webinars and Dairy Australia's DairyPod.

Science conferences and collaborations identified in Section 4 were the primary extension avenue for the science community. Large-scale national and international conferences provided extensive reach.

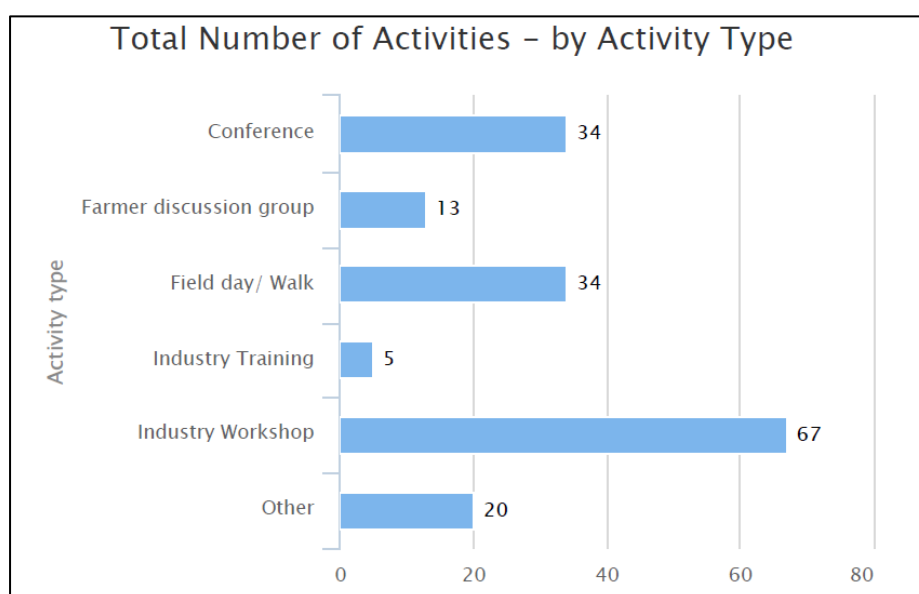


Figure 8. 2021 MPfN Program extension outputs via activity type

(Source: MPfN M&E Database)

There were 165 communication outputs achieved (Figure 9), engaging an audience of 413,843. Most of these activities were in relation research projects communicating upon progress and outcomes to industry primary producers, service providers and private consultants through industry magazines, eNewsletters, website articles, videos and social media.

The reporting of communications throughout the duration of the MPfN Program has also integrated “Project Materials”, of which 84 have been produced and extended to an audience of 63,831 (Appendix 4). It is important to include the BMP guidelines and DSS tools that have been published

in the latter stages of the 2020/2021 program phase in the context of extension and adoption, as these have had limited time to be fully extended through the MPfN Program partners, and the importance of the ongoing role of industry RDCs and extension programs in continuing this role has been a major finding of the MPfN Program Final Evaluation (AgEcon, June 20210).

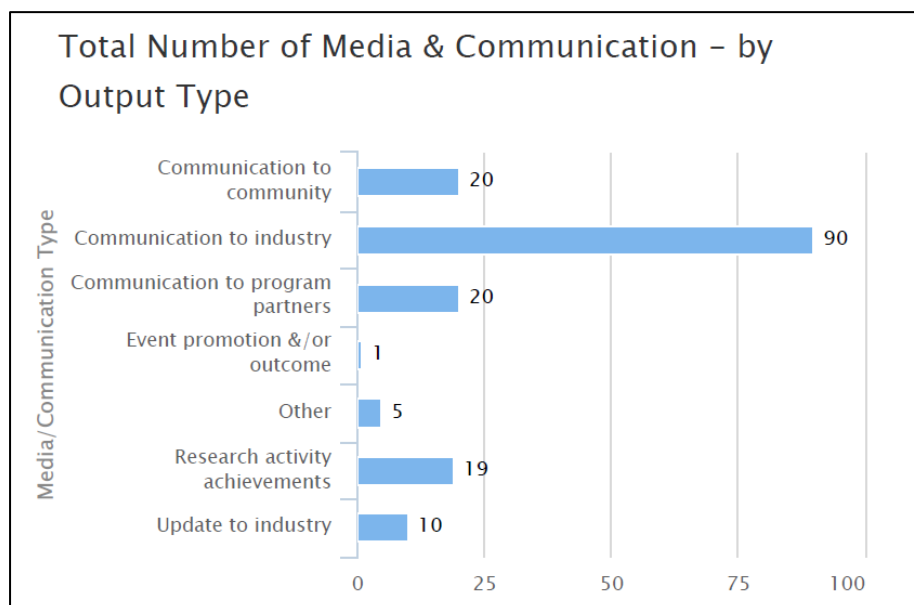


Figure 9. MPfN Program communication outputs via activity type/target audience
(Source: MPfN M&E Database)

The MPfN Program's delivery against the Communications and Extension Plan was evaluated as strong (MPfN Final Evaluation Report, June 2021), with 150% of planned activities and outputs delivered.

Overall, stakeholders rated the MPfN Program extension and external communication activities as being moderately effective at communicating the outcomes of the program and demonstrating industry opportunities for greater production and profit through increased NUE (average rating 3.6, n=61). Although lower than the mid-term evaluation rating of 3.8 (n=41), this likely reflects affected the cancellation or modification of some planned activities in the last two years of the program because of COVID restrictions. On average research level stakeholders provided a high rating (average rating 3.7, n=42) while industry level stakeholder provided a moderate rating (average 3.6, n=19).

Stakeholders commented extensively on the effectiveness of MPfN Program extension and communication activities at conveying the research findings. They also identified the effectiveness of targeting service providers to generate a multiplier effect, including through collaborations with Fertiliser Australia. The MPfN Program success in this area directly aligns with the RRD4P intent to focus on the growing role of private service delivery in industry RD&E and adoption. Research level stakeholders in all industries recognised that extension of the final recommendations was not a primary MPfN Program objective but was instead primarily the responsibility of industries going forward. As such, the industry stakeholder moderate rating on extension activities was likely linked to their lack of awareness of the MPfN Program's primary focus on research, and the ongoing work to integrate the MPfN Program findings into industry resources and extension programs at the time

of survey (April 2020 & 2021). Those industries who had already delivered new resource materials and had actively extended these in 2019-2020, received the highest rating for effectiveness of extension and communications (Dairy via publication and extension of the *Fert\$mart* resources developed- 3.9/5 (refer Section 5.2) and Cotton via the publication and extension of the *Australian Cotton production Manual* (2020 & 2021)- 3.7/5 (refer Section 5.1).

Although stakeholders identified the ongoing work needed by industry RDCs and extension programs to continue to condense the finding of the MPfN Program into simple messages and farmer language, there has been substantial work undertaken between April - July 2021 at both the industry and program level to collate findings into primary producer resources, namely economic case studies NUE guidelines (refer Section 3).

Feedback from field days was always very positive and small group discussions at workshops were very targeted and cited as useful by the growers involved (cotton).

Industry had great interaction with researchers so we are much more aware and prepared to manage N over the entire season and have benefited greatly from direct interaction with research staff (dairy).

What does it mean in 'real terms' and what can growers do in 'practical application' — provided growers with 'usable' information (sugar).

Farmers responded well to online videos. Great analytics on social. Social media are the best supporting material for the research, providing short, targeted messages (dairy).

The fact that the research was thorough, and was translated into meaningful outcomes that farmers could understand and implement in their own business (dairy on publication of industry guidelines and pocket guide)

Next step is identifying the best extension approach, which wasn't explicitly built into the program, so its industries job going forward (cotton).

The research was more focussed on fundamentals, so there is a need now to support this with specific the specific tools and strategies integrated into the 6ES (Sugar)

Full impact of the new knowledge generated by the MPfN project will occur over time (not straight away) as it is incorporated into industry extension/literature and is it becomes known by the wider industry (dairy).

5.2 Cotton extension and adoption activities

In collaboration with CottonInfo/CRDC communications and extension programs over five years, together with ongoing support from the NSW DPI Development Officer for the Soils Unit, primarily through *SNoK* initiatives, both the NSW DPI and USQ projects delivered 46 extension events, 23 communication outputs and 14 project materials.

The NSW DPI project used the satellite sites (6 project duration) to conduct local field days for local grower engagement (Figure 10). These were also used to gain input from growers on issues and treatments they were seeking to address, informing trial experiments for the following season.

The research teams were also strongly involved in guest speaker roles at grower groups (e.g., Gwydir Irrigators Association) field days and local service provider workshops. In 2018, four of the NSW DPI team, and one of the USQ team were invited as speakers on the *CottonInfo 2018 Research Tour* (Figure 11). The annual cotton initiative theme was “*nitrogen and irrigation management*”, to extend the work of the MPfN Program and aligned research of the industry. The researchers presented on work of the MPfN Program to over 400 cotton industry stakeholders at 6 farm events, from Brookstead in SE Queensland to Griffith in Southern NSW. For example, Dr Graeme Schwenke gave an invited presentation “What can growers do to improve fertiliser NUE?”, and Jon Baird presented, “How does irrigation management influence crop N losses?”.



Figure 10. Gwydir Valley Irrigators Association field day at the MPfN Norwood research satellite site of property owner Peter Glennie.



Figure 11. MPfN Cotton researchers, together with the Science Coordinator, join others on the whirl-wind CottonInfo Nitrogen & Irrigation Research Tour, photographed in Warren, NSW.

I took part in the CottonInfo researchers tour 2018 to communicate this project to industry growers. Feedback received from growers suggested that research was well received and highly relevant.”
(Research team – Cotton)

The successful communication mechanisms used were articles written for the industry’s primary research and extension magazines, *Spotlight on cotton R&D* and the *Australian Cotton Grower* (minimum 3 per year). These are delivered in print and electronically to industry growers, service providers and commercial advisors. CottonInfo uses a twice monthly eNewsletter to distribute

seasonally relevant information directly to all growers and stakeholders. The research of the MPfN Program, including relevant chapters of the 2020 and 2021 *Australian Cotton Production Manual*, continues to be used in assisting growers to make informed decisions and develop budgets for improved NUE and P management.

5.3 Dairy extension and adoption activities

In collaboration with Dairy Australia, the combined efforts of the three dairy research projects delivered 52 extension events, 55 communication outputs and 30 project materials.

The major achievement and long-term legacy of the dairy collaborations were the final outputs of the [Fert\\$mart Nitrogen Pocket Guide](#) and [Fert\\$mart Nitrogen Guidelines- Best Management Practice](#), published by Dairy Australia September, 2020.

Although the three projects were completed by May 2020, each of the project leaders continued to extend these resources, and the key messages, to industry farmers, extension program officers, service providers and private farm consultants via a series of eight webinars conducted by Dairy Australia (4- Southern dairy systems) and Hunter Local Land Service's NLP supported *Making more from Nitrogen project* (4- Subtropical dairy systems) in late 2020.

During the four years of project delivery, The University of Melbourne conducted annual field days at the Allansford (Vic) commercial core trial site (Figure 12), as did QUT on the Casino (NSW) core trial site. Both projects worked collaboratively with The University of Melbourne Modelling project to deliver common understandings and recommended BMPs to local audiences. The Victorian field days also included an early morning breakfast presentation to the south-west dairy advisor network, an initiative of Agriculture Victoria (Figure 13).

The University of Melbourne Modelling project also conducted workshops in 2018 and 2019 (Figure 14) to increase the skills of dairy nutrient advisors to use the industry's model, *DairyMod*, to better inform farmers of the outcomes of their



Figure 12. Dr Helen Suter demonstrates the use of remote sensing technologies to farmers at a field day, Allansford, Vic.



Figure 13. Dr Helen Suter demonstrates the Mineralisation Calculator to AgVic's dairy service provider breakfast to seek input and feedback (May 2019), Warnambool, Vic

N decisions and assist in their understanding of the benefits of using a seasonal strategic approach to N applications.

Dairy Australia supported the projects to publish three major articles in the Australian Dairyfarmer, as well as newsletter and eNewsletter articles across all seven dairy regions of Australia. The organisation also conducted a major social media campaign in September 2020 to promote the new resource materials, resulting in over 3,000 engagements. Ongoing, the resources will be used in seasonal communication campaigns at key periods in the dairy calendar, to be coordinated by the Soils and Irrigation Technical Leader at Dairy Australia, with the assistance of Dairy Australia's Regional Extension Officers and communication team.

5.4 Sugar extension and adoption activities

The three sugar projects were proactive in conducting local research trials applicable to each sugarcane growing region of Australia. By collaborating with regionally trusted sugarcane productivity services and private agronomy companies, relationships enabled the projects to cover the expansive sugar industry- Herbert Cane PSL (Herbert region, QLD), Faramacist Pty Ltd (Central & Mackay regions, QLD) (Figure 15), Sunshine Sugar (NSW region) and TRAP Services (Far North, QLD). Having a local presence through on-ground trials provided an excellent platform for local field days, bus tours and presentations at industry workshops. They delivered 43 extension events, 17 communication outputs and 10 project materials.

A major extension activity for the QDES and QDAF projects, was Fertilizer Australia's FertCare® Program and the Queensland Government's Office of the Great Barrier Reef Sugar FertCare® Sugarcane Nutrient Advisors Workshops in late March 2020. Team leaders, Dr Weijin Wang (QDES) (Figure 16) and Dr Matt Redding (QDAF), were



Figure 14. Dr Richard Rawnsley (TIA) delivers DairyMod training at a workshop in Melbourne, May 2017



Figure 15. Farmacist agronomist presents on the Mackay site at the I Mackay Area Productivity Services research workshop, 2018



Figure 16. Dr Weijin Wang presents at the Mackay Fertilizer Australian FertCare® workshop, March 2020

invited to present at six workshops, held over ten days, from Cairns to Bundaberg. The pair travelled with several other guest speakers to extend the outcomes of their MPfN Program research outcomes and recommendations directly to 166 regional agronomists and fertiliser resellers. The evaluation of the workshops revealed that the two MPfN Program presentations were in the top 3 (out of 7) most highly regarded topics.

In May 2020, Dr Lukas Van Zwieten, NSW DPI Project Leader, presented project findings and recommendations to industry and the Six Easy Steps nutrient program, to Northern NSW sugarcane farmers at an AgInfo Webinar, in partnership with SRA & Sunshine Sugar. The webinar was titled: *N mineralisation practical testing and calculations*. This was a major deliverable for the project, planned for a farm-based field day, but due to Covid-19 restrictions was changed to this platform. The early morning session was attended by 28 NSW cane growers and service providers. The recording of the webinar currently has 187 views. The recording is available on the SRA You Tube channel: www.youtube.com/watch?v=sndePIOdVew

Similarly, in September 2021 Dr Weijin Wang, QDES Project Leader, presented project findings and recommendations to industry and the Six Easy Steps nutrient program, at an AgInfo Webinar, in partnership with SRA, titled: *Enhanced-Efficiency Fertilisers- Potential benefits and selection of products for sugarcane*. The target audience was growers and service providers of the Queensland sugarcane regions, in which the research sites were located, Far North, Burdekin, Central and Southern. The webinar has an attendance of 40 and the webinar recording currently has 134 further views. The recording is available on the SRA You Tube channel: <https://youtu.be/V-YsSOBxyUI>

SRA's industry magazine publication, *CaneConnections*, was supportive of the research which saw the Science Coordinator prepare 6 articles for the sugarcane industry project. Initially 2017 and 2018 publications helped to inform growers and service providers of the localised research, with a series of articles in Winter, Spring and Summer of 2020 communicating on the outcomes and recommendations of the research. The focus was on key messages for growers.

5.5 Horticulture extension and adoption activities

5.5.1 Mangos

The major annual event for mango growers in the Northern Territory, the Australian Mango Industry Association (AMIA) Pre-Harvest Grower Updates (Figure 17), saw the NT DITT research team present each year in both Darwin and Katherine. Additionally, the group prepared an extensive hand-out each year that was subsequently published on the AMIA and NT DITT websites. These are the primary extension mechanism of the region.



Figure 17. Pre-harvest Mango Roadshow, Darwin Export Hub, August 2020.

Communication avenues used were the AMIA *Mango Matters* Magazine (207, 2018, 2019, 2020), *The Slice* eNewsletter, and the *Australian Tree Crop* magazine. The project delivered 12 extension events, 28 communication outputs and 16 project materials.

5.5.2 Cherries

The University of Tasmania-Tasmanian Institute of Agriculture research team formed a consultative committee to help guide their research. The growers and agronomists involved were also used as “champions” of the research at Cherry Grower Australia Ltd and Fruit Growers Tasmania field days, hosted at the sites in 2019 and 2020.

AGFest, Tasmania's premier agricultural field days, were attended each year of the project where the team promoted the progress of the research and discussed one on one with growers. The event also enabled the team to recruit growers to have trees fully excavated in the name of research.

Local Tasmanian media were very supportive of the research, with general media articles published in the Launceston Examiner, Tasmanian Country and The Mercury. Two articles were also published in the Australian Tree Crop Magazine.

The first NUE BMP guidelines for the industry, developed as an outcome of the MPfN Program ([Optimising nitrogen management in cherry orchards](#)) is now published on the Tasmanian Institute of Agriculture website along with the economic case study for cherries. Having developed a strong, trusted relationship with the Tasmanian industry, the website is the primary source of new information and innovation for growers. The team plans to continue it's local partnerships to extend these invaluable resources throughout 2022 at key seasonal times.

The project delivered 11 extension events, 15 communication outputs and 4 project materials.



Figure 18. Project steering committee meets at the orchard of the Rosegarland trial site, 2019



Figure 19. James Clements, manager for Wandin Valley Orchards, Rosegarland, and Andrew Hall, manager for Reid Fruits' Honeywood orchard at the Jericho research sites were advocates of the research project.

6. Project media and communications

www.crdc.com.au/more-profit-nitrogen

The final More Profit from Nitrogen webpage is hosted by Cotton Research and Development Corporation. It has been fully updated as the platform for industry and project level assembled final reports and presentations, new industry Nitrogen Use Guidelines that have been informed by the findings of MPfN Program research, and economic case studies developed to demonstrate the potential impact to business profit by implementing key NUE strategies trialed, tested, and recommended to industry through project research of the program. These also include the two economic case studies into cross-sector, longer-term economic impacts and links to key communication and extension outputs for visitors to the site.

It is anticipated that the site will be accessed by primary producers, service providers, the private sector (farm advisors and fertiliser companies/ resellers) and future research projects. The site will continue to be maintained by the Science Coordinator, with assistance from the CRDC Communications Manager.

The site hosts the of whole-of-program [Program Science Publications and Conference List](#) booklet, referencing the published or in review/ preparation journal articles and conference proceedings/ presentations delivered across the program .

The MPfN Program's delivery against the Communications and Extension Plan was evaluated as strong (Table 6), with **150%** of planned activities and outputs delivered (Figure 20). An additional 46 activities and outputs were also registered as completed in the MPfN Program M&E database that did not directly align with the planned tools. The online database platform was used for formal tracking of all activities, progressively updated by the Science Coordinator and Project Leaders as activities were delivered over the five years.

Table 6. Evaluation of delivery against the MPfN Communication and Extension Plan

M&E area	Planned tools	Delivery of CEP tools assessed as strong	Overall evaluation
Internal communication and extension	PMC, Science Coordinator, Program Partner Forums, Project Steering Committees, Dairy Industry Forums, Nitrogen Natters, Partner webinars and professional development, emails, workshops.	8/9 (89%)	Strong
External communication and extension	Science Coordinator, Websites, Industry Extension, social media, Industry Circulars, Media Releases, Program Booklet, Comms templates, Industry resources, Field days /workshops, technical forums, videos/case studies, project interim and final reports, conferences, science journals.	14/15 (93%)	
Overall evaluation of delivery against the MPfN CEP		22/24 (92%)	Strong

(Source: MPfN Final Evaluation Report, AgEcon, June 2021)

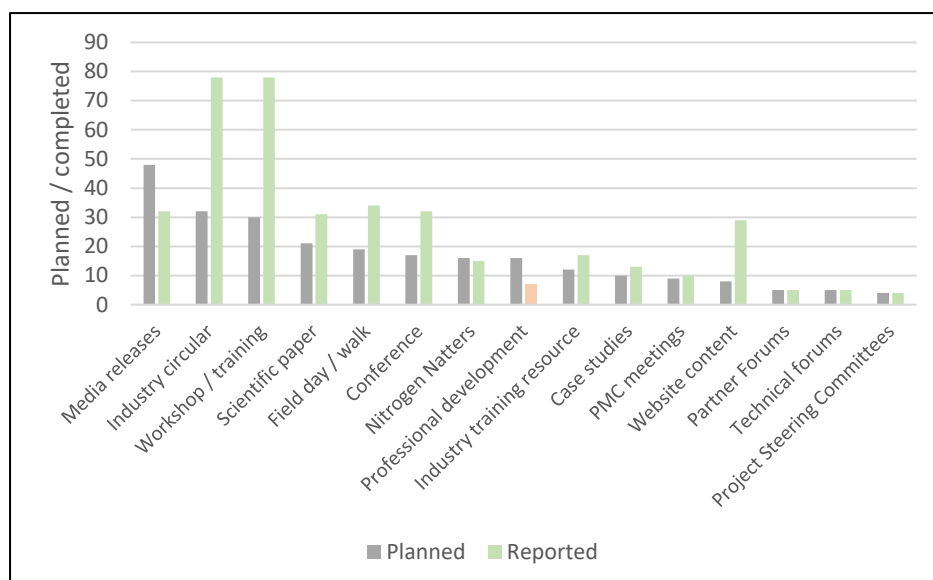


Figure 20. Communications & Extension Plan: planned compared to delivered activities
(Source: MPfN Final Evaluation Report, AgEcon, June 2021)

A summary of the overall MPfN Program output activities is provided:

Extension Activities

- 173 activities (Field Days, Workshops, Training, Discussion Groups, Conferences (industry & research))
- 16,044 people directly engaged in the MPfN Program via these events.

Media, Communications & Project Materials

- 249 Outputs (Industry media, Broad Agricultural media, social media, Websites, Conference Presentations/ Proceedings, Research Papers)
- 477,674 distributions

Formal Collaborations

- 77 activities
- 1,462 people directly involved in intra and external program additional collaboration initiatives.

A comprehensive account of the completed communications & media, extension activities, project materials and formal collaborations for the five-year duration of the MPfN Program is provided in Appendix 4, including direct links to all resources and materials produced for review by the RnD4P team.

7. Additional project information

7.1 Intellectual Property

Nature of intellectual property	Number	Details (Please provide details if appropriate (e.g., links to publicly available documents))
IP patents and/or prototypes	2	RRDP19: Discussions are underway to determine the appropriate pathway (including patent protection) for effective matrix encapsulated formulations to be incorporated in fertilisers for producers to use in the future. RRDP1715: Dairy Mineralisation Calculator
Commercialisation		
New markets		
Any return on investment (impact assessment)		
Other: (please specify)	1	RRDP1717: Calibration set of 82 soils (41 sites x 2 depths) for NSW DPI's Thermo MIR. Currently calibrated against multi-time PMN, and Total organic C. The calibration set has been archived for future purposes.

7.2 Equipment and assets

List of all equipment or assets created or acquired during the period covered by the project (>\$10,000).

Item purchased	Date of purchase	Purchase price (GST exclusive)
RRDP1712: Additional sample processing module for flow injection analyser at TAI soil chemistry laboratory	9/6/2017	\$14,992

7.3 Monitoring and evaluation

A final evaluation of the MPfN Program was conducted as a two-phase project to reflect the rolling sub-project final reporting timeframes across the program. AgEcon were formally engaged in March 2020, after they successfully responded to an open tender process conducted by CRDC in late 2019. Stage 1 was conducted March 30, 2020- June 30, 2020, and stage 2, February 28, 2021- June 30, 2021. The full evaluation report is available for public viewing on the MPfN Program webpage and is attached to this report as Appendix 5.

[Link to More Profit from Nitrogen- Final Evaluation Report on CRDC Website](#)

George Revell, Principal Economist, AgEcon was the lead investigator of the project and delivered a presentation on the outcomes of the evaluation to all partners at the 2021 MPfN Program Partner Forum, 27th June 2021:

[Link to More Profit from Nitrogen Final Evaluation Presentation on CRDC Website](#)

The *MPfN Program Monitoring and Evaluation Plan* (MEP) was completed in April 2017, in line with Activity B2, output 2(c) of the Commonwealth Agreement. The MEP contains 42 performance indicators across four M&E areas (7). Through a review of MPfN Program documentation, and quantitative and qualitative feedback from stakeholders, 83% of performance indicators were assessed as strongly achieved, and overall delivery against the MEP was assessed as strong. The remaining seven performance indicators (17%) were evaluated as having been moderately achieved, which was primarily due to stakeholders rating the MPfN Program as moderately effective in achieving some specific research and extension outcomes.

The MPfN Program Final Evaluation report has been used extensively throughout the relevant sections of this final program report.

Table 7. Evaluation of MPfN MEP performance indicators

M&E area	Description	Performance indicators assessed as strong	Overall evaluation
Initiation activities	Underpinning structures and process—What will be managed and how?	9/10 (90%)	Strong
Program Materials	Research and stakeholder adoption—What will the project produce?	7/8 (88%)	Strong
Program Activities	Research and stakeholder engagement outputs—What will the project deliver?	9/12 (75%)	Strong
Intermediate outcomes	Achievable within the life of the project—What will result from the project activities?	10/12 (83%)	Strong
Overall evaluation of delivery against the MPfN MEP		35/42 (83%)	Strong

(Source: MPfN Final Evaluation Report, AgEcon, June 2021)

7.4 Lessons learnt

Each of the research projects conducted through the MPfN Program was required to report upon the lessons they had learnt from the research, industry and primary producer/ service provider levels in final reporting. For those seeking insights into the detail of these for future learnings, it would be appropriate to read Section 6 of the relevant industry reports.

In collation of the feedback from the project level, the following were mentioned frequently across project reports:

Efficiency and effectiveness through collaboration

- There are efficiency gains in seeking information from other research projects on methodology or in sourcing certain equipment.
- Activities that brought people together provided opportunity for unconstrained, open dialogue which is very rare in research.
- The relationships that have developed have resulted in new partnerships on future research.
- Increased confidence to approach potential research partners from other organisations. Where once these organisations were seen as “competitors”, now they are identified as potential “collaborators”.
- Collaboration is not necessarily a priority in the beginning so it is important to have a dedicated, bi-partisan role, such as the Science Coordinator, to facilitate the process and keep the momentum continuous for the duration.
- Frequent interactions between researchers and service providers help update each other with new techniques, research finding and industry needs. While all the field days, bus trips and workshops have proved to be very successful, informal contacts and conversations are also important. It was therefore important to have a program team contacts list in reach.
- Opportunities are developed for growing research capability in Australian agriculture where research agencies work with tertiary institutions to offer post-graduate positions that are multi-disciplinary- important where agriculture and technically advancements e.g., remote sensing, must come together.
- There have been a few research projects on EEFs in the sugar industry in recent years. While there have been communications between project leaders/participants through various channels, a coordinated approach across the industry would be more beneficial.

Undertaking research on commercial farms

Benefits

- Improved understanding of commercial pressures from the grower perspective- contribute to better directed research programs.
- Helped to ensure that the research directly targeted challenging real industry issues, obtained support from growers and kept the end-users updated through various communication activities.
- Sites are in regions where primary producers want to see and hear from researchers that are learning more about their farming systems and taking account of these.
- Delivers strong advocacy for the project by respected farmers as industry events.

Difficulties

- Commercially managed tree crops were already managed as best as they possibly could limiting the positive or negative influence of trial treatments.
- Trial design had to be arranged in ways that were generally convenient to primary producers which meant that some compromises had to be made.
- Carryover effect from historical management limits the effects of N treatments but it is very difficult to find sites where N was below recommended limits.
- Host farmers have genuine intentions to assist, but there are times when they forget to inform the research about how they have managed the site or apply a management that was not planned for the trial.
- Measurement in-field/paddock needs to be responsive to the primary producers schedule and this may not always be possible because of logistical requirements.

Influencing practice change

Drivers

- The price of N in the form of urea has been increasing from September 2020.
- Quantifying production and quality benefits of strategic seasonal/ crop timing and rates provides an incentive to primary producers.
- Quantifying losses from N pathways is meaningful to primary producers- putting a kg/ha or \$/ha loss resonates, especially in those industries where social licence to operate is becoming more pronounced.
- Quantifying N contributions from soil mineralisation sources the following season/ crop provide increases confidence that N rates can be reduced.
- Innovative farmers are willing to change nutrient and irrigation management to improve yield and profit where they have heard it first-hand from trusted researchers and seen the evidence.
- New guidance that is underpinned by science in real-life scenarios works.
- Keep the messages concise but primary producers still want to see the uncomplicated version of the science.
- Developing skills to undertake the strategies or use the tools is integral but make it engaging and make sure the deliverer is a trusted source in the eyes of the producers.

Constraints

- N is currently perceived as relatively cheap compared to other management requirements (i.e., labour), therefore adding N at a rate that is likely to be more than necessary is undertaken as an “insurance” strategy.
- Confidence to rely upon the quantification of N supplied from soil N sources from one year to the next, or one location to another, and making an accurate decision on how much to reduce rates. N requirements are very site specific.
- Additional machinery or equipment to change application strategies can be expensive and the pay-back period can be extensive.

- EEFs are relatively expensive and rarely result in production gains. They are only economically viable in high rainfall seasons when N losses are more extreme, though the right scenario for use relies upon confidence in seasonal climate and weather predictions.
- Data conveyed in a complicated or over-bearing format at field days is confusing and reduces understanding or acceptance of the science.
- Field trials are not replicated throughout all regions, soil types and farming systems of an industry.

Location and seasonal specific circumstances

- The seasonal variations seen in productivity and NUE indicate a change in N fertiliser management is required. Use of the ¹⁵N fertiliser approach has enabled a clear identification of the role of soil-N in pasture and crop nutrition, which is much higher than imagined at commencement of the project. The long-term impacts of a single fertiliser event should be considered when thinking about N nutrition. Contributions of N to the soil organic matter pool, and subsequent release may provide an opportunity to target fertilisation to times of low loss, and to ensure more efficient N fertiliser use.
- To inform field evaluation of EEFs, a simulation analysis to quantify and explain the effects of climate, soil type and management on agronomic and environmental outcomes from using PCU in cropping systems could be conducted. These simulation analyses could show which years, and which EENF products are likely to provide benefit. However, while these simulation models are important for predicting responses, they should also be supported/ validated using field evaluation.
- Seasonal forecasts can be utilised to determine whether a research field trial will proceed. This would require significant flexibility with the funding body and milestone requirements. e.g., it was predictable that while testing EEFs in seasonally dry conditions, conventional urea application would perform equally as well, as loss pathways were not present. However, it is the years with 'average' or 'above average' rainfall, where N loss pathways do exist. Future project allocations from industry for this work would need to have contracts established with the agreement that the project commences as soon a suitable testing season is predicted.

Adoption of tools and resources

- Conducting a program that fostered research to extension approach was invaluable to industry in expediting outcomes. Although the next step is to ensure extension programs continue to extend the new/amended tools and resources for greater adoption, those projects that concluded with the development of new resources and tool for industry have elevated the confidence of primary producers in the effectiveness and efficiency of research projects, and investment decisions of the RDCs.
- Whole farm systems modelling remains a very powerful and low-cost tool to evaluate the applicability of research conducted under one set of conditions, more broadly across soils, pasture types and climates of the dairy industry.
- Whole farm systems modelling is therefore a very cost-effective mechanism to extend local research results into a farming systems context. To conduct similar research and to the range of field conditions examined here would be both prohibitive and unachievable with the

resources available. Providing workshops to upskill service providers and consultants in use of *DairyMod* had resulted in the model being used beyond research.

- There seemed to be little use in commercial systems of the decision support tool “NutriLogic” in cotton to derive N fertiliser recommendations. Growers/advisors believed this tool to be out-of-date and not relevant to crops with the current high yield potential. It is, therefore, important that industry tools and guidelines are supported to be well maintained.
- The outcomes from the dairy mineralisation calculator showed that mineralisation can occur even under periods where there is little soil moisture (summer) if there are regular, albeit they may be small, inputs of water to the system.

7.5 Budget

The final financial report will be submitted within 60 days of submitting this final milestone report. Overall, the MPfN Program has been expertly administered by the Science Coordinator, CRDC, RDCs and research partners.

Internal stakeholders were asked to rate the effectiveness of internal planning, monitoring, and reporting in supporting the delivery of research, communication and extension objectives. All stakeholder groups rated these processes highly, with an average rating of 4.2 (n=34) (Table 8). This is comparable to the high rating from the mid-term evaluation (average rating 4.3, n=27).

When asked specifically about the administrative support from CRDC as Program Manager, the Science Coordinator, and the RDC partners, stakeholders rated the support as highly effective (average rating 4.2, n=26) (Figure 1). In particular, the support provided by the Science Coordinator gained the highest rating of all questions asked in the survey (average rating 4.7, n=26).

Table 8 Quantitative feedback summary: project planning, monitoring and reporting

Average score by stakeholder type	
Stakeholder group	Rating
RDC	4.2 (n=6)
Research leader	4.3 (n=12)
Research team member	4.1 (n=18)
Research partner	NA
Industry service provider	NA
Producer / grower	NA
Industry group	
Sugarcane	4.1 (n=8)
Dairy	4.5 (n=8)
Cotton	4.3 (n=7)
Mango	4.0 (n=8)
Cherry	4.0 (n=4)
Stakeholder average	4.2 (n=34)

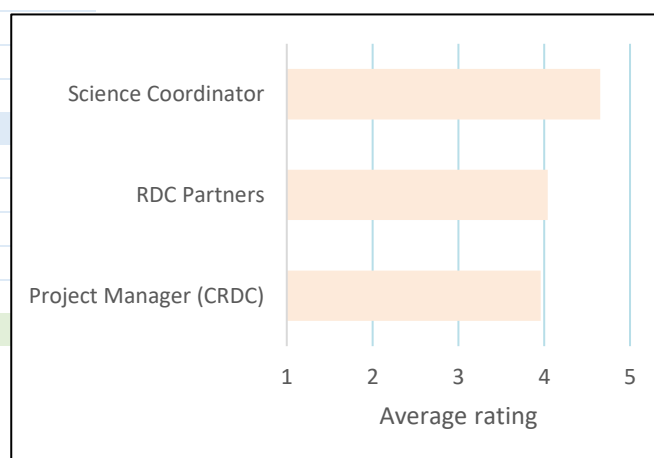


Figure 21. Stakeholder rating of administrative support
(Source: MPfN Final Evaluation Report, AgEcon, June 2021)

Appendix 1. MPfN Program research personnel 2016-2021

RnD4Profit-15-02-021 More Profit from Nitrogen Project Management Committee*

Name	Position	Organisation	Role	Duration of involvement
Marguerite White	Independent Program Manager	ICD Project Services	Science Coordinator	Program Duration
Allan Williams	General Manager, R & D Investment	Cotton Research & Development Corporation	Program Manager PMC CRDC Representative	Program Duration 2016-2019
Merry Conarty	CRDC Program Manager	Cotton Research & Development Corporation	PMC CRDC Representative	2019-2021
Cathy Phelps	Program Manager	Dairy Australia	PMC Dairy Australia representative	2016-2019
Cath Lescun	Technical Lead- Soils & Irrigation	Dairy Australia	PMC Dairy Australia representative	2019-2021
Brenda Kranz	Program Manager	Hort Innovation	PMC Hort Innovation representative	2016-2018
Byron de Kock	Program Manager	Hort Innovation	PMC Hort Innovation representative	2018-2021
Felice Driver	Program Manager	Sugar Research Australia	PMC Hort SRA representative	2016-2019
Peter Samson	Program Manager	Sugar Research Australia	PMC Hort SRA representative	2019-2020
Gus Manatsa	Program Manager	Sugar Research Australia	PMC Hort SRA representative	2020-2021
Warwick Dougherty	Senior Research Scientist	NSW Department of Primary Industries	PMC NSW DPI representative	Program Duration
Paul Lawrence	Executive Director- Science and Technology Division	Queensland Government of Environment and Science	PMC QDES representative	2016-2018
Phil Moody	Science Leader (Soil and Nutrient Management)	Queensland Government of Environment and Science	PMC QDES representative	2018-2019

*PMC also included all project leaders over the duration of the program

Total: 93 research personnel**

**There are personnel who worked across multiple projects. These have been counted only once but their names appear in all associated project tables below.

RRDP1712- NSW Department of Primary Industries (Cotton)

Name	Position	Organisation	Role	Duration of involvement
Dr Graeme Schwenke	Senior Research Scientist	NSW DPI	Project leader, Project Researcher, UM PhD student co-supervisor, MSc student co-supervisor	Project Duration
Dr Guna Nachimuthu	Senior Research Scientist	NSW DPI	Project Researcher, MSc student co-supervisor, UQ PhD student co-supervisor	Project Duration
Mr Jon Baird	Research and Development Agronomist, PhD student	NSW DPI, UM	Project Researcher, UM PhD student	Project Duration
Mr Clarence Mercer	Senior Technical Officer	NSW DPI, UNE	Technical support, MSc student (UNE)	Project Duration
Ms Annabelle Mcpherson	Technical Officer	NSW DPI	Technical support	3/7/2017—30/9/2020
Mr Tim Grant	Technical assistant	NSW DPI	Technical support	1/8/2016—31/12/2018
Mr Brad Sargent	Technical assistant	NSW DPI	Technical support	1/4/2019—30/9/2020
Mr Lloyd Finlay / Mr Hugh Coman	Technical Assistant	NSW DPI	Technical support	Start—30/4/2018
Mr Andy Hundt	Technical Officer	NSW DPI	Technical support	17/9/2018—31/10/2020
Dr Ben Macdonald	Soils and Landscapes Group Leader	CSIRO	Project Researcher, UM PhD student co-supervisor	Project Duration
Dr Helen Suter	Associate Professor	University of Melbourne	Project Researcher, UM PhD student supervisor	Project Duration
Dr Mei Bai	Postdoctoral fellow	University of Melbourne	Project Researcher	Project Duration
Dr Mike Bell	Professor	University of Queensland	UQ PhD student supervisor	Project Duration
Mr Callum Bischof	PhD student	University of Queensland	PhD student	Project Duration

RRDP1713- University of Southern Queensland- Centre for Engineering in Agriculture (Cotton)

Name	Position	Organisation	Role	Duration of involvement
Dr Diogenes L. Antille	Senior Research Fellow (Conservation Agriculture)	University of Southern Queensland, Centre for Agricultural Engineering, Toowoomba QLD (then CSIRO Agriculture and Food, Canberra ACT from July 2018)	Principal Investigator	Project Duration
Dr Alice R. Melland	Senior Research Fellow (Soils and Environmental Chemistry)	University of Southern Queensland, Centre for Agricultural Engineering, Toowoomba QLD	Associate Researcher	Project Duration
Dr Pamela Pittaway	Adjunct Senior Research Fellow	University of Southern Queensland, Centre for Agricultural Engineering, Toowoomba QLD	Associate Researcher	Project Duration
Dr Serhiy Marchuk	Research Fellow (Analytical Chemistry)	University of Southern Queensland, Centre for Agricultural Engineering, Toowoomba QLD	Technical Research Officer	Project Duration

RRDP1714- Queensland University of Technology (Dairy)

Name	Position	Organisation	Role	Duration of involvement
Dr David Rowlings	Chief Investigator	Queensland University of Technology	Project Leader	Project Duration
Dr Warwick Dougherty	Partner Investigator	NSW Department of Primary Industries	Project lead (NSW DPI component)	Project Duration
Dr Johannes Friedl	Partner Investigator	Queensland University of Technology	Associate Researcher	Project Duration
Michael Fitzgerald	Research assistant	NSW Department of Primary Industries	Technical Research Officer	Project Duration
Sarah Carrick	Research assistant	Queensland University of Technology	Technical Research Officer	Project Duration
Majella Mumford	PhD student	Queensland University of Technology	PhD student	Project Duration

RRDP1715- The University of Melbourne (Advanced Technologies)

Name	Position	Organisation	Role	Duration of involvement
Dr Helen Suter	Associate Professor	The University of Melbourne (FVAS)	Project Leader	Project Duration
Dr Oxana Belyaeva	Research Fellow	The University of Melbourne (FVAS)	Research Fellow	Project Duration
Mr Graeme Ward	Technician / Extension provider	The University of Melbourne (FVAS)	Technician / Extension provider	1/08/16-30/11/19
Prof. Deli Chen	Professor	The University of Melbourne (FVAS)	Advisor and mentor (N dynamics)	Project Duration
Prof. Jizheng He	Professor	The University of Melbourne (FVAS)	Advisor and mentor (N and soil ecology)	Project Duration
Mr Alexis Pang	Senior Tutor	The University of Melbourne (FVAS)	Remote sensing (hand-held)	Project Duration
Prof. Yong Li	Professor	The University of Melbourne (FVAS)	Mineralisation calculator	5/11/17-30/05/20
Mr Michael Hall	Senior Analyst	The University of Melbourne (FVAS)	Analytical, particularly 15N	1/11/17-30/05/20
Mr Manish Patel	PhD student	The University of Melbourne (MSE)	Student (remote sensing)	5/11/17-30/05/20
Prof. Dongryeol Ryu	Professor	The University of Melbourne (MSE)	Remote sensing (drones)	5/11/17-30/05/20
Dr Dona Thushari Wijesinghe	Research assistant	The University of Melbourne (FVAS)	Research assistant (field and lab)	1/09/18-01/04/20
Mr Tord Ranheim Sveen	Masters student	The University of Melbourne (OEP)	Student (mineralisation)	27/07/18-30/11/19
Dr Arjun Pandey	Research assistant	The University of Melbourne (FVAS)	Research assistant N ₂ :N ₂ O (lab)	23/09/18-01/04/20

RRDP1716- The University of Melbourne (Whole Farm Systems Modelling)

Name	Position	Organisation	Role	Duration of involvement
Prof. Richard Eckard	Professor	The University of Melbourne	Project Leader	Project Duration
Dr Andrew Smith	Research Fellow	The University of Melbourne	Co-investigator	2016-2019
Dr Brendan Cullen	Senior Lecturer	The University of Melbourne	Co-investigator	Project Duration
Rachelle Meyer	Research Fellow	The University of Melbourne	Co-investigator	2016-2019
Dr Richard Rawnsley	Associate Professor	Tasmanian Institute of Agriculture	TIA project Leader	2016-2019
Karen Christie	Research Fellow	Tasmanian Institute of Agriculture	Co-investigator	Project Duration
Dr Matt Harrison	Associate Professor	Tasmanian Institute of Agriculture	Co-investigator	Project Duration
Esmee de Loof	Masters Student	Wageningen University	Masters Student	2018-2019
Dr Karina Marsden	Post-Doctoral Fellow	Bangor University	Post-Doctoral Fellow	2018-2020

RRDP1717- NSW Department of Primary Industries (Sugar)

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

RRDP1718- Queensland Government Department of Environment and Science (Sugar)

Name	Position	Organisation	Role	Duration of involvement
Dr Weijin Wang	Principal scientist	DES Queensland	Project leader	Project Duration
Steven Reeves	Soil scientist	DES Queensland	Sample and data management	Project Duration
Marijke Heenan	Senior technical officer	DES Queensland	Laboratory analyses	Project Duration
Rui Liu	Research fellow	Griffith University	Research and laboratory analyses	11/2017 – 03/2019
Fang You	Technical officer	UQ	Research	02/2017 – 08/2017
Lawrence Di Bella	Manager	HCPSL	Project management	10/2016 – 12/2019

Adam Royle	Extension agronomist	HCPSL	Trial Site Project management & extension	10/2016 – 12/2019
Minka Ibanez	Field technician	HCPSL	Trial sampling	10/2016 – 12/2019
Robert Sluggett	Director	Farmacist	Trial Site Project management	10/2016 – 12/2019
Katelin Reddacliff	Field technician	Farmacist	Trial sampling	07/2019 – 12/2019
Kylie Bezzina	Field technician	Farmacist	Trial sampling	10/2016 – 07/2019
Charissa Rixon	Director	T.R.A.P. Services	Trial Site Project management	10/2016 – 12/2019
Keith Rixon	Field technician	T.R.A.P. Services	Trial sampling	10/2016 – 12/2019
Stephen Ginns	Senior extension officer	DAF Queensland	Bundaberg project coordinator	10/2016 – 12/2019
William Rehbein	Senior technical officer	DAF Queensland	Bundaberg project technician	10/2016 – 12/2019

RRDP1719- Queensland Government Department of Agriculture and Fisheries (Sugar)

Name	Position	Organisation	Role	Duration of involvement
Dr Matt Redding	Senior Principal Scientist	DAF Queensland	Project Leader	Project Duration
Dr Ian Phillips	Senior Scientist	DAF Queensland	Senior Project Contributor, Lead on field trials	2018 - 2021
Mr Ben Hunter	Scientist	DAF Queensland	Experimental implementation	2020 - 2021
Ms Brianna Smith	Technician	DAF Queensland	Experimental implementation	2020 - 2021
Ms Taleta Bailey	Technician	DAF Queensland	Experimental implementation	2017 - 2019
Prof Susanne Schmidt	Professor	University of Queensland	Supervising the UQ SAFS team inputs	Project Duration
Dr Richard Brackin	Scientist	University of Queensland	Experimental Implementation	2017 - 2019

Dr Maren Westermann	PhD Student	University of Queensland	Experimental Implementation	2017 - 2019
Mr Aidan Chin	Scientist	University of Queensland	Experimental Implementation	2017 - 2019
Prof Bronwyn Laycock	Professor	University of Queensland	Supervising the UQ Engineering team inputs	Project Duration
Prof Steve Pratt	Associate Professor	University of Queensland	Supervision of UQ Engineering team student	Project Duration
Dr Ian Levett	PhD Student	University of Queensland	Project PhD student	Project Duration
Lawrence Di Bella	Manager	HCPSL	Project management- Macknade Site	2019-2021
Adam Royle	Extension agronomist	HCPSL	Trial Site Project management & extension- Macknade Site	2019-2021
Jayson Dowie	Director	Farmacist	Trial Site Project management- Ayr Site	2019-2021

RRDP1720- Northern Territory Department of Industry, Tourism and Trade (Horticulture- Mango Tree Crops)

Name	Position	Organisation	Role	Duration of involvement
Dr Mila Bristow	Senior Principal Scientist	DITT	Project Leader	Dec 2016 – Aug 2018
Dr Matt Hall	Extension Coordinator	DITT	Project Manager Extension	Aug 2018 – July 2021 April 2018 – Aug 2018
Dr Constancio (Tony) Asis	Plant nutrition scientist	DITT	Project Leader/ Senior Researcher	Project Duration
Dr David Rowlings	Chief Investigator	QUT	Responsible for the QUT component of the project including science direction, PhD supervision, lab methodologies and analysis, and preparation of report.	Project Duration
Dr Joanne (Jo) Tilbrook	Senior Scientist	DITT	Senior Researcher	Feb 2017 – July 2021
Danilo Guinto	Research scientist	DITT	Assist in the conduct of field experiment in Katherine and coordinate with mango growers.	May 2018 – Jan 2020
Alan Niscioli	Senior technical officer	DITT	Technical leadership across the project, coordinate technical staff on all aspects of the project and maintain grower liaison/ industry engagement.	Dec 2018 – July 2021
Dallas Anson	Technical officer	DITT	Provide technical assistance with trial implementation and management.	April 2017 – March 2020
Heshan Jayasekara	Technical officer	DITT	Technical assistance with trial management.	Aug 2018 – Jan 2020

RRDP1721- University of Tasmania- Tasmanian Institute of Agriculture (Horticulture- Cherry Tree Crops)

Name	Position	Organisation	Role	Duration of involvement
Dr Nigel Swarts	Senior Research Fellow	UTAS-TIA	Project Leader	Project Duration
Dr Peter Quin	Junior Research Fellow	UTAS-TIA	Post doctorate researcher	Project Duration
Nadine Macha	PhD student	UTAS-TIA	PhD student	1/7/2016- 30/6/2020
Dr Dugald Close	Professor	UTAS-TIA	Research associate	Project Duration

RRDP1901- Nitrogen use efficiency indicators for the Australian cotton, grains, sugar, dairy and horticulture industries

Name	Position	Organisation	Role	Duration of involvement
Dr Diogenes L. Antille	Senior Research Scientist (Soil Physics)	CSIRO Agriculture and Food	Principal Researcher	Project Duration
Dr Phil Moody	Science Leader (Soil and Nutrient Management)	The University of Queensland/ DES Queensland	Principal Researcher	Project Duration

Characterising the soil organic carbon and nitrogen pools, and the potentially mineralisable soil nitrogen at MPfN field trial sites project***

Name	Position	Organisation	Role	Duration of involvement
Dr Phil Moody	Science Leader (Soil and Nutrient Management)	DES Queensland	Principal Researcher	Project Duration
Dr Diane Allen	Technical Analysis	DES Queensland	Technical Leader	Project Duration

***Project also included all teams of the MPfN Program, especially the project leaders in collation and supply of the soil samples and assistance in interpretation of analysis results.

Appendix 2. MPfN Program research locations 2016-2021

45: 1 to 4-year experimental trial sites

49: sites used for further deep soil core/plant sampling

13: Laboratories used for sample testing, glasshouse experiments, simulations and modelling

Lead Partner	Year/s	Research Site Type	Name	Location	Site Coordinates	Experiment
RRDP1712 NSW DPI (Cotton)	2016-2020	Core 1	Australian Cotton Research Institute- pdk C4	Narrabri, NSW	-30.193848 149.611548	Irrigation deficits; N fertiliser timing; N fertiliser rates including nil N, budgeted N and a high N rate; N fertiliser products including several enhanced efficiency products; in-crop N application types; growth regulator application strategy or nil; nil P fertiliser or P fertiliser applied before cotton. Nil P fertiliser; P fertiliser mixed or banded; P fertiliser applied before cover crop or before cotton.
	2016-2020	Core 2	Australian Cotton Research Institute- pdks 3&4	Narrabri, NSW	-30.202836, 149.597726	
	2018-2020	Core 3	Australian Cotton Research Institute- pdk D1	Narrabri, NSW	-30.195249, 149.614643	
	2017-2018	Satellite 1 a	Peter Glennie – Norwood- Commercial Farm	Moree, NSW	-29.387919, 149.776577	Ammonia volatilisation case study
	2017-2018	Satellite 1 b	Peter Glennie – Norwood- Commercial Farm	Moree, NSW	-29.400435, 149.786990	N rate x nitrification inhibitor (anhydrous ammonia)
	2018-2019	Satellite 3	Peter Glennie – Norwood- Commercial Farm	Moree, NSW	-29.407976, 149.771096	N strategy x P fertiliser addition
	2017-2018	Satellite 2	Noel Donnelly- Sunningdale- Commercial Farm	Gunnedah, NSW	-30.926810, 150.284756	N rate x nitrification inhibitor (anhydrous ammonia)
	2018-2019	Satellite 4	Andrew Wilson- Kilmarnock- Commercial Farm	Boggabri, NSW	-30.727263, 150.074867	N timing x P fertiliser addition
	2019-2020	Satellite 5	Tim Gainsford- Central Farm- Commercial Farm	Narromine, NSW	-32.224855, 148.094917	Late N application impact on boll retention
	2019-2020	Satellite 6	Mark Dugan- Toobaroo West- Commercial Farm	Narromine, NSW	-31.965876, 148.167877	N strategy x P fertiliser addition
	2017-2018	Deep core soil sampling	Auscott Warren- Commercial Farm	Warren	-31.783333, 147.766667	P stratification study
	2017-2018	Deep core soil sampling	Beechworth- Commercial Farm	Merah North	-30.183333, 149.300000	P stratification study
	2017-2018	Deep core soil sampling	Glenarvon- Commercial Farm	Wee Waa	-30.150000, 149.516667	P stratification study
	2017-2021	Laboratory	CSIRO Agriculture and Food Black Mountain Science and Innovation Precinct	Canberra, ACT	-35.2740473,149.11255	Soil & plant testing/ analysis
	2017-2021	Laboratory & glasshouse	Australian Cotton Research Institute	Narrabri, NSW	-30.2068025,149.593806	Soil & plant testing/ analysis
RRDP1713	2016-2018	Core 1 & 3	Naas Family- Commercial Farm	Yargullen (Jondaryn), QLD	-27.448458, 151.553982	2016-2017: post-emergence fertiliser 125 kg/ha N as urea or DMPP urea applied on 30th Oct 2016 in 25 cm bands plus 0

USQ (Cotton)						fertiliser control treatment. No mid-crop fertiliser applied. 2017-2018: post-emergence fertiliser 150kg/ha N as urea or DMPP urea applied on in 25 cm bands plus 0 fertiliser control treatment. No mid-crop fertiliser applied to a) long-term overhead irrigated site cotton-corn b) conversion overhead irrigated site cotton-cotton.
	2016-2017	Core 2	Clapham Family- Commercial Farm	Kincora (Pittsworth), QLD	-27.832336, 151.525774	Post-emergence fertiliser 140 kg/ha N as urea or DMPP urea applied on 4th Nov 2016 in 50 cm bands plus 0 fertiliser control treatment. No mid-crop fertiliser applied.
	2016-2018	Laboratory	University of South Queensland- Centre for Engineering in Agriculture	Toowoomba, QLD	-27.6353381, 151.9292218	Soil, water & plant testing/analysis
RRDP1714 QUT (Dairy)	2016-2019	Core 1	Clark Family- Commercial Farm	Casino, NSW	-28.8052, 152.9841	Pasture response to applied N fertiliser trials; Pasture demand for PAN; Fertiliser recoveries using ¹⁵ N labelled urea; Winter irrigation campaign; Irrigations impact on N loss following intense rainfall; Agronomic importance of NH ₃ volatilisation N losses and effectiveness of Green urea; Annual irrigation trial; The Long term DMPP trial; The effect of DMPP on direct fertiliser and urine N losses
	2017-2019	Core 2	Elizabeth Macarthur Agricultural Institute, NSW DPI	Camden, NSW	-34.1244, 150.7053	Pasture response to applied N fertiliser trials; Pasture demand for PAN; Fertiliser recoveries using ¹⁵ N labelled urea; Winter irrigation campaign; Irrigations impact on N loss following intense rainfall; Agronomic importance of NH ₃ volatilisation N losses and effectiveness of Green urea
	2019	¹⁵ N Satellite	Neal Family- Commercial Farm	Taree, NSW	-31.88567, 152.57483	Fertiliser recoveries using ¹⁵ N labelled urea

RRDP1714 UoM -Adv. Tech (Dairy)	2019	¹⁵ N Satellite	Commercial Farm	Berry, NSW	-34.79, 150.74	Fertiliser recoveries using ¹⁵ N labelled urea
	2016-2019	Laboratory	Queensland University of Technology	Brisbane, NT	-27.477603, 153.027603	Plant, soil and ¹⁵ N labelled urea recovery testing and analysis.
	2016-2019	Core 1	Commercial Farm- Irrigated	Mepunga West (Allansford), Vic	-38.418055,142.64	N response and agronomic NUE were investigated in response to two fertilization strategies with and without addition of (i) the urease inhibitor N-(n-butyl) thiophosphorictriamide (NBPT) and (ii) nitrification inhibitor 3,4-Dimethylpyrazole phosphate (DMPP). The N response was studied from application of urea at 0, 20, 40, 60 and 80 kg N /ha. The response of inhibited urea was studied from application of urea at 0, 10, 20 and 40 kg N /ha. In addition to this, the nitrogen availability from urine patches was studied from application of synthetic urine at 1000 kg N ha ⁻¹ .
	2016-2019	Core 2	Commercial Farm- Dryland	Mepunga West (Allansford), Vic	-38.418055,142.64	As Above
	2019	Satellite	Commercial Farm	Coorimungle, Vic	-38.536726,143.05885	The N response and agronomic NUE were studied from application of urea at 0, 20, 40, 60 and 80 kg N/ha.
	2016-2019	Laboratory	The University of Melbourne	Parkville, Vic	-37.7971759,144.954775	Plant, soil and ¹⁵ N labelled urea recovery testing and analysis.
	2016-2020	Modelling	Tasmanian Institute of Agriculture, Dairy Research Centre	Elliott, TAS	-41.08, 145.78	Modelling studies comparing a range of N rate and N timing over 20 years.
RRDP1716 UoM- Modelling (Dairy)	2016-2020	Modelling	Ellinbank Dairy Research Farm (DETDJR Vic)	Ellinbank, VIC	-38.24, 145.94	As above
	2016-2020	Modelling	Commercial Farm	Mt Gambier, SA	-37.90, 140.79	As above
	2016-2020	Modelling	Neal Family- Commercial Farm	Taree, NSW	-31.88567, 152.57483	As above
	2016-2020	Modelling	Demo Dairy Demonstration Farm	Terang, VIC	-38.24, 142.92	As above
	2016-2019	Modelling- partner	Clark Family- Commercial Farm	Casino, NSW	-28.8052, 152.9841	Modelling studies comparing a range of N rate and N timing over 20 years, including benefits of nitrification inhibitors. Modelling seasonal soil N

RRDP1717 NSW DPI (Sugar)						mineralisation using three models.
	2016-2019	Modelling- partner	Elizabeth Macarthur Agricultural Institute, NSW DPI	Camden, NSW	-34.1244, 150.7053	Modelling studies comparing a range of N rate and N timing over 20 years. Modelling seasonal soil N mineralisation using three models.
	2016-2020	Modelling-partner	Commercial Farm	Mepunga West, Vic	-38.2505, 142.3824	Modelling studies comparing a range of N rate and N timing over 20 years, including benefits of nitrification inhibitors.
	2016-2017	Core 1	Quirk Family- Commercial Farm	Stotts Creek, NSW	-28.28185, 153.50739	Field trial assessing EENF (PCU) vs urea at 0, 50, 100, 200, 300, 400 units N each for each formulation of fertiliser. Plots a minimum of 33m in length, Random complete block design (n=3).
	2016-2018	Core 2	Rodgers Family- Commercial Farm	Pimlico, NSW	-28.89123, 153.51904	As above
	2018-2020	Core 3	Pye Family- Commercial Farm	Coraki, NSW	-29.008100, 153.294945	As above
	2018-2020	Core 4	Munroe Family - Commercial Farm	Woodford Island, NSW	-29.525483, 153.110182	As above
	2016-2020	Deep core soil sampling	Clarence Catchment Sites, NSW	8 sites	-29.52417, 153.12073 -29.52559, 153.11119 -29.45663, 153.26624 -29.45633, 153.25976 -29.42276, 153.24615 -29.42115, 153.24786 -29.46841, 153.27304 -29.48088, 153.28129	4 deep soil cores taken per field, 1 used for assessment of BD and root mass, 3 bulked for chemical assessment. Cores divided into 0-20cm, 20-40cm, 40-60cm, 60-80cm and 80-100cm layers. Soils used throughout project for assessment of soil N stocks, PMN, calibration with MIR and other factors.
	2016-2020	Deep core soil sampling	Richmond Catchment Sites, NSW	16 sites	-28.89122, 153.52121 -28.89312, 153.49715 -28.9099, 153.48656 -28.89123, 153.51904 -29.01496, 153.30189 -29.00669, 153.29093 -28.92178, 153.53275 -28.91872, 153.53044 -28.88113, 153.52955 -28.88203, 153.53852 -28.91912, 153.23892 -28.93017, 153.24054 -28.84262, 153.49591	As above

					-28.83956, 153.49689 -29.08937, 153.32968	
	2016-2020	Laboratory	Wollongbar Primary Industries Institute	Wollongbar, NSW	-28.8167187, 153.3924008	Laboratory assessment in ISO17025 (NATA) labs for Mineral N, TN, TC. ISO17025:2015 certification of PMN, MIR, TOC, TON, HWEC, HWEN, biomass C.
	2016-2020	Deep core soil sampling	Tweed Catchment Sites, NSW	16 sites	-28.28417, 153.50022 -28.28852, 153.42681 -28.33726, 153.41036 -28.308326, 153.456325 -28.309082, 153.456175 -28.273063, 153.467871 -28.273261, 153.467023 -28.276134, 153.469730 -28.314763, 153.423814 -28.315622, 153.423149 -28.316751, 153.421851 -28.313087, 153.399620 -28.316232, 153.399666 -28.316204, 153.400133 -28.335517, 153.412204 -28.337761, 153.412316	3 Sites- As above 13 Sites- 3 cores taken per field from 0-20 and 20-40cm layer and bulked for assessment of PMN to expand the calibration set for MIR.
RRDP17118 QDES (Sugar)	2016-2020	Core 1	Department of Agriculture & Fisheries	Bundaberg, QLD	-24.8475, 152.40194	12 treatments at each field trial, with a major focus to investigate the effects of different blending ratios of PCU rates (Agromaster®, ICL Specialty Fertilisers) to urea on sugarcane productivity, sugar yield, fertiliser N use efficiency and profitability. Treatments with nitrification inhibitor-coated urea (ENTEC® with DMPP, 3,4-dimethyl pyrazole phosphate, as the nitrification inhibitor; Incitec Pivot Ltd) included for comparison.
	2016-2019	Core 2	Commercial Farm	Mackay, QLD	-21.410278, 149.159444	As above
	2016-2019	Core 3	Commercial Farm	Lannercost, Ingham, QLD	-18.603056, 146.050278	As above
	2016-2019	Core 4	Commercial Farm	Lillypond, Ingham, QLD	-18.592639, 146.232778	As above

RRDP1719 QDAF (Sugar)	2016-2019	Core 5	Commercial Farm	Tully, QLD	-18.053333, 145.877778	As above
	2016-2019	Core 6	Commercial Farm	Innisfail, QLD	-17.771944, 146.013333	As above
	2016-2019	Laboratory	EcoSciences Precint	Dutton Park (Brisbane), QLD	-27.4946951, 153.027620	Plant, Soil & N analysis
	2017-2021	Core 1 & Laboratory	AgriScience Queensland Laboratory Facilities	Toowoomba, QLD	Laboratories: -27.59989, 151.93121 Field: -27.5347411, 151.93052	Small field trials- Urea, DMPP, cwax/DMPP, starch/DMPP, PHA+PCL/DMPP Rainfall runoff simulation trial- Ammonium Sulphate, DMPP, cwax/DMPP, high ammonium-preference zeolite. Laboratory process reaction vessel trials to screen materials- 18 formulations (nitrification inhibitor formulations, and two urea hydrolysis inhibitor formulations) Growth accelerator trials- Urea, DMPP, cwax/DMPP, PHA+PCL/DMPP, in two sugar cane production soils and one high-quality agricultural soil for comparison
	2019-2021	Core 2	Herbert Sugarcane Region Commercial Farm	Macknade, QLD	-18.5869528, 146.2520444	Field Validation trial- Urea, DMPP, cwax/DMPP, PHA+PCL/DMPP
	2020-2021	Core 3	Burdekine Sugarcane Region Commercial Farm	Ayr, QLD	-19.64823, 147.32989	Field validation trial- Urea, DMPP, cwax/DMPP, PHA+PCL/DMPP
	2017-2021	Laboratory	The University of Queensland School of Agriculture & Food Sciences, Faculty of Science	St Lucia, QLD	-27.500, 153.000	Soil biology testing and analysis
RRDP1720 NT DITT (Mango)	2016-2020	Core 1 & Laboratory	Coastal Plains Research Station, NTG Research Station	Middle Point (Darwin), NT	-12.56407, 131.32996	A manual chamber system was set up in an established orchard to collect gas samples for analysis of N ₂ O emissions. Litter decomposition rates were measured and soil cores taken periodically for analysis of N mineralisation and other parameters. KP orchard planted and 15N-labelled fertiliser applied over time to assess N

						uptake efficiency by destructive sampling of the trees. ¹⁵N-labelled fertiliser was infused into replicate trees to assess N movement at phenological timepoints. Destructive sampling of trees allowed the recovery of the labelled fertiliser across the tree parts. Ripening chambers were used onsite in 2019, and imaging of fruit was carried out in the laboratory.
	2017-2019	Core 2 & Laboratory	Katherine Research Station- NTG Research Station	Katherine, NT	-14.466700, 132.312539	Orchard: In situ soil N mineralisation, litter decomposition and gaseous emissions studies Generated ¹⁵N-labelled leaf litter for decomposition studies Conducted leaf nutrient resorption studies Mango orchard outdoor laboratory: automated gas sampling from stainless steel chambers with insulated acrylic lids, quantified in situ using a gas chromatograph to measure N₂O. Litter decomposition rates were measured and soil cores taken periodically for analysis of N mineralisation and other parameters. Laboratory: estimating mango fruit dry matter as a % of the fresh weight of the fruit (fruit % DM), using a calibrated F-750 near infrared spectroscope.
	2017-2020	Laboratory	Bermimah Farm	Berimah (Darwin), NT	-12.444108, 130.929614	Agriculture laboratory-washing, drying and milling plant and soil samples, preparation for analyses Post-harvest laboratory-ripening fruit, cold store of material, post-harvest assessments,

						destructive measurements of fruit. Grow, graft and maintain mango seedlings for ¹⁵ N foliar uptake experiments
2016-2021	Satellite	Acacia Hills Mango Farm- Commercial Orchard	Acacia Hills, NT	-12.748, 131.177492		Remote sensing collaboration using satellite imagery to predict mango and other crop yields – ongoing. Collecting ground-based data to validate predictions; Litter and pruned material collection
2018-2020	Satellite	Nutrano-Eumaralla Farm- Commercial Orchard	Katherine, NT	-14.466642, 131.312608		Two-year trial designed to quantify N impacts on fruit yield and quality Litter and pruned material collection
2016-2021	Satellite	Tou's Garden- Commercial Orchard	Acacia Hills, NT	-12.791131, 131.159908		Remote sensing collaboration using satellite imagery to predict mango and other crop yields – ongoing. Collecting ground-based data to validate predictions Litter and pruned material collection
2018-2020	Satellite	NTLD Katherine- Commercial Orchard	Katherine, NT	-14.46996, 132.30701		Litter and pruned material collection
2017-2018	Soil Sampling	Jabiru Tropical Orchards- Commercial Orchard	Arnhem Hwy, NT	-12.552881, 131.262822		Soil sampling for laboratory analysis of N mineralisation, leaching and amendment experiments
2016-2017	Soil Sampling	Happy Mangoes- Commercial Orchard	Darwin, NT	-12.789444, 131.011806		As above
2016-2017	Soil Sampling	Manbullo Mangoes- Commercial Orchard	Katherine, NT	-14.58729, 132.00912		As above
2016-2017	Soil Sampling	Pinata- Commercial Orchard	Katherine, NT	-14.548361, 132.472644		As above
2016-2017	Soil Sampling	Seven Fields- Commercial Orchard	Katherine, NT	-14.54025, 132.468389		As above
2016-2017	Soil Sampling	NTLD Darwin River- Commercial Orchard	Darwin, NT	-12.779689, 131.031794		As above
2017-2020	Laboratory	Queensland University of Technology	Brisbane, NT	-27.477603, 153.027603		All laboratory-based soil experimental work including cores sampled in the NT orchards and trialling of impacts of soil amendments

RRDP1721 UTAS-TAS (Cherry)						Analysis of plant material and soils, including ¹⁵ N content using isotope ratio mass spectrometry (IRMS) and inductively coupled plasma mass spectrometry (ICP-MS)
	2016-present	Core 1	Reid Fruits Honeywood Orchard – Commercial Orchard	Jericho, TAS	-42.3734, 147.2464	Young trees: Conventional (calcium nitrate) rate treatments applied via fertigation system and alternative biological treatments applied either via fertigation or spread (i.e., manure)
	2016-present	Core 2	Wandin Valley Farms- Commercial Orchard	Rosegarland, TAS	-42.7123 146.9428	¹⁵ N treatments applied pre- and post-harvest over two seasons; Mature trees: Conventional (calcium nitrate) rate treatments applied via fertigation system and alternative biological treatments applied either via fertigation or spread (i.e., manure); ¹⁵ N labelled proline delivered via foliar application as an alternative nutrient source.
	2017-2020	Laboratory	TIA Horticulture Research Centre	Sandy Bay, TAS	-42.90539, 147.32454	Litter bag treatments with labelled ¹⁵ N litter derived from a highly enriched ¹⁵ N treated cherry tree at Wandin Valley farms

Appendix 3. MPfN Program Milestone 10 KPI Reporting Table

RnD4Profit-15-02-021 Whole-of-program

KPI number & description	KPI Due Date	Summary of final outcome of the research concluded by this KPI															
KPI 10.1 – Provide the final evaluation of the Activity (Section E2- Final Report).	30/09/2021	A final evaluation of the MPfN Program was conducted as a two-phase project to reflect the rolling sub-project final reporting timeframes across the program. AgEcon were formally engaged in March 2020, after they successfully responded to an open tender process conducted by CRDC in late 2019. Stage 1 was conducted March 30, 2020- June 30, 2020, and stage 2, February 28, 2021- June 30, 2021. Link to More Profit from Nitrogen- Final Evaluation Report on CRDC Website George Revell, Principal Economist, AgEcon was the lead investigator of the project and delivered a presentation on the outcomes of the evaluation to all partners at the 2021 MPfN Program Partner Forum, 27th June 2021: Link to More Profit from Nitrogen Final Evaluation Presentation on CRDC Website Part 1. Evaluation of delivery against MPfN plans The delivery of MPfN activities and outputs against the three MPfN Plans was evaluated as strong overall. Across the three plans, an average 91% of planned outputs, milestones and performance indicators were evaluated as strongly delivered (Table 1). <i>Table 1. Summary of evaluation of program delivery against the MPfN plans (Source: MPfN Final Evaluation Report, AgEcon, June 2021)</i> <table> <tr> <th>MPfN plan</th><th>Elements rated as strong</th><th>Overall evaluation</th></tr> <tr> <td>Overall evaluation of delivery against the MPfN PMP</td><td>132/133 (99%)</td><td>Strong</td></tr> <tr> <td>Overall evaluation of delivery against the MPfN CEP</td><td>22/24 (92%)</td><td>Strong</td></tr> <tr> <td>Overall evaluation of delivery against the MPfN MEP</td><td>35/42 (83%)</td><td>Strong</td></tr> <tr> <td>Overall stakeholder rating of planning, monitoring and reporting</td><td>4.2 (n=34)</td><td>Strong</td></tr> </table>	MPfN plan	Elements rated as strong	Overall evaluation	Overall evaluation of delivery against the MPfN PMP	132/133 (99%)	Strong	Overall evaluation of delivery against the MPfN CEP	22/24 (92%)	Strong	Overall evaluation of delivery against the MPfN MEP	35/42 (83%)	Strong	Overall stakeholder rating of planning, monitoring and reporting	4.2 (n=34)	Strong
MPfN plan	Elements rated as strong	Overall evaluation															
Overall evaluation of delivery against the MPfN PMP	132/133 (99%)	Strong															
Overall evaluation of delivery against the MPfN CEP	22/24 (92%)	Strong															
Overall evaluation of delivery against the MPfN MEP	35/42 (83%)	Strong															
Overall stakeholder rating of planning, monitoring and reporting	4.2 (n=34)	Strong															

Overall evaluation of delivery against the MPfN plans (average rating)**91%****Strong**

In terms of program facilitation; online database, templates for reports, all very well managed. Have a look at how this program was managed and use that as a benchmark for how others should be managed (dairy)

Nitrogen Natters has been my go-to cross industry read (mangos)

The MPfN Program delivered more than 150% of planned activities and outputs across collaboration, communication, and extension. Internal stakeholders rated the project planning, monitoring and delivery as highly effective (average 4.2, n=34), and the administrative support provided as highly effective (average 4.2, n=26), with generally positive comments supporting these ratings.

Part 2. Evaluation of delivery against program objectives

Overall, delivery of the MPfN against the three program objectives was evaluated as strong (Table 2).

Table 2. Summary of evaluation of program delivery against the MPfN objectives (Source: MPfN Final Evaluation Report, June 2021)

Evaluation of successful delivery against the project objectives		Average stakeholder rating	Overall evaluation
Primary objectives	Generate knowledge and understanding	3.9 (n=62)	Strong
	Inform NUE resources	3.6 (n=60)	Moderate
Secondary objectives	Support collaboration (internal stakeholders only)	4.0 (n=33)	Strong
	Support extension pathways	3.6 (n=61)	Moderate
Overall evaluation of delivery against the MPfN objectives (average rating)		3.8	Strong

We had very little knowledge on the seasonal dynamics of nitrogen use in cherry orchards up until we commenced these trials. The ¹⁵N trial facilitated new knowledge and understanding of NUE in this context for both researchers and industry (cherry)

The MPfN project has enabled more accurate values to be placed on N dynamics, such as mineralisation and the reason for seasonality in N response, which will provide industry with greater knowledge for decision making around N nutrition (dairy)

One recommendation was to consider and understand seasonal potential. If they have a prediction of seasonal rainfall then this may influence the application of EEFs. This was not necessarily previously considered (sugar)

There are enough commonalities between the different industries and the underlying science. Having the workshops and formats have enabled me to avoid some pitfalls based on other industry research (sugar)

The MPfN program has been very productive, and the national coordination provides great opportunities for collaboration and information exchange. Grouping the industry teams together also strengthens industry specific research collaboration (dairy)

Across the MPfN Program objectives, the perceived effectiveness against research level outcomes (research level knowledge and fostering collaboration) was strong, reflecting the delivery of a high level of research outcomes for what was fundamentally a research program. While the perceived effectiveness against industry level outcomes (contribution to industry level resources, extension, and changes in industry level knowledge) was moderate, the lower ratings were consistent with these primarily being secondary objectives of the program. In particular, comments recognised that while the MPfN Program delivered clear R&D outputs to inform industry resources (a primary objective), responsibility for integrating the findings into industry resources and extending these to growers lay primarily with the individual industries and would continue beyond the completion of the MPfN. In addition, while all industries had begun to integrate the MPfN recommendations into industry resources, or had plans to do so, the comments indicated that service providers and producers were not as aware of this ongoing process, which likely contributed to their lower ratings in this area.

Part 3. Evaluation of immediate and legacy impact

Stakeholders rated producer confidence to adopt as moderate; however, it is important to note that the timeframe for practice change within an agricultural R&D context can take years (or decades). It is rare for industry adoption of R&D to occur rapidly following the completion of the underlying research, but rather, adoption occurs in stages depending on the overlapping of a range of underlying factors including the strength of extension pathways and stakeholders' appetite for risk and change (social aspects), and underlying market conditions relating to the commodity and the innovation (economic aspects). A wide range of social and economic barriers were identified by MPfN stakeholders, with the primary impediments being the perceived risk of missing out on lost productivity with reduced N application, combined with the low cost of traditional N sources such as urea. Together, these factors support a culture where N is applied as a form of cheap insurance to maximise productivity.

The identified social and economic factors present potential barriers to practice change, reducing the rate or level of overall adoption of new practices and technologies. Understanding and addressing these barriers to change where possible and reinforcing the key research messages through industry specific resources and extension becomes critical to achieving incremental practice change and industry impact. While this process can be supported with communication and extension throughout the R&D process (as the MPfN has done through the delivery of 150% of planned communication and extension activities and outputs), it's success is ultimately dependent on extension of the final research results in the longer term following the completion of the research phase, with this responsibility falling to the industry research organisations and supporting industry bodies. Importantly, the significance of this ongoing process was clearly recognised by research level stakeholders through their feedback, and across all stakeholders adoption was considered likely to occur over time as the MPfN recommendations are integrated into industry resources

and extension programs. Promisingly, stakeholders commented that adoption was already evident in all industries, with demonstrated potential for economic and environmental benefits including yield or quality improvements, reduced N inputs, and reduced losses of N to the environment.

Considering the above, the MPfN Program's 1) strong contribution to generating knowledge and understanding; 2) identification of NUE strategies or technologies that were made available for inclusion (and in some cases already included) in industry NUE resources; and 3) contribution to a moderate (borderline high) industry confidence to adopt the NUE strategies, are together assessed to generate a strong immediate research impact, and a strong foundation supporting potential future adoption of NUE practices resulting in improved profitability and reduced environmental impact (Table 3). Importantly, it is up to individual industry research and extension bodies to convert this potential into realised NUE practice change and industry impact by continuing the process of integrating the MPfN recommendations into industry resources and extension programs and understanding and addressing industry specific barriers to NUE practice change.

Table 3. Summary of evaluation of immediate and legacy impact to improve on-farm NUE (Source: MPfN Final Evaluation Report, AgEcon, June 2021)

Evaluation of immediate and legacy impact to improve on-farm NUE	Average stakeholder rating	Overall evaluation
Generate knowledge	3.9 (n=62)	Strong
Inform NUE resources	3.6 (n=60)	Moderate
Confidence to adopt MPfN strategies and recommendations	3.7 (n=65)	Moderate
Overall evaluation of immediate and legacy impact (average rating)	3.7	Strong

The integration of dairy R&D findings into industry BMPs was a highly effective means of focussing interpretation and a path to next and end users of knowledge (dairy)

Developed a practical tool. Depending on different harvest dates, applications, weather, it helps guide which combination of N to use, including EEF (sugar)

Next step is identifying the best extension approach, which wasn't explicitly build into the program, so its industries job going forward (cotton)

KPI 10.2 – Provide a summary of completed Communication and Extension Activities, including the dissemination	30/09/2021	Output 3(a) – Identify target audiences and establish appropriate contacts with them, including peak industry bodies, growers in target regions, industry extension agents and crop consultants / agronomists. Output 3(b) – 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.
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of final Project outcomes to industry and stakeholders (Outputs 3(a) and 3(b)).	www.crdc.com.au/more-profit-nitrogen The final More Profit from Nitrogen webpage is hosted by Cotton Research and Development Corporation. It has been fully updated as the platform for industry and sub-project level assembled final reports and presentations, new industry Nitrogen Use Guidelines informed by the findings of MPfN Program research, and economic case studies developed to demonstrate the potential impact to business profit by implementing key NUE strategies trialed, tested, and recommended to industry through sub-project research of the program. These also include two economic case studies into cross-sector, longer-term economic impacts. The site also hosts the of whole-of-program <i>Program Science Publications and Conference List</i> that references the published or in review/ preparation journal articles and conference proceedings/ presentations delivered across the program (https://www.crdc.com.au/sites/default/files/CRD21004-015%20References%20MK4.pdf). A collation of collaborative activities is also provided on the website, such as the annual <i>More Profit from Nitrogen Partner Forums (2016-2021)</i>, 2018 and 2021 <i>National Soils Science Conference- MPfN Program special sessions</i>, and reports on cooperative projects delivered- <i>Characterising the soil organic carbon and nitrogen pools, and the potentially mineralisable soil nitrogen at MPfN field trial sites project</i> and <i>Nitrogen use efficiency indicators for the Australian cotton, sugar, dairy and horticulture industries NUE Indicators for the Cotton, Dairy, Sugar and Horticulture industries project</i>. All industry and research organisation partners have integrated resources and materials from this site into industry nutrient/nutrition program websites and extension aids such as Dairy Australia's Fert\$mart webpage, the sugar industry's Six-Easy-Steps webpage and CottonInfo's nutrition program. For the horticulture tree crop industries of cherry and mango, the research organisations are the primary extension arm for providing information relating to nutrient use efficiency, and as such, both the University of Tasmania- Tasmanian Institute of Tasmania, and the Northern Territory Department of Industry, Tourism and Trade have established their own websites to extend MPfN Program materials and have communicated these through partner industry organisations, Cherry Growers Australia and the Australian Mango Industry Association. A comprehensive account of the completed communications & media, extension activities, project materials and formal collaborations for the five-year duration of the MPfN Program is provided in Appendix 4, including direct links to all resources and materials produced for review by the RnD4P team. The MPfN Program used a formal Monitoring and Evaluation (M&E) Database, updated by the Science Coordinator and Project Leaders as activities were delivered over the five years. The program's delivery against the Communications and Extension Plan was evaluated as strong (MPfN Final Evaluation Report, June 2021), with 150% of planned activities and outputs delivered. A summary of the output activities and evaluation of these is provided below.
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Program Outputs**Extension Activities** (Table 1)

- 173 activities (Field Days, Workshops, Training, Discussion Groups, Conferences (industry & research))
- 16,044 people directly engaged in the MPfN Program via these events.

Media, Communications & Project Materials (Further outlined in KPI 10.3)

- 249 Outputs (Industry media, Broad Agricultural media, social media, Websites, Conference Presentations/ Proceedings, Research Papers)
- 477,674 distributions

Formal Collaborations (Table 2)

- 77 activities
- 1,462 people directly involved in intra and external program additional collaboration initiatives.

Table 1. MPfN Program extension activities by activity type (Source: MPfN Program M&E Database)

Activity type	Activities	Farmers	Ha	Service providers	Count	Other	Total
Conference	34	230	3,000	545	5,420	1,475	7,670
Farmer discussion group	13	181	46,915	50	21	18	270
Field day/ Walk	34	820	66,517	341	141	225	1,527
Industry Training	5	0	8,000	44	24	86	154
Industry Workshop	67	1,140	55,740	1,626	579	522	3,867
Other	20	809	130,575	610	79	1,058	2,556
Total	173	3,180	310,747	3,216	6,264	3,384	16,044

Table 2. MPfN Program collaboration activities by activity type (Source: MPfN Program M&E Database)

Collaboration Type	Activities	Farmers	Service providers	Researchers	Other	Total
Cross sector forum	2	0	42	49	3	94
Industry forum	3	105	54	52	45	256
Meeting discussion	34	28	17	231	58	334
Other	9	11	9	46	15	81
Partnership activity with MPfN partner	21	22	37	278	46	383
Partnership activity with industry program/ project	4	4	15	31	2	52
Partnership activity with private sector	4	130	83	49	0	262
Total	77	300	257	736	169	1462

Overall, stakeholders rated the MPfN extension and external communication activities as being moderately effective at communicating the outcomes of the program and demonstrating industry opportunities for greater production and profit through increased NUE (average rating 3.6, n=61). Although lower than the mid-term evaluation rating of 3.8 (n=41), this likely reflects affected the cancellation or modification of some planned activities in the last two years of the program as a result of COVID restrictions. On average research level stakeholders provided a high rating (average rating 3.7, n=42) while industry level stakeholder provided a moderate rating (average 3.6, n=19).

The effectiveness of individual MPfN extension and communication activities at disseminating relevant project information to industry was rated from moderate to high (average rating 3.7, n=63), with in-person events viewed as the most effective at disseminating the project information (Figure 1). On average, research level stakeholders rated the extension activities highly (average 3.7, n=44), while industry level stakeholders rated extension activities as moderate (average 3.5, n=19).

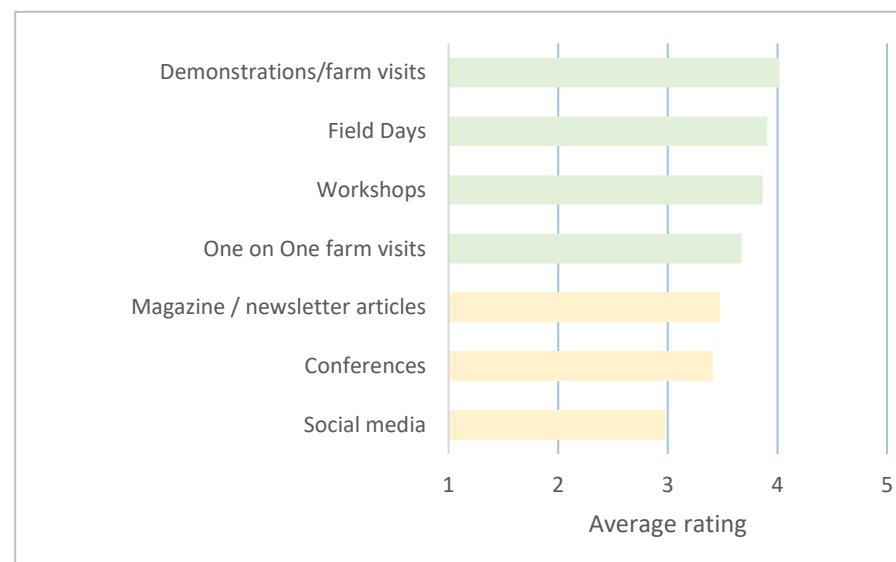


Figure 1. Stakeholder rating of MPfN Program extension and external communication

(Source: MPfN Final Evaluation Report, AgEcon, June 2021)

Stakeholders commented extensively on the effectiveness of MPfN extension and communication activities at conveying the research findings. They also identified the effectiveness of targeting service providers to generate a multiplier effect, including through collaborations with Fertiliser Australia. The MPfN success in this area directly aligns with the RRD4P intent to focus on the growing role of private service delivery in industry RD&E and adoption. Research level stakeholders in all industries recognised that extension of the MPfN final recommendations was not a primary MPfN objective but was instead primarily the responsibility of industries going forward. As such, the industry stakeholder moderate rating on extension activities was likely linked to their lack of awareness of the MPfN Program's primary focus on research, and the ongoing work to integrate the MPfN findings into industry resources and extension programs. Stakeholders identified the ongoing work needed by industry RDCs and extension programs to continue to condense the finding of the MPfN Program into simple messages and farmer language.

		<i>Feedback from field days was always very positive and small group discussions at workshops were very targeted and cited as useful by the growers involved (cotton).</i> <i>Industry had great interaction with researchers so we are much more aware and prepared to manage N over the entire season and have benefited greatly from direct interaction with research staff (dairy).</i> <i>What does it mean in 'real terms' and what can growers do in 'practical application' — provide growers with 'usable' information (sugar).</i> <i>Farmers responded well to online videos. Great analytics on social. Social media are the best supporting material for the research, providing short, targeted messages (dairy).</i> <i>The fact that the research was thorough, and was translated into meaningful outcomes that farmers could understand and implement in their own business (dairy on publication of industry guidelines and pocket guide)</i> <i>Next step is identifying the best extension approach, which wasn't explicitly build into the program, so its industries job going forward (cotton).</i> <i>The research was more focussed on fundamentals, so there is a need now to support this with specific tools and strategies (Sugar)</i> <i>Full impact of the new knowledge generated by the MPfN project will occur over time (not straight away) as it is incorporated into industry extension/literature and is it becomes known by the wider industry (dairy).</i> Internal research and industry stakeholders were asked to assess the effectiveness of supporting collaboration. Across 9 collaboration activity type, stakeholders rated the MPfN activities highly for supporting collaboration (average rating 4.0, n=33) (Figure 2).
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KPI 10.3 – Provide a list of prepared, submitted and published research (Output 3(c)).	30/09/2021	Output 3(c) – Prepare articles for publication in local media outlets and/or industry-specific magazines, newsletters, journals and websites; and prepare abstracts for presentation at industry-specific conferences. Publish research findings. The overall MPfN Program extension, communications, project materials and collaboration achievements were presented at the 2021 MPfN Program Partner Forum by the Science Coordinator. Link to More Profit from Nitrogen Science Coordinator Final Presentation on CRDC Website The <i>Program Science Publications and Conference List</i> references 145 published or in review/ preparation journal articles, conference proceedings/ presentations, Masters thesis and PhD thesis delivered by the MPfN Program. This publication can be found on the MPfN Program webpage- https://www.crdc.com.au/sites/default/files/CRD21004-015%20References%20MK4.pdf The MPfN Program database reports that for Media, Communications & Project Materials, the program delivered 249 Outputs (Industry media, Broad Agricultural media, social media, Websites, Conference Presentations/ Proceedings, Research Papers) that had a reach of 477,674 people. Importantly, Figure 1 shows that the program’s primary focus of communicating on research activity and outcomes/ outputs was directly to industry stakeholders. The industry R&D and association magazines provided a direct route to market for articles prepared by the research teams, often in collaboration with industry extension programs. These included Australian Dairyfarmer, Spotlight on Cotton Research, Cotton Grower, CaneConnections, Australian Canegrower, Mango Matters and Australian Tree Crops. Similarly, the industry and research organisational eNewsletters (e.g., NSW DPI’s SNoK, CottonInfo, SRA) and social media provided opportunity for brief updates and extension of resources such as videos, technical tips, and guidelines on N use nearer the conclusion of the program. These are all available from Appendix 4.
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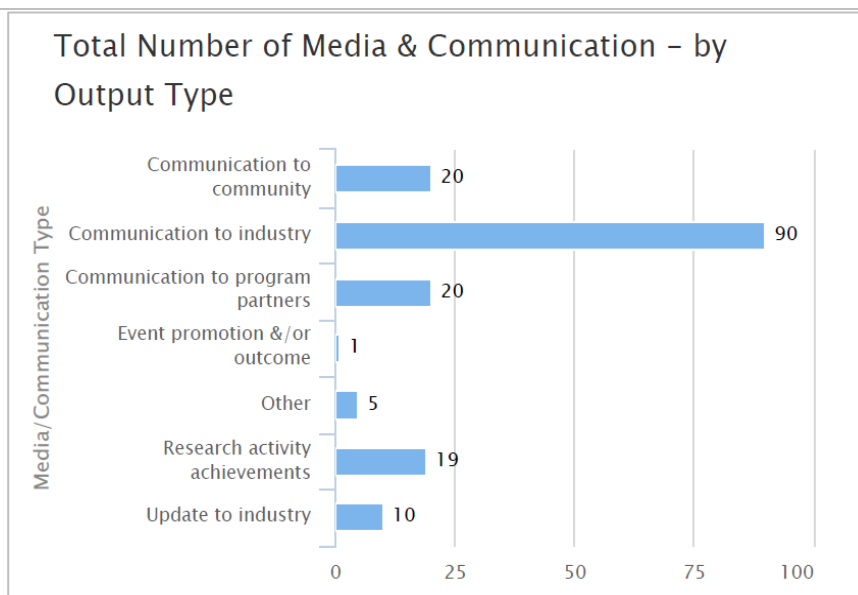


Figure 1 MPfN Program Media & Communication activities by type.

(Source: MPfN Program M&E Database)

The types of project materials produced by the MPfN Program is outlined in Figure 2.

Demonstrating the economics was highlighted as a key focus area for extension to support producer confidence in the research (MPfN Final Evaluation Report, June 2021). The importance of this was recognised in the MPfN Program planning, and as a result the program has delivered least two economic case studies for each industry group that highlight the farm level economic benefits of applying the MPfN recommended strategies. These case studies are all published on the MPfN Program webpage under the relevant sector.

There were 69 abstracts prepared and accepted for presentations (*Program Science Publications and Conference List- 18 Cotton, 27 Dairy, 9 Sugar 9, 9 Horticulture 9, 6 Cross-sector*) at 29 industry-specific conferences (e.g., Australian Society of Sugar Cane Technologists, Australian Mango Conference, Australasian Dairy Science Symposium, Australian Cotton Research Conference) and science discipline-specific conferences (e.g., Soil Science Australia Conferences (2018 & 2021), Nutrition Society of Australia, Greenhouse Gas and Animal Agriculture conference, Australian Agronomy Conference, International Congress on Modelling and Simulation N Workshop, 8th Global Nitrogen Conference).

The preparation of industry Nitrogen Use Guidelines/ Manual Chapters (represented as Booklets/Fact Sheets in Figure 2) across all industries, with the exception of Mangoes (coming in 2022) and sugar (outcomes to be considered by the Six-Easy-Steps industry committee for integration into the guidelines), has been a significant contribution to each industry sector. The value of translating new or updated knowledge into clear guidelines for industry came in the latter stages of the program for most industries and was not necessarily reflected in the outcomes of the final evaluation

due to timing. **Nitrogen Use Guidelines/ Manual Chapters** emanating from the MPfN Program research are all published on the MPfN Program webpage under the relevant sector.

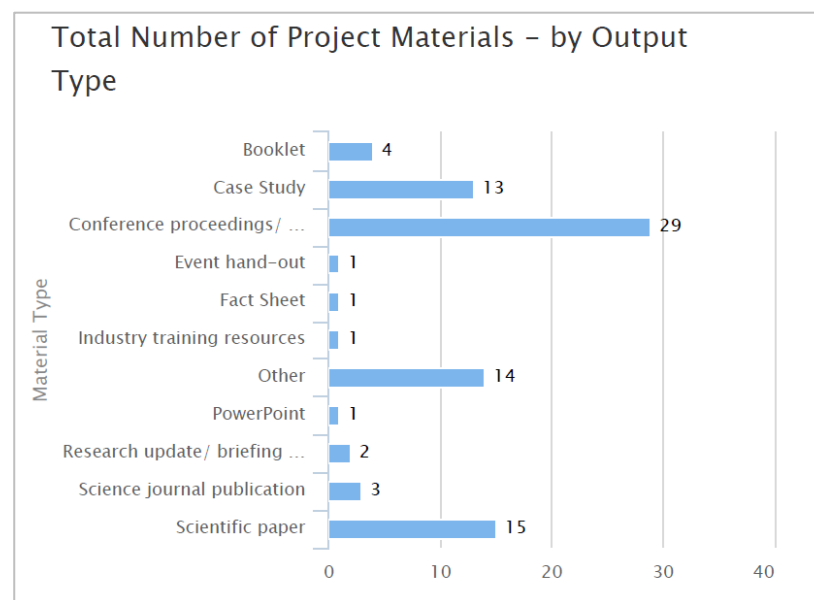


Figure 2 MPfN Program Project materials by type

(Source: MPfN Program M&E Database)

The integration of dairy R&D findings into industry BMPs was a highly effective means of focussing interpretation and a path to next and end users of knowledge (dairy)

Developed a practical tool. Depending on different harvest dates, applications, weather, it helps guide which combination of N to use, including EEF (sugar)

It has become apparent that there is a lot of carryover N in the soil of high-yielding cotton farms that is not being accounted for in N fertiliser recommendations (cotton- in relation to update of the Australian Cotton Production Manual)

Confirms practices you have been doing for years. Gives the confidence on when, why, how much (dairy)

Economic analysis of the N impact on mangoes will provide basis for our extension activities after the project (mango).

RRDP1712- NSW Department of Primary Industries (Cotton)

[Link to RRDP1712 Final Report on CRDC Website](#)

[Link to RRDP1712 Final Presentation on CRDC Website](#)

KPI number & description	KPI Due Date	Summary of final outcome of the research concluded by this KPI
KPI 10.4 – Provide a complete and final account on cotton experiments at the satellite and core research sites (Outputs 5(a) and 5(b)).	30/09/2021	Output 5(a) – Conduct cotton experiments on the core research site at Narrabri to investigate fertiliser by irrigation interactions Output 5(b) – Conduct cotton experiments on two satellite sites, informed by findings of Output 5(a) and any specific local influences or factors. <i>A scientific review of N fertiliser research in irrigated Australian cotton systems</i> A paper outlining historical N fertiliser in research conducted in Australia was published within the Journal of Cotton Research 1(1), 15. (Published on-line: 20/12/2018). DOI: 10.1186/s42397-018-0015-9. A summary of this paper was published in the CRDC Spotlight magazine. A literature review on plant growth response to N fertiliser application was completed by Jon Baird for his PhD. A summary of the review was published in “The CottonGrower” magazine. [See section 8.5.1 of project final report for more detail] <i>What is the significance of ammonia volatilisation as an N loss pathway in furrow irrigated cotton systems?</i> A review of the current state of knowledge of ammonia volatilisation from irrigated cotton systems was conducted and presented in the Spring 2019 edition of CRDC Spotlight magazine. It was also incorporated into the introduction of the research paper that was published from this work [See project final report for more detail] Accurate micrometeorological measurements of N loss via ammonia volatilisation were conducted in response to three different in-crop N application strategies in an on-farm case study. These scenarios were: (a) urea broadcast over a dry soil surface (by airplane) then followed within 2 days by an irrigation event; (b) anhydrous ammonia injected into the irrigation water just before it enters the field; (c) urea broadcast over a wet soil surface (recently irrigated) but not followed by an irrigation. Measurements for each scenario began either just before or at the time of the N fertiliser application, then continued for 1–2 weeks after or until the next irrigation event. [See project final report for more detail] The results of the case study measurements were published in a Journal article. Ammonia loss following the first broadcast urea scenario (onto dry soil followed by irrigation—recommended practice) were negligible. Net loss of N applied via anhydrous ammonia injection was 24% of the N applied but could have been greater had the crop canopy been smaller. Ammonia loss from the third scenario could not be determined because the crop canopy height exceeded that of the detection equipment. [See project final report for more detail]

- *How does the interaction of irrigation management and N fertiliser timing affect N use efficiency in cotton?*

Experiments conducted over four seasons of field trials showed that Australian cotton growers can produce lint yields with a moderate irrigation frequency (70 mm deficit) that were comparable to those produced with a more intensive irrigation strategy (50 mm deficit). The moderate irrigation deficit produced equal lint yield with greater water use efficiency. The interaction of irrigation management and N timing strategy was negligible, but the timing of N fertiliser can improve NUE through reduction of N losses from the cotton field. For example, where N fertiliser was applied 100% pre-plant there were greater N losses from the field compared to fertiliser applied in a split ratio or applied 100% in-crop. Applications of N at “industry average” rates did not increase lint yield but did increase N uptake and plant growth in some years and N runoff in all years. Greater plant growth was curtailed by multiple pix applications and lint yield increased as a result [See section 8.7.1 of project final report for more detail]

On-farm studies occurred every cotton season during the project, with two studies in the Gwydir valley, two in the lower Namoi and two in the Macquarie valleys. Treatments varied for each experiment, but included the use of EFF, N fertiliser timing ratio, late N application and the interaction between N and P application in a commercial cropping system. [See section 8.7.3 of project final report for more detail]

There was frequent communication between the research team and the CottonInfo REO's during the project life, which was vital in delivering key outcomes quickly and efficiently to the cotton industry. Forms of communication included: attending CottonInfo teleconferences, presentations on the CottonInfo N tour, preparing field day materials, organizing with localized Northern NSW REO's information forums on an annual basis which delivered results from both the core site experiments and localized on-farm experiment data. [See section 8.7.3 of project final report for more detail]

- *How does irrigation management affect mineralisation of N from soil organic matter in furrow irrigated cotton systems?*

The effects of irrigation deficit on soil N mineralisation were studied in detail in three seasons of the ACRI core-site experiments. Overall, the lower deficit (more frequent) irrigation treatments tended to accumulate more mineral N than the higher deficit treatments, likely due to the larger irrigation volumes applied in the less frequent irrigation events, which would have increased waterlogging duration and thus denitrification losses and N runoff. Transect sampling showed that SOM mineralisation was strongly concentrated in the plant line at the center of the plant bed, with limited activity in the irrigation furrows and intermediate in the plant-bed hill-sides [See section 8.8.1 of project final report for more detail]

Quantification of the effects of irrigation deficit on soil N mineralisation was impractical in on-farm situations since we could not vary irrigation deficits on-farm, and also could not impose nil-N plots/strips due to the widespread use of whole-paddock broadcast or water-run N applications. [See section 8.8.2 of project final report for more detail]

We produced a journal article and an industry magazine article on soil N mineralisation as affected by irrigation strategy (Journal article currently in revision for Soil Research). A simulation exercise was conducted using APSIM to model the expected inorganic N soil content at sowing as influenced by early (up to 9 months pre-plant) applications of urea fertiliser. Early pre-season applications of N have a high degree of risk and support the findings of Humphreys et al. (1990) that significant amounts of N would be lost via denitrification and leaching losses before planting of cotton. Modelling of SOM mineralisation using the CottonInfo calculator provided a reasonable estimate of mineralized N measured in this

		project (MinNAP) of between 2–5% of the total soil N from the surface soil (0–30cm) or whole profile estimates. [See section 8.8.3 of project final report for more details] • <i>How does the method of in-crop N fertiliser application affect N use efficiency in cotton?</i> In-crop N application methods, products and strategy were compared in 4 years of field experiments at ACRI. The best in-crop method for N supply to the plant and least N loss was side-dressing urea. Broadcast urea and water-run urea treatments gave similar cotton lint yields but left more N unused in the soil post-crop (broadcast) or led to greater N loss via runoff (water-run). Of the three water-run products compared, runoff losses from urea were slightly more than UAN and ammonia, but ammonia lost as much again via ammonia volatilisation. All of these products produced similar cotton lint yields. A simple strategy to reduce N runoff losses during water-run N applications nearly halved N runoff, increased cotton N supply and increased cotton lint yield in one of the two years [See section 8.9.1 of project final report for more detail] It proved to be impractical to compare in-crop N application strategies in on-farm trials, but we did conduct a case study looking at the potential value of late-N application on a commercial farm and in the ACRI core site experiments in 2019–20 [See section 8.9.2 of project final report for more detail] The application of in-crop fertiliser resulted in greater fertiliser N recovery by the plant compared to fertiliser N applied 100% pre-plant. Within flood irrigated cotton fields, 20% of applied N fertiliser was lost from the application point between planting and first square. The continual application of irrigation water diluted the fertiliser N through the planting hill but there were biases of N fertiliser movement from the application point to the non-irrigated furrow. As a result of the N fertiliser movement, the irrigated furrow had a lower concentration of fertiliser N throughout the growing season. Applying N in-crop on the side- hill compared to pre-plant increased N concentration in the irrigated furrow and provided more consistent available N throughout the planting bed. [See section 8.9.3 of project final report for more detail]
KPI 10.5 – Provide a complete and final account of the investigations into the potential impact of long-term P decline and/or stratification on the nitrogen cycle in cotton farming systems (Output 6(b)).	30/09/2021	Output 6(b) – Investigate the potential impact of long-term phosphorous (P) decline and/or stratification on the nitrogen cycle in cotton farming systems. • <i>Is there long-term P stratification or decline in cotton farming systems?</i> Five historical long-term experimental sites in the NSW Namoi and Macquarie irrigation regions were selected for the study of soil P stratification/decline study over time. Two of these experiments, located on the ACRI research station, are still active—the other experiments were all on-farm and concluded years ago. Soil samples collected at the beginning of these experiments had been archived at ACRI and were retrieved for this study, along with soils collected at the end of the completed studies. In addition, we also collected new soil samples from these old experimental paddocks as well as samples from adjacent native vegetated areas. All samples for the study were to a depth of 60 cm [See project final report for more detail] All soil samples collected for the long-term P study were analysed at the TAI laboratory for several available P indices including: solution P, Colwell P, BSES P and PBI. Soil P was observed to decline during most of the long-term experiments (and continuing since their conclusion) at most depths analysed. Cotton farming (rotation/tillage) systems that minimised P decline were identified. The cotton farming systems that adopted minimum tillage resulted in higher Colwell P (plant available P) in spite of having similar BSES P (reserve P levels) compared with maximum tillage systems. The Macquarie valley site was initially low in soil P due to the inherent soil properties of that soil type. Soil P had

	increased in the surface of this site due to the application of P fertiliser during the historical experiment and since then stratification is evident. A scientific journal article documenting the results of this study is in preparation [See section Error! Reference source not found. of project final report for more detail] A detailed literature review of P nutrition in Australian cotton farming systems was prepared and has been submitted to a scientific journal. A summarized overview of this review has been submitted for publication in the 2021 Spring Edition of the CRDC Spotlight Magazine by Dr Mike Bell (UQ). [See final report for more detail] • <i>How much phosphorus is being taken up by cotton plants from surface and subsoil layers?</i> An investigation of P utilisation from different soil depths by two modern cotton varieties at different growth stages was conducted in a highly instrumented glasshouse study at UQ. The results and conclusions of this study were not yet available at the time of this report [See project final report for more detail]. However, the investigation on long-term changes in P pools was used indirectly to assess the contribution of each depth to seed P export [See project final report for more detail] The root responses of two contrasting cotton varieties to different P-placement techniques and timings was investigated in a glasshouse-based rhizotron study at UQ by Mr. Callum Bischof. The results suggest varietal differences and root proliferation effects due to method and location of P fertiliser. [See project final report for more detail] Management options to improve the efficiency of utilization of applied P fertilisers was developed. Application of P fertiliser before a cover crop or a rotation crop was effective in fields with sodic subsoil. Mixing P fertiliser through the soil in the plant bed is preferred to banding. This contradicts the use of minimum tillage for improved soil health, so needs to be investigated as a once in 3–5 year application strategy. • <i>Is the response of P affected by varied irrigation and N management?</i> Growers need to carefully manage the irrigation frequency, nitrogen and phosphorus application as the results demonstrate an interaction between all these inputs in a season with less than optimum in-crop rainfall. Lower deficits in a year with higher in-crop rainfall could lead to excessive vegetative growth and a lack of yield benefits. The interaction of irrigation and N on improved root length density has implications for P acquisition as improved cotton roots could explore more soil volume and result in improved P uptake. The frequent wetting impacts the soil Colwell P levels and has implications for P availability. The results suggest optimising the irrigation and nutrient inputs with consideration to environmental conditions such as in-crop rainfall and seasonal length. Irrigation strategy for improving P use efficiency identified. [See project final report for more detail] N management options for improving P use efficiency identified. Improved P fertiliser use efficiency could be achieved by applying a higher proportion of seasonal N requirement pre-planting. [See project final report for more detail] Irrigation and N management interactions and their implications for improving P use efficiency understood. During low in-crop season rainfall, frequent irrigation could interact with N and improve the fertiliser P use efficiency [See project final report for more detail]
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		Does P movement in runoff pose a risk to on-farm dams in cotton farms Cotton farming (rotations/tillage) system that minimise the risk of P loss in irrigation network identified. Most of the cotton systems minimised the P movement in runoff. There was net addition of P to cotton fields [See section project final report for more detail]
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RRDP1719- Queensland Government Department of Agriculture and Fisheries (Sugar)

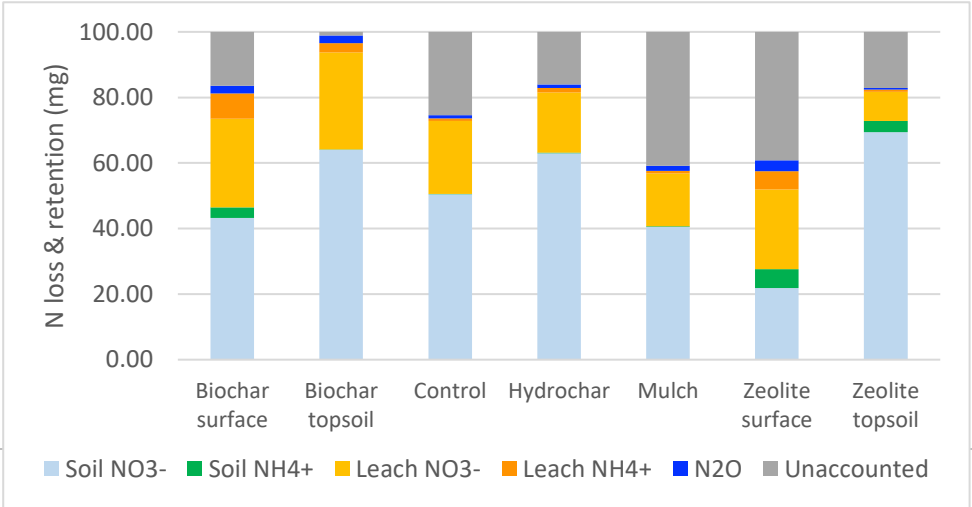
Link to RRDP1719 Final Report on CRDC Website (*coming-* undergoing legal IP review) [Link to RRDP1719 Final Presentation on CRDC Website](#)

KPI number & description	KPI Due Date	Summary of final outcome of the research concluded by this KPI
KPI 8.4 – Provide a brief and final account of the identification of products that decrease vulnerability to leaching and the stabilisation of nitrogen transformations (Output 4(f)).	30/09/2021	Output 4(f) – ‘Next generation fertiliser formulation’: identify products that can decrease vulnerability to leaching and stabilise nitrogen transformations. Biodegradable, novel controlled release DMPP formulations were developed with proven capacity to decrease leaching losses of N and to stabilise this nutrient against transformations. Two formulations, in particular, showed promise. These formulations demonstrated high-efficacy in different soils in laboratory reaction vessel trials and growth accelerator pot trials. These formulations also showed statistically valid improvements relative to conventional DMPP in some laboratory investigations ($P < 0.05$) and limited field data suggests that these advantages can result in improved agronomic performance relative to conventional DMPP ($P < 0.1$).

RRDP1720- Northern Territory Department of Industry, Tourism and Trade (Horticulture- Mango Tree Crops)

[Link to RRDP1720 Final Report on CRDC Website](#)

[Link to RRDP1720 Final Presentation on CRDC Website](#)

KPI number & description	KPI Due Date	Summary of final outcome of the research concluded by this KPI
KPI 8.6 – Provide a brief and final account of the evaluation of best performing EEFs in mango crops (Output 4(k)). KPI 8.7 – Provide the department with the EEF recommendations and a brief account of optimising NUE at both plot and farm-scale level (Output 4(l)).	30/09/2021	Output 4(k) – Evaluate the best performing EEF (mangos)/biological fertiliser (cherries) from the experiments conducted in Output 4(j). Output 4(l) – Develop recommendations for the timing, rate and placement of EEFs and any potential EEF blends to reduce nitrogen losses; and optimise Nitrogen Use Efficiency (NUE) both at a plot and farm scale level. Enhanced efficiency fertilisers show limited economic or environmental benefit in NT weather conditions and appropriate biological fertilisers were unavailable locally. There was biochar being produced locally, and an alternative program was designed to assess the potential of soil amendments to improve N retention in local horticultural soils. The work was conducted in a laboratory setting using zeolite, biochar, hydrochar or leaf litter with urea and simulated rain events on soil column incubations over time. Overall, soil nitrate levels increased over the period while ammonium levels decreased as the fertiliser was hydrolysed and nitrified. Zeolite mixed into the topsoil retained the most mineralised N, being significantly more effective than zeolite placed on the surface. The same result was seen with biochar mixed into the topsoil compared to surface placement. After rain events, leachate was collected from the columns and zeolite mixed with topsoil released the least nitrate and ammonium leachates. Soil emissions of N₂O varied significantly between treatments but were minor, showing that the main loss pathways were leaching of nitrate and ammonium (Figure 1).  Figure 1 Breakdown of N loss pathways and N retention in soils for each treatment based on final (Day 100) values. (100 mg of N applied)

A summary comparing the N retained in soils, N lost via leaching and unaccounted for each amendment combination shows zeolite mixed with topsoil having the highest N retention, closely followed by biochar mixed with topsoil and hydrochar (Figure 2). Also, zeolite nutrient losses were close to zero after ~30 days of 100, suggesting potential for longer-term retention capacity.

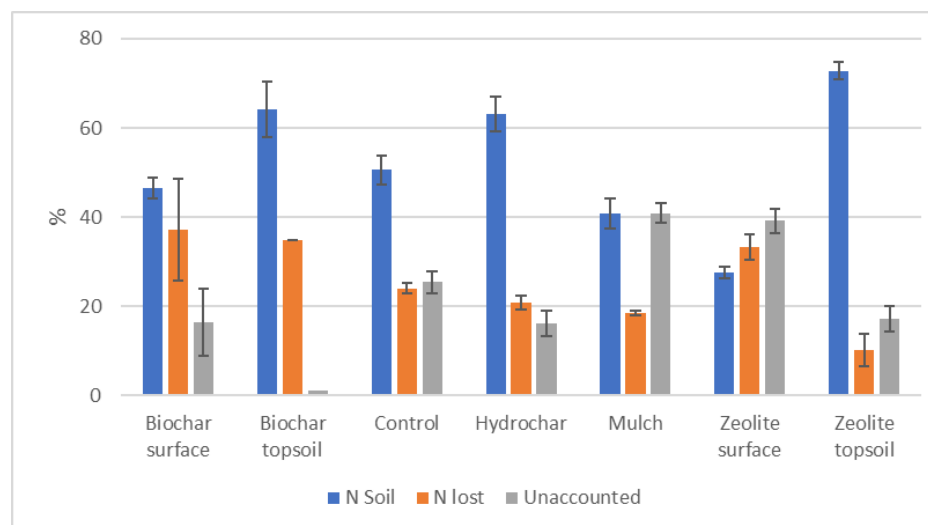


Figure 2: Percentage and comparison of soil N retained, N lost and unaccounted for loss pathways at the end of incubation for all treatments. Bars indicate standard error. N loss includes leachate and N₂O emissions.

For the soil tested (Kandosol, sampled from Coastal Plains Research Farm in the Darwin region), zeolite mixed into topsoil was the best performing amendment. While zeolites do not break down in the environment, the longer-term impacts on soil physiochemical properties are unknown.

- *Industry outcomes*

An application of zeolite on a broad scale would cost about \$50,000 ha⁻¹. Biochar is being produced on a small, domestic scale in the NT, and is costed at \$17,600 ha⁻¹ at an application rate of 2 L m⁻². Neither of these are viable in dollar terms; however, the results do indicate that soil amendments can make large differences in N retention if an economic option can be found. It is new, baseline research for industry to build upon. Refer to Appendix D of the project final report for further details.

KPI 8.9 – Provide a brief and final account of calculating NUE for

30/09/2021

Output 5 (e)- Determine seasonal and inter-annual cherry and mango plant nitrogen (N) demand, quantify N losses, uptake and calculate NUE.

- *Measuring nitrogen uptake efficiency in mangoes*

mango nitrogen use
(Output 5(d)).

In the environment, N occurs naturally in two stable isotopic forms, ^{14}N and ^{15}N . Over 99.6 % occurs in ^{14}N form and less than 0.4 % as ^{15}N , which has an extra neutron and is heavier. This natural ratio can be enriched, increasing the ^{15}N component in fertilisers such as ammonium sulphate $(\text{NH}_4)_2\text{SO}_4$ and potassium nitrate (KNO_3) . This enriched or labelled form of N can be measured in plant tissues using mass spectroscopy techniques.

We mixed the labelled $(\text{NH}_4)_2\text{SO}_4$ fertiliser with standard $(\text{NH}_4)_2\text{SO}_4$, and applied it to the soil in a developing mango orchard. Over three years, from the juvenile phase to mature and entering commercial productivity, we quantified how much of the applied fertiliser was taken up by trees by measuring the $^{14}\text{N}:^{15}\text{N}$ ratio in the tree tissues. From these direct measurements, we found that N uptake efficiency (NUE) in a maturing mango tree reduces as the amount applied increases (Figure 3). Not only did the uptake efficiency reduce, the amount of N taken up reduced. There were no differences in fruit yield, number of fruit, % DM of fruit, fruit N content or tree size in response to the N treatments.

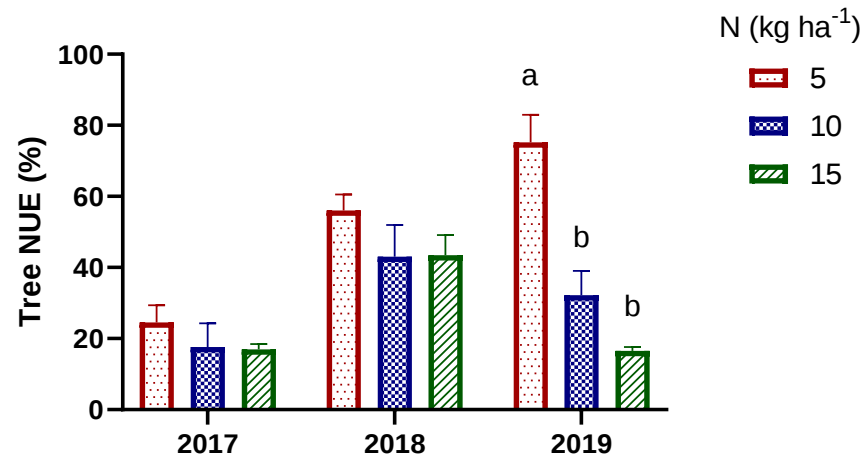


Figure 3: Nitrogen uptake efficiency (NUE) of trees changed over time, as trees matured and began commercial production in 2019.

Trees with the lowest quantity of N applied showed significantly higher uptake than the two larger N applications in 2019 (letters indicate significant difference), time series analysis of variance (ANOVA), Tukey's post-test, $p < 0.0001$, $n = 3$).

Foliar uptake of N applied to fruit trees has never been measured directly. Also, it is usually applied as a dilute KNO_3 solution for the potassium to maximise flowering and fruit retention on panicles. The spray adds about 2.2 kg N ha^{-1} if a 2 % solution is applied twice. A method was developed using a ^{15}N -labelled solution of KNO_3 and potted, grafted mangoes. N was absorbed through the leaf surface over two days, and the NUE into the leaves varied from 27 % to 44 %, depending on the mango variety (Figure 4).

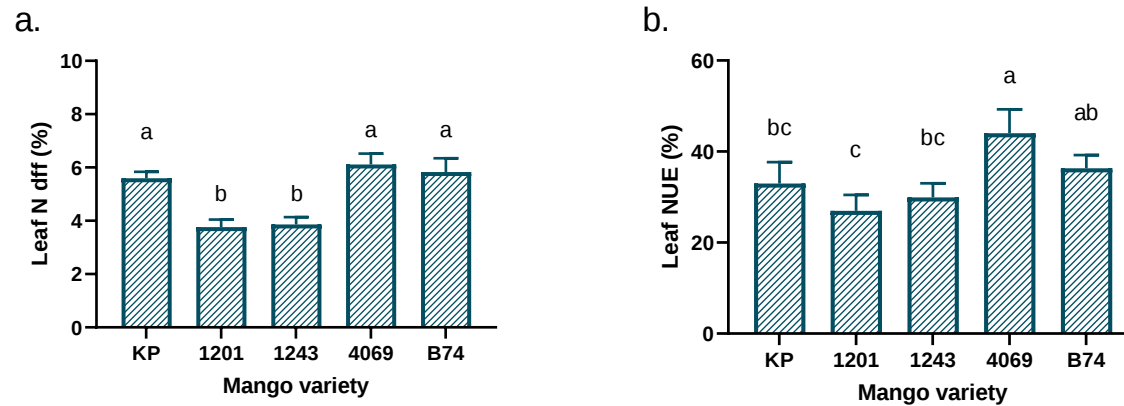


Figure 4: The amount of N derived from the KNO₃ dipping solution showed significant varietal differences with letters indicating similarities and differences (a) ANOVA, $p=0.0009$, mean, standard error of the mean (sem), $n=10$, LSD post-test). Varietal differences were also significant when N uptake efficiency was calculated (b). Means with different letters are significantly different at 5 % LSD ($p=0.033$, mean, (sem), $n=10$).

To assess seasonal use and movement of N in mango trees, a method was developed to infuse ¹⁵N-labelled (NH₄)₂SO₄. This provided evidence that N is moved rapidly within trees and the labelled N was evenly distributed in every tissue, including the roots, xylem and phloem within 70 days of infusion. Leaf N content increased during the quiescent period, as trees approached the flowering induction period, then dropped as high N content flowers developed, using almost 10 % of total tree N (Figure 5a). Much of the reduction in tree N over the season (Figure 5b) is accounted for by N measured in flowers and fruit (Figure 5a), but not all. The flower N can be recycled on the orchard floor but fruit N will leave the orchard.

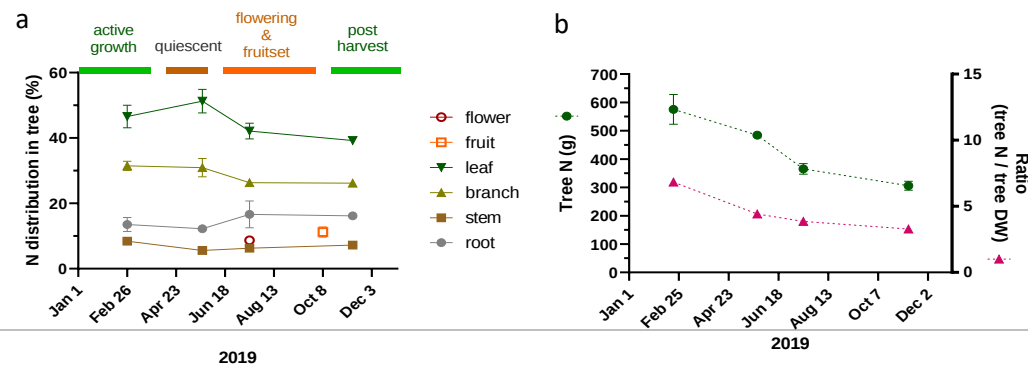


Figure 5 Nitrogen (N) distribution in tree components over time (a) and total N in trees over time (b)

Excess application of N can have negative effects on the colour of skin while fruit is ripening. A grower may not be aware they are picking fruit with this ripening defect as it is not possible to see when fruit is harvested at the mature, green stage. While it will depend on the soil, season, orchard history and how much N is applied, we established some guidelines to work within to reduce the incidence of 'stay green' skin. For example: at a commercial KP orchard, on a low yield year of 20 tonnes fruit ha⁻¹ and 250 trees ha⁻¹, fruit from trees receiving 25 kg N ha⁻¹ had blotchy green skin when ripe, and at 50 kg N ha⁻¹ the fruit stayed green when ripe (Figure 6). Fruit from trees receiving 12.5 kg N ha⁻¹ or 50 g tree⁻¹ ripened normally. The same rates applied after that harvest generated yields approaching 40 tonnes ha⁻¹, and no fruit harvested ripened with 'stay green' skin. The difference in skin colour when ripening was quantitatively measured (Figure 7).

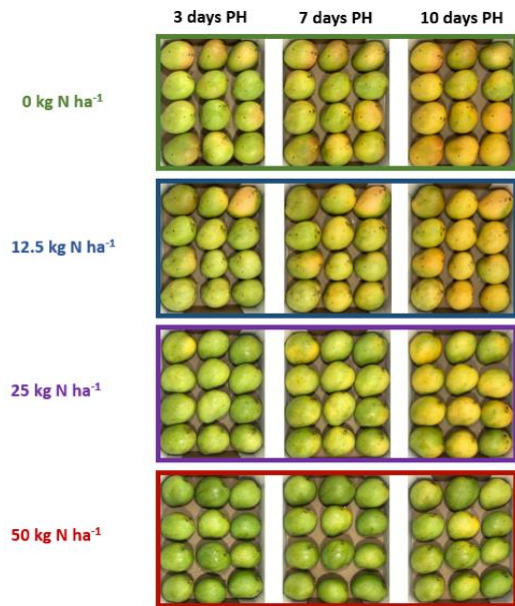


Figure 6: Fruit from trees with a range of levels of N were harvested on the same day and imaged every second day to visually track ripening progress. At each level of N application, 0, 12.5, 25 and 50 kg ha⁻¹ (above, top to bottom), the same tray of replicate fruit from a single tree is shown 3 days post-harvest (left column of images above), 7 days post-harvest (centre column of images) and 10 days post-harvest (right column of images above).

of leaf N content (Output 5(e)).		Imagery analysis can reliably predict yield and number of fruit. The models are refining with work overtime, and we continue to provide field estimates of number of fruit and annual yield, then harvest the fruit to validate the modelling. It has the potential to assess tree health and biosecurity issues in the future.
KPI 8.11 – Provide a brief and final account of the NUE benchmarks developed for the mango industry (Output 5(f)).	30/09/2021	Output 5(f) – Develop NUE benchmarks for the horticulture industry to target. • <i>Summary of industry guideline to be developed into series of materials by NT DITT extension in 2022:</i> The new knowledge to incorporate into mango orchard management in the NT will expand grower knowledge on how much N is in mango orchards, how it cycles annually, how much is taken up, and how much is lost. Further extension work and materials are in preparation that will encourage growers to review N application and, for many, will encourage a reduction in N application and associated savings. <i>New knowledge includes:</i> • How much N a tree takes up from soil-applied fertiliser is related to how much is applied. ○ If it is less than the tree needs, ~75 % of applied N can be taken up. ○ Otherwise, it is 20–35 % uptake of applied N and less N overall. • Foliar uptake of N into leaves has an efficiency similar to soil-applied fertiliser. Uptake is fast, N is rapidly transported around trees, and there is a second uptake opportunity as the N is recycled on the orchard floor in rainfall or litter. • Most available N is lost from soils annually between the break of seasonal rains to the end of the wet season. • Apply fertiliser to soils immediately post-harvest to take advantage of first rainfall events, before the monsoon period. ○ Avoid applying ‘insurance’ N, it is wasted. ○ If N is need during the dry season, fertigation or foliar application is preferred. • Decomposition of litter in response to rain events releases ~11 kg of available N ha⁻¹ in the top 20 cm of soil in the Darwin region and 18 kg N ha⁻¹ in the Katherine region. These amounts cycle each year. • Mangoes contain ~0.8–1 kg N tonne⁻¹ of fruit harvested. This amount of N leaves the property and needs to be replaced. • An understanding of the relationship between yield, excess N application and ‘stay green’ skin on ripe mangoes. ○ For example: at a commercial KP orchard, on a low yield year of 20 tonnes fruit ha⁻¹ and 250 trees ha⁻¹, fruit from trees receiving 25 kg N ha⁻¹ had blotchy green skin when ripe, and at 50 kg N ha⁻¹ the fruit stayed green when ripe. Fruit from trees receiving 12.5 kg ha⁻¹ or 50 g tree⁻¹ ripened normally. ○ The same rates applied after that harvest generated yields approaching 40 tonnes ha⁻¹, and no fruit harvested ripened with ‘stay green’ skin.
KPI 8.13 – Provide a brief and final account of the investigations to	30/09/2021	Output 6(c) – Quantify the timing and amount of N released in tree crop residues & Output 6(d) – Quantify the N mineralisation from soil organic matter (SOM) in key cherry and mango soils.

quantify the timing and amount of N released in tree crop residues (Output 6(c)).

KPI 8.14 – Provide a brief and final account of quantifying N mineralisation from organic soil matter (Output 6(d)).

By collecting litter and pruned material in commercial orchards, we found that significant quantities of N are recycling on the orchard floor annually, 17–27 kg N annually (Figure 8).

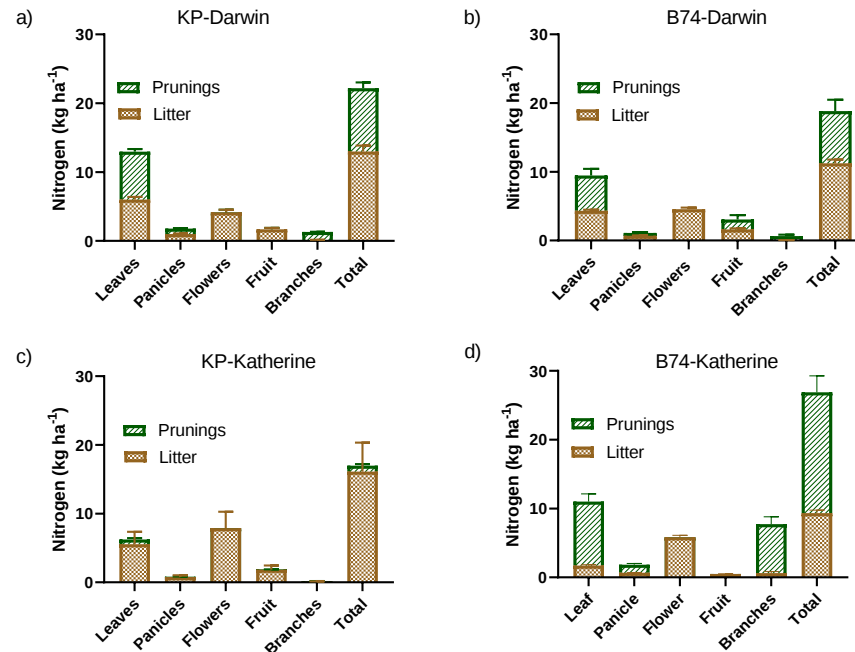


Figure 8: The N content of in-orchard annual litter and pruned material in the Darwin region litter was similarly proportioned (a, b). In the Katherine region, the KP orchard with large, mature trees and minimal branch tip pruning, shed most N in litter over the year 2018–19 (c). In contrast, the B74 were pruned heavily and reshaped, with most N accumulated in the prunings (d). Mean, sem, n=10 collection trays at each site. Data is standardised to a tree density of 250 trees ha⁻¹.

Litter and pruned material also deposits ~40 kg ha⁻¹ of calcium (Ca) annually along with other macro and micronutrients. In the Darwin region, 100 % of leaf litter decomposes annually over the build-up and wet season, and in the Katherine region the figure is 85 %. The difference is attributed to reduced rainfall in the Katherine region. Decomposition of litter in response to rain events releases ~11 kg of available N ha⁻¹ in the top 20 cm of soil in the Darwin region and 18 kg N ha⁻¹ in the Katherine region. These amounts cycle each year. Soil samples suggest that any available N that is not taken up by trees is leached and lost annually. There is little or no capacity for sequestration of N in soils.

Minimal N₂O emissions (~0.2 kg N ha⁻¹) were measured with decomposing litter, CO(NH₂)₂ applied to soils and in combination.

RRDP1721- University of Tasmania- Tasmanian Institute of Agriculture (Horticulture- Cherry Tree Crops)

[Link to RRDP1721 Final Report](#)[Link to RRDP1721 Final Presentations](#)

KPI number & description	KPI Due Date	Summary of final outcome of the research concluded by this KPI
KPI 8.6 – Provide a brief and final account of the evaluation of best performing biological fertilisers in cherry crops (Output 4(k)).	30/09/2021	Output 4(k) – Evaluate the best performing EEF (mangos)/biological fertiliser (cherries) from the experiments conducted in Output 4(j). The trials showed that pre-harvest N application can result in a wasteful amount being lost in fruit. Post-harvest application could increase N uptake efficiency, but if excessive can result in unnecessary N being removed in pruned material. Thus, applying most annual N post-harvest is recommended, but the balance of pre- and post-harvest application might vary from season to season depending on yield and regional climatic factors. To best inform N management, testing of fruitlet and fruit N concentrations, and that of N in plant tissue and soil, is recommended. Efficiency of N uptake can be further enhanced by applying N frequently in smaller doses, and without excessive water where possible, to avoid the loss of excess N through leaching and denitrification emissions. These losses can be further minimised by restricting N application if substantial rainfall is imminent in the week ahead.
KPI 8.7 – Provide the department with the biological recommendations and a brief account of optimising NUE at both plot and farm-scale level (Output 4(l)).	30/09/2021	Output 4(l) – Develop recommendations for the timing, rate and placement of EEFs and any potential EEF blends to reduce nitrogen losses; and optimise Nitrogen Use Efficiency (NUE) both at a plot and farm scale level. Alternative biological based fertiliser treatments at the nitrogen rate applied performed (45 kg N/ha) in general, comparably to the conventional calcium nitrate-based fertiliser applied at the same rate over the three seasons trialed. For growers considering these sources of N as a viable alternative, some longer-term studies investigating the soil health benefits of this form on top of fruit quality outcomes would be necessary given the high input cost. The biological based forms of N tested here clearly provide an effective alternative to conventional based fertilisers, yet based on ¹⁵N recovery trials, we would recommend applying at a greater rate than the 45 kg N /ha trialed here for ongoing tree health and adequate nutrition. This additional cost would need to be offset by further evidence of improved long-term soil and orchard health to encourage industry to adopt these N management approaches.
KPI 8.9 – Provide a brief and final account of calculating NUE for cherry nitrogen use (Output 5(d)).	30/09/2021	Output 5 (e)- Determine seasonal and inter-annual cherry and mango plant nitrogen (N) demand, quantify N losses, uptake and calculate NUE. Our data suggests that 76.5 g N/tree is likely to be a reasonable seasonable ‘replenishment’ quantity of N (from harvested fruit and pruning material) that would provide adequate N for optimum yield of quality fruit and healthy, but not excessive, vegetative development. A quantity as high as 135 g N/tree, as provided in the higher of the split 50:50 treatments appear excessive as it provided no benefits to fruit yield or quality and at dormancy the trees retained 68.5 g N/tree, compared with 59.4 g N/tree when half that rate was applied, much of the ‘missing’ N being lost to the environment and some removed prior to dormancy. Attempts to

		improve N uptake efficiency, substantially lower when the higher rate of N (135 g N/tree) was applied, would appear a preferable way to replenish tree N than increased N application. Taking the above value of 76.5 g N/tree as an annual replenishment quantity of N required by mature trees, at an uptake efficiency of 40% at best, would require the application of about 190 g N/tree if no other inputs were considered and/or uptake efficiency improved. One additional input to the 'N cycle' to be considered is N suitable for uptake that might be supplied by the mineralisation of pruned material and shed leaves. The measured uptakes of N fertiliser applied over the 2017-18 season, split 50:50 between pre- and post-harvest, at the rates of 67.5 and 135 g N/tree (equivalent to 90 and 180 kg N/ha respectively) were measured as 37.9 and 29.6% respectively. While not significantly different on account of substantial variances associated with the mean values, the lower uptake of fertiliser applied at the higher rate does suggest a lower NUE. The rate of N applied apparently did not affect its relative distribution amongst tree organs. However, as might be expected, the amounts of fertiliser N allocated to tree organs were for the most part substantially higher with the higher rate of N applied.
KPI 8.11 – Provide a brief and final account of the NUE benchmarks developed for the cherry industry (Output 5(f)).	30/09/2021	Output 5(f) – Develop NUE benchmarks for the horticulture industry to target. Management of fertigated N application in small, regular doses is certainly constrained by the irrigation/fertigation infrastructure of each orchard. However, improvements in nitrogen use efficiency (NUE) to higher levels than those found should be possible. Regular soil testing would be necessary to improve NUE in cherry cropping systems. Another vital tool to improving NUE in cherry orchards, already undertaken in many, would be real-time monitoring of soil moisture, including that below the root zone, to prevent application of excessive irrigation water. Some orchards leave long lengths of pruned stems within the tree rows. The breakdown of stems to release their considerable organic N content for potential mineralisation is very slow. The removal of all pruned material for composting, as already practiced in some orchards, is worthy of consideration. At the least, much more substantial pulverisation of pruned stems before they are replied to tree rows would seem advisable. Pursuing such a suite of improvements might well result in improvements in NUE to over 50%, with benefits to return on investment and the environment. To determine changes in NUE, regular monitoring of N forms in soil, and N contents of fruit, leaves and pruned material would be necessary. Such testing would also act as a safeguard for orchard managers aiming to decrease their applications of N, which understandably would need to proceed with a degree of caution. A Cherry NUE BMP has been prepared and is available on the TIA and CRDC- MPfN Program websites.
KPI 8.13 – Provide a brief and final account of the investigations to quantify the timing and amount of N released in tree crop residues (Output 6(c)).	30/09/2021	Output 6(c) – Quantify the timing and amount of N released in tree crop residues. The mineralisation of shed leaves and pruned material into readily available forms of N is important as a potential source of recycled N that may be available for tree uptake. Our research showed that at the end of growing season, as leaves were beginning to dehisce and fall from the tree, the total N content of the leaf material ranges from 23 to 40g, depending on tree size and prior fertiliser application. Over the 1-year trial period up to 10% of that N was mineralised for tree N uptake, with rate of decomposition increased with higher soil and air temperatures. This equates to approximately 4kg N/ha of the annual N budget for cherry tree growing. Additional N is likely to also come from decomposing branch prunings and some orchards leave long lengths of pruned stems within the tree rows. The breakdown of stems to release their considerable organic N content for potential mineralisation is very slow, much slower than leaves. The removal of all pruned material for composting, as already practiced in some orchards, is worthy of

		consideration. At the least, much more substantial pulverisation of pruned stems before they are replied to tree rows would seem advisable.
KPI 8.14 – Provide a brief and final account of quantifying N mineralisation from organic soil matter (Output 6(d)).	30/09/2021	Output 6(d) – Quantify the N mineralisation from soil organic matter (SOM) in key cherry and mango soils. Soil analysis conducted by Moody (2019) showed that at depth of 0 – 10cm of a typical slightly acidic cherry tree growing soil in southern Tasmania had a particulate Organic Carbon content of 11.3g/kg and an Organic Nitrogen content of 0.7g/kg. Moody et al showed that the percentage of total organic carbon comprised of labile carbon is just over 8%. This value is equivalent to the average value determined for agricultural soils analysed as part of the MPFN project which included dairy, cotton, sugarcane, and mango growing soils. The mean 7 day potentially mineralizable N value for the cherry growing soil was 25 mg/kg and 33 mg/kg after 14 days. The results showed that particulate organic carbon is the driver of short-term mineralisation whilst particulate organic nitrogen drove steady state mineralisation.

Appendix 4. MPfN Program M&E Database Results

Supplied as a separate Excel Workbook File to enable filters and use of supplied links to evidence documents/ files.

Appendix 5. MPfN Program Final Evaluation Report



More Profit from Nitrogen

Final Evaluation

June 2021

More Profit from Nitrogen Final Evaluation

Client: Cotton Research and Development Corporation (CRDC)

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Summary

About the MPfN program

The More Profit from Nitrogen (MPfN) program was a partnership between the agriculture industry's four major intensive users of nitrogenous fertilisers— dairy, sugar, cotton, and horticulture (mango and cherry). The MPfN was funded through the Department of Agriculture, Water and the Environment's Rural R&D for Profit program.

The MPfN was established with an aim to bring about increased farm profitability and reduced environmental impact by increasing nitrogen use efficiency (NUE) across the four participating industries, as measured by a reduction in the amount of applied N required to produce each unit of product. This was to be achieved through research into three areas:

- How enhanced EEF formulations can better match a crop's or pasture's specific N requirements (Activity B4—Extracting value from enhanced efficiency fertilisers).
- The interplay of soil, weather, climatic and farm management factors to optimise nitrogen N formulation, rate and timing across industries, farming regions, as well as irrigated and non-irrigated situations (Activity B5—Optimising NUE in irrigated systems).
- The contribution (quantifying rate and timing) of mineralisation to a crop or pasture's N budget (Activity B6—Better understanding N supply through mineralisation)

The MPfN commenced in July 2016 and will conclude in September 2021.

About the MPfN Final Evaluation

Ag Econ was engaged by the Cotton Research and Development Corporation (CRDC), the MPfN program manager, to complete a Final Evaluation of the MPfN program.

The Evaluation focused on three components:

- Delivery against the MPfN plans
- Delivery against the MPfN objectives
- The immediate and legacy impact upon nitrogen practices to improve NUE across the sugar, dairy, cotton, mango and cherry industries.

The Evaluation was based on a combination of document review, and feedback from 69 MPfN stakeholders. Stakeholders completed an online survey where they rated and provided comments on the MPfN delivery and outcomes. Follow-up telephone interviews were conducted with 38 stakeholders to gain additional feedback.

Summary of evaluation findings

The delivery of the MPfN program was assessed to be strong against the three evaluation components.

Part 1. Evaluation of delivery against MPfN plans

The whole-of-program activities and deliverables were evaluated against the outputs, milestones and performance indicators of the three MPfN plans:

- The Program Management Plan (PMP)
- The Communication and extension Plan (CEP)
- The Monitoring and Evaluation Plan (MEP).

Stakeholder feedback on program delivery was also captured, including for the program planning, reporting, and internal communications.

The delivery of MPfN activities and outputs against the three MPfN Plans was evaluated as strong overall. Across the three plans, an average 91% of planned outputs, milestones and performance indicators were evaluated as strongly delivered (Table 1).

Table 1. Summary of evaluation of program delivery against the MPfN plans

MPfN plan	Elements rated as strong	Overall evaluation
Overall evaluation of delivery against the MPfN PMP	132/133 (99%)	Strong
Overall evaluation of delivery against the MPfN CEP	22/24 (92%)	Strong
Overall evaluation of delivery against the MPfN MEP	35/42 (83%)	Strong
Overall stakeholder rating of planning, monitoring and reporting	4.2 (n=34)	Strong
Overall evaluation of delivery against the MPfN plans (average rating)	91%	Strong

The MPfN delivered more than 150% of planned activities and outputs across collaboration, communication, and extension. Internal stakeholders rated the project planning, monitoring and delivery as highly effective (average 4.2, n=34), and the administrative support provided as highly effective (average 4.2, n=26), with generally positive comments supporting these ratings.

Part 2. Evaluation of delivery against program objectives

Building on the evaluation of delivery against the MPfN plans, stakeholder ratings and comments were used to evaluate program delivery against the MPfN primary and secondary objectives.

Primary objectives:

- Generate greater knowledge and understanding of the factors that influence NUE.
- Identify new NUE strategies and technologies, or update or validate existing NUE strategies and technologies to inform NUE resources across the four industries.

Secondary objectives:

- Support the establishment and fostering of industry and research collaborations that form the basis for ongoing innovation and growth of Australian agriculture.
- Support strengthened pathways to extend the results of rural R&D, including understanding the barriers to adoption.

Overall, delivery of the MPfN against the three program objectives was evaluated as strong (Table 2).

Table 2. Summary of evaluation of program delivery against the MPfN objectives

Evaluation of successful delivery against the project objectives		Average stakeholder rating	Overall evaluation
Primary objectives	Generate knowledge and understanding	3.9 (n=62)	Strong
	Inform NUE resources	3.6 (n=60)	Moderate
Secondary objectives	Support collaboration (internal stakeholders only)	4.0 (n=33)	Strong
	Support extension pathways	3.6 (n=61)	Moderate
Overall evaluation of delivery against the MPfN objectives (average rating)		3.8	Strong

Across the MPfN objectives, the perceived effectiveness against research level outcomes (research level knowledge and fostering collaboration) was strong, reflecting the delivery of a high level of research outcomes for what was fundamentally a research program. While the perceived effectiveness against industry level outcomes (contribution to industry level resources, extension, and changes in industry level knowledge) was moderate, the lower ratings were consistent with these primarily being secondary objectives of the program. In particular, comments recognised that while the MPfN delivered clear R&D outputs to inform industry resources (a primary MPfN objective), responsibility

for integrating the findings into industry resources and extending these to growers lay primarily with the individual industries and would continue beyond the completion of the MPfN. In addition, while all industries had begun to integrate the MPfN recommendations into industry resources, or had plans to do so, the comments indicated that service providers and producers were not as aware of this ongoing process, which likely contributed to their lower ratings in this area.

Part 3. Evaluation of immediate and legacy impact

Stakeholders rated producer confidence to adopt as moderate; however, it is important to note that the timeframe for practice change within an agricultural R&D context can take years (or decades). It is rare for industry adoption of R&D to occur rapidly following the completion of the underlying research, but rather, adoption occurs in stages depending on the overlapping of a range of underlying factors including the strength of extension pathways and stakeholders' appetite for risk and change (social aspects), and underlying market conditions relating to the commodity and the innovation (economic aspects). A wide range of social and economic barriers were identified by MPfN stakeholders, with the primary impediments being the perceived risk of missing out on lost productivity with reduced N application, combined with the low cost of traditional N sources such as urea. Together, these factors support a culture where N is applied as a form of cheap insurance to maximise productivity.

The identified social and economic factors present potential barriers to practice change, reducing the rate or level of overall adoption of new practices and technologies. Understanding and addressing these barriers to change where possible, and reinforcing the key research messages through industry specific resources and extension becomes critical to achieving incremental practice change and industry impact. While this process can be supported with communication and extension throughout the R&D process (as the MPfN has done through the delivery of 150% of planned communication and extension activities and outputs), it's success is ultimately dependent on extension of the final research results in the longer term following the completion of the research phase, with this responsibility falling to the industry research organisations and supporting industry bodies. Importantly, the significance of this ongoing process was clearly recognised by research level stakeholders through their feedback, and across all stakeholders adoption was considered likely to occur over time as the MPfN recommendations are integrated into industry resources and extension programs. Promisingly, stakeholders commented that adoption was already evident in all industries, with demonstrated potential for economic and environmental benefits including yield or quality improvements, reduced N inputs, and reduced losses of N to the environment.

Considering the above, the MPfN's 1) strong contribution to generating knowledge and understanding; 2) identification of NUE strategies or technologies that were made available for inclusion (and in some cases already included) in industry NUE resources; and 3) contribution to a moderate (borderline high) industry confidence to adopt the NUE strategies, are together assessed to generate a strong immediate research impact, and a strong foundation supporting potential future adoption of NUE practices resulting in improved profitability and reduced environmental impact (Table 3). Importantly, it is up to individual industry research and extension bodies to convert this potential into realised NUE practice change and industry impact by continuing the process of integrating the MPfN recommendations into industry resources and extension programs, and understanding and addressing industry specific barriers to NUE practice change.

Table 3. Summary of evaluation of immediate and legacy impact to improve on-farm NUE

Evaluation of immediate and legacy impact to improve on-farm NUE	Average stakeholder rating	Overall evaluation
Generate knowledge (from Part 2)	3.9 (n=62)	Strong
Inform NUE resources (from Part 2)	3.6 (n=60)	Moderate
Confidence to adopt MPfN strategies and recommendations	3.7 (n=65)	Moderate
Overall evaluation of immediate and legacy impact (average rating)	3.7	Strong

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Introduction

About the program

The More Profit from Nitrogen Program (MPfN) program was a partnership between the agriculture industry's four major intensive users of nitrogenous fertilisers— dairy, sugar, cotton, and horticulture (mango and cherry).

The MPfN program was led by the Cotton Research and Development Corporation (CRDC) in partnerships with Dairy Australia, Sugar Research Australia, and Hort Innovation. The MPfN received funding through the Department of Agriculture, Water and the Environment's Rural R&D for Profit (RRD4P) program, each of the participating RDCs, and the research organisations responsible for project delivery.

The objective of RRD4P was to realise productivity and profitability improvements for primary producers. In support of this, MPfN was established to bring about increased farm profitability and reduced environmental impact by increasing nitrogen use efficiency (NUE) across the four industry sectors, measured by a reduction in the amount of applied nitrogen (N) required to produce each unit of product.

The Commonwealth Grant Agreement (CGA) committed the MPfN to focus on three key areas of research:

- How enhanced EEF formulations can better match a crop or pasture's specific N requirements (Activity B4—Extracting value from enhanced efficiency fertilisers).
- The interplay of soil, weather, climatic and farm management factors to optimise nitrogen N formulation, rate and timing across industries, farming regions, as well as irrigated and non-irrigated situations (Activity B5—Optimising NUE in irrigated systems).
- The contribution (quantifying rate and timing) of mineralisation to a crop or pasture's N budget (Activity B6—Better understanding N supply through mineralisation)

Through this research focus, as well as supporting collaboration, communication and extension activities and outputs, the MPfN delivered against its primary and secondary objectives, which align with the RRD4P objectives:

Primary objectives:

- Generate greater knowledge and understanding of the factors that influence NUE across the four industries.
- Identify new NUE strategies and technologies, or update or validate existing NUE strategies and technologies to inform NUE resources across the four industries.

Secondary objectives:

- Support the establishment and fostering of industry and research collaborations that form the basis for ongoing innovation and growth of Australian agriculture.
- Support strengthened pathways to extend the results of rural R&D, including understanding the barriers to adoption.

The MPfN Program commenced in July 2016 and will conclude in September 2021.

Under the umbrella of MPfN, ten sub-projects, consisting of a mix of field, laboratory and modelling based studies were established. An additional small cross-program project was also contracted on May 2019, focussing on standardising NUE language and metrics across the industries involved. The eleven projects and project delivery partners are listed in *Appendix A*.

About the evaluation

Ag Econ was engaged by the CRDC to undertake an independent final evaluation of the MPfN program. The evaluation scope was informed by the *Final Evaluation & Economic Case Study Consultant Terms of Reference* (TOR) and discussions with the MPfN Science Coordinator and the CRDC Program Manager.

The report is laid out in three parts to reflect this scope.

Part 1. Evaluate program delivery against MPfN plans:

- Assess whole-of-program activities and deliverables against the Project Management Plan (PMP), Communication and Extension Plan (CEP), Monitoring and Evaluation Plan (MEP), and the Mid-term evaluation report.

Part 2. Evaluate program delivery against MPfN objectives:

- Assess the extent to which the MPfN Program has achieved its primary objectives to increase NUE knowledge and understanding, and inform new or updated industry NUE resources; and its secondary objectives to support collaboration, and support extension pathways.

Part 3. Evaluate immediate and legacy impact upon industry nitrogen management practices to improve on-farm NUE:

- Assess the extent to which the MPfN activities have resulted, or will over time result in greater confidence to adopt the NUE strategies and recommendations.
- Assess the extent to which potential adoption of the NUE strategies and recommendations will result in increased profitability and reduced environmental impact.

Evaluation Method

The evaluation methodology was informed by the TOR in conjunction with the MEP, the PMP, the CEP, and the findings from the Mid-Term Evaluation report.

Two stage approach

The evaluation was undertaken in two defined stages in 2020 (Stage 1) and 2021 (Stage 2). The staged approach was designed to evaluate underlying projects at a similar time in relation to their completion date. The projects included in each stage are in *Appendix A*.

Seven key evaluation questions (KEQs) were provided in the TOR which relate to MPfN program delivery and outcomes. The KEQs and their alignment to the project scope are shown in *Appendix B*.

The KEQs were evaluated based on a combination of surveys and interviews with internal and external stakeholders, and a review of project and program documentation.

Stakeholder surveys and interviews

A register of 69 stakeholders was confirmed through the research project leads and the MPfN Science Coordinator. *Appendix C* shows the breakdown of the 69 stakeholders engaged for the final evaluation by stakeholder type, project, and industry.

The seven KEQs were aligned to appropriate survey and interview questions based on the Mid-Term Evaluation (where appropriate, to provide consistency and continuity), as well as the Performance Indicators from the Program Logic Framework in the MEP.

Through an online survey and follow up interviews, the stakeholders answered questions that included a mixture of quantitative ratings using a Likert scale (asking respondents to provide a rated response of 1 (lowest) to 5 (highest)), supported by open-ended qualitative questions to provide detail and context. The full list of survey and interview questions are identified in *Appendix D*.

The stakeholder quantitative ratings were presented as an average of the stakeholder groups. Where appropriate, the quantitative findings of the Final Evaluation were compared to the findings of the Mid-Term Evaluation to gain an understanding of changes in stakeholder perceptions¹.

The results of the qualitative responses were summarised using a thematic analysis template. The qualitative responses were broken into key themes with the number of responses and the proportion of stakeholders responding for each industry, and a sample quote provided.

Some stakeholders were part of multiple projects and industries, so stakeholder totals presented in qualitative and quantitative summary tables do not equal the sum of underlying industry stakeholders.

Document review

A list of relevant program and project level documentation was identified through the TOR and in discussion with the MPfN Science Coordinator. The document register is in *Appendix E*.

Evaluation criteria

To evaluate the whole-of-program activities and deliverables against the MPfN Plans and objectives a three-level traffic light system was used.

For the document review the evaluation status was determined as shown in Table 1.

Table 1. Output evaluation criteria

Evaluation Status	Evaluation criteria
Strong	Delivery of outputs against planned criteria in full or with minor omissions or gaps
Moderate	Partial delivery of outputs against planned criteria, with moderate omissions or gaps
Weak	Limited delivery of outputs against planned criteria, with significant omissions or gaps

For the stakeholder quantitative ratings the evaluation status was determined as shown in Table 2.

Table 2. Stakeholder quantitative response ratings

Stakeholder rating	Evaluation criteria
Strong	Rating of between 3.68 to 5
Moderate	Rating of between 2.34 to 3.67
Weak	Rating of between 1 to 2.33

In some instances, a combined approach was required, including both output review and stakeholder feedback. In these instances, the stakeholder criteria (Table 1) and activity and output criteria (Table 2) were combined as shown in Table 3.

Table 3. Combined evaluation criteria

		Stakeholder response evaluation status		
		Strong	Moderate	Weak
Document review evaluation status	Strong	Strong	Strong	Moderate
	Moderate	Strong	Moderate	Weak
	Weak	Moderate	Weak	Weak

¹ The MEP noted that when reporting on changes in knowledge, understanding, and resources relating to NUE, the Mid-Term and Final Evaluation should report against the baseline data report. No baseline data report was completed so the Final Evaluation has used the Mid-Term Evaluation as a baseline for comparison where appropriate.

PART 1: EVALUATION OF DELIVERY AGAINST MPfN PLANS

This section evaluates the whole-of-program activities and deliverables against the outputs, milestones and performance indicators of the three MPfN plans:

- The Program Management Plan (PMP)
- The Communication and extension Plan (CEP)
- The Monitoring and Evaluation Plan (MEP).

Stakeholder feedback on program delivery was also captured, including for the program planning, reporting, and internal communications.

Delivery against the MPfN Program Management Plan

The PMP was completed in Feb 2017, in line with Activity B2, output 2(a) of the CGA. A Deed of Variation (DoV) to the CGA was developed on 24 August 2017 and ratified on 01 December 2017, which included some adjustment of dates and addition of KPIs throughout the MPfN program. The executed DoV was subsequently used as an ongoing supporting document to the PMP.

Through a review of MPfN documentation, delivery of the MPfN program against the PMP was evaluated as strong (Table 4). All activities were successfully completed according to the DoV, with the exception of activity B4 where one KPI was partially achieved and carried through to the following milestone. A full list of the MPfN activities, outputs, KPIs, and milestones making up the DoV are shown in *Appendix F*, including their status as determined through this evaluation.

Table 4. Evaluation of delivery against MPfN PMP activities

Activity	Description	KPI delivery assessed as strong	Overall evaluation
B1	Project initiation	5/5 (100%)	Strong
B2	Project planning and management	5/5 (100%)	Strong
B3	Communication and extension	34/34 (100%)	Strong
B4	Extracting value from enhanced efficiency fertilisers (EEF)	22/23 (95%)	Strong
B5	Optimising nitrogen use efficiency (NUE) in irrigated systems	31/31 (100%)	Strong
B6	Better understanding N supply through mineralisation (quantifying rate and timing)	34/34 (100%)	Strong
Overall evaluation of delivery against the MPfN PMP		132/133 (99%)	Strong

Delivery against the MPfN Communication and Extension Plan

The CEP was completed in March 2017, in line with Activity B2, output 2(b) of the DoV. The CEP was prepared as the guiding document on communication and extension activities for the sector and research partners of the MPfN Program.

The CEP outlined 24 tools for internal and external communication and extension activities of the MPfN Program. Across the 24 tools in the CEP, 263 planned activities and outputs were identified. A document review showed 394 activities and outputs were completed against these planned tools

(Figure 1), equal to 150% of the total planned activities. An additional 46 activities and outputs were also registered as completed in the M&E database that did not directly align with the planned tools².

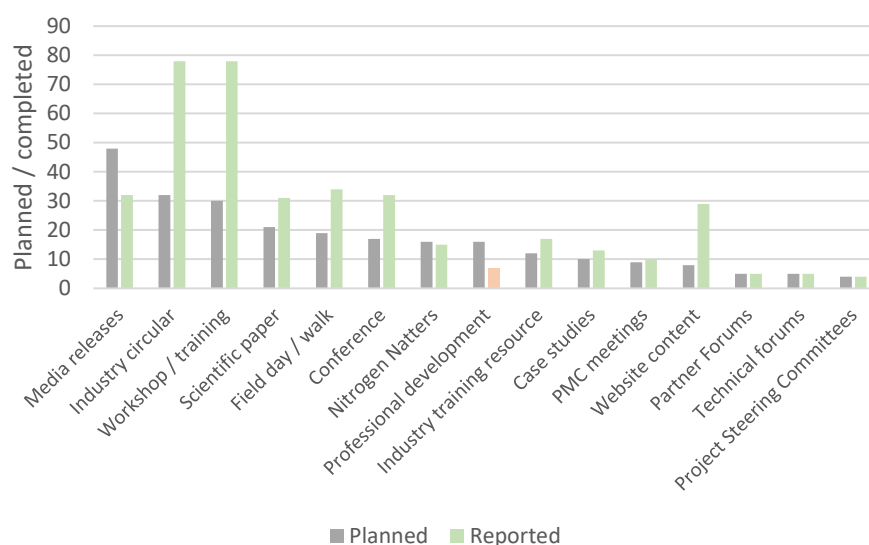


Figure 1. CEP tools: planned and completed

Based on the completion of planned activities and outputs, the MPfN is assessed to have achieved strong delivery against the CEP, with 22 out of 24 (92%) individual CEP tools evaluated as strongly achieved (Table 5). A full breakdown of the individual CEP tools with evaluations is in *Appendix G*.

Table 5. Evaluation of delivery against the MPfN Communication and Extension Plan

M&E area	Planned tools	Delivery of CEP tools assessed as strong	Overall evaluation
Internal communication and extension	PMC, Science Coordinator, Program Partner Forums, Project Steering Committees, Dairy Industry Forums, Nitrogen Natters, Partner webinars and professional development, emails, workshops.	8/9 (89%)	Strong
External communication and extension	Science Coordinator, Websites, Industry Extension, Social Media, Industry Circulars, Media Releases, Program Booklet, Comms templates, Industry resources, Field days /workshops, technical forums, videos/case studies, project interim and final reports, conferences, science journals.	14/15 (93%)	Strong
Overall evaluation of delivery against the MPfN CEP		22/24 (92%)	Strong

Delivery against the MPfN Monitoring and Evaluation Plan

The final MEP was completed in April 2017, in line with Activity B2, output 2(c) of the DoV. The MEP contains 42 performance indicators across four M&E areas (Table 6). Through a review of MPfN documentation, and quantitative and qualitative feedback from stakeholders, 83% of performance indicators were assessed as strongly achieved, and overall delivery against the MEP was assessed as strong. The remaining seven performance indicators (17%) were evaluated as having been moderately achieved, which was primarily due to stakeholders rating the MPfN as moderately effective in achieving some specific research and extension outcomes. *Part 2* provides more detail on this by

² The fields used in the M&E database for labelling individual activities and outputs did not directly align to those identified in the CEP. The activities and outputs were aligned where possible in consultation with the Science Coordinator to make an evaluation of their completion.

reviewing the effectiveness of the MPfN delivery against program objectives. A full list of the MPfN performance indicators making up the MEP is shown in *Appendix H*, including details on their assessed achievement.

Table 6. Evaluation of MPfN MEP performance indicators

M&E area	Description	Performance indicators assessed as strong	Overall evaluation
Initiation activities	Underpinning structures and process—What will be managed and how?	9/10 (90%)	Strong
Program Materials	Research and stakeholder adoption—What will the project produce?	7/8 (88%)	Strong
Program Activities	Research and stakeholder engagement outputs—What will the project deliver?	9/12 (75%)	Strong
Intermediate outcomes	Achievable within the life of the project—What will result from the project activities?	10/12 (75%)	Strong
Overall evaluation of delivery against the MPfN MEP		35/42 (83%)	Strong

Stakeholder feedback on program delivery

Internal stakeholders were asked to rate the effectiveness of internal planning, monitoring, and reporting in supporting the delivery of research, communication and extension objectives. All stakeholder groups rated these processes highly, with an average rating of 4.2 (n=34) (Table 7). This is comparable to the high rating from the mid-term evaluation (average rating 4.3, n=27).

When asked specifically about the administrative support from CRDC as Program Manager, the Science Coordinator, and the RDC partners, stakeholders rated the support as highly effective (average rating 4.2, n=26) (Figure 2). In particular, the support provided by the Science Coordinator gained the highest rating of all questions asked in the survey (average rating 4.7, n=26).

Table 7 Quantitative feedback summary: project planning, monitoring and reporting

Average score by stakeholder type	
Stakeholder group	Rating
RDC	4.2 (n=6)
Research leader	4.3 (n=12)
Research team member	4.1 (n=18)
Research partner	NA
Industry service provider	NA
Producer / grower	NA
Industry group	
Sugarcane	4.1 (n=8)
Dairy	4.5 (n=8)
Cotton	4.3 (n=7)
Mango	4.0 (n=8)
Cherry	4.0 (n=4)
Stakeholder average	4.2 (n=34)

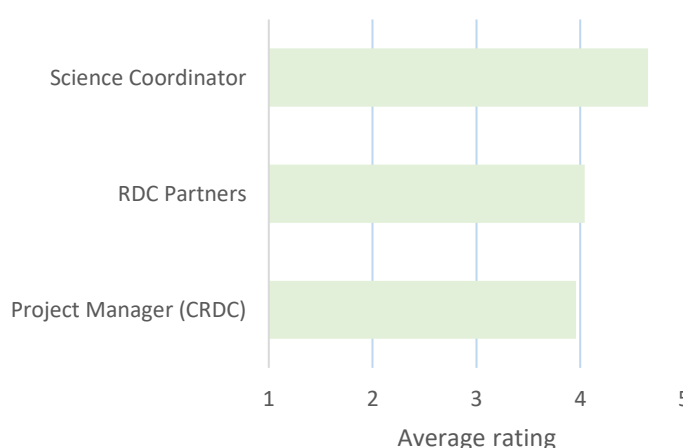


Figure 2. Stakeholder rating of administrative support

Stakeholder comments were overall highly supportive of the MPfN internal planning, monitoring and reporting processes, and the extent to which they supported project research and extension objectives (Table 8). Across the stakeholder ratings and comments, the support provided by the Science Coordinator was noted as being particularly effective at ensuring the successful delivery of the program. Among sugar and cotton stakeholders there were 5 comments that lengthy delays in the initial contracting process created follow on issues, including payment delays and the ability to

coordinate research staff; however, all stakeholders reflected that once contracted, the project was managed to a high standard.

Table 8 Qualitative feedback summary: project planning, monitoring and reporting

Sub-theme	Sample quotes	Sugar	Cotton	Dairy	Mango	Cherry	Total
A great program to be involved in / overall well planned and delivered.	<i>The program was well coordinated and will no doubt provide a valuable addition to industry knowledge (sugar)</i>	6 29%	0	5 26%	0	2 22%	13 19%
Science coordinator was really effective / a great asset / should be brought in earlier to help planning.	<i>The Science Coordinator has been a real asset to the program. An excellent communicator and organiser (mango)</i>	4 19%	3 20%	1 5%	3 30%	3 33%	13 19%
Internal reporting and communication processes were well organised / really effective / timely / Science Coordinator did a great job with this	<i>In terms of program facilitation; online database, templates for reports, all very well managed. Have a look at how this program was managed and use that as a benchmark for how others should be managed (dairy)</i>	2 10%	1 7%	3 16%	1 10%	1 11%	7 10%
Integrating contracting timelines across organisations caused problems / contracting was convoluted / significant delays	<i>Unfortunately a lot of delays in contracting. So this an area to improve; convoluted process. But once set up no issues with commss, reporting or management (sugar)</i>	3 14%	2 13%	0	0	0	5 7%
M&E database was a useful reporting tool for the program.	<i>The database ensured that data that were needed for measuring research impact were collated and reported in a useful way (cotton)</i>	0	1 7%	2 11%	0	0	3 4%
Basic templates for presentation and branding were not well developed / was a bit confusing / could have been done better.	<i>The standard PowerPoints were not properly constructed, so couldn't actually be used effectively. Had to be converted into a formal PowerPoint template (dairy)</i>	2 10%	0	1 5%	0	0	3 4%
Would have benefited from greater integration of objectives and research with other N research outside of MPfN / More planning on this at an industry level.	<i>MPfN sits as one facet of research in N use in the sugar industry, but perhaps it was not well enough connected to other research being conducted (sugar)</i>	3 14%	0	0	0	0	3 4%

Concluding remarks on the evaluation of program delivery

The delivery of MPfN activities and outputs against the three MPfN Plans was evaluated as strong overall. Across the three MPfN plans, there was an average 91% of planned outputs evaluated as strongly delivered (Table 9).

Table 9. Summary of evaluation of program delivery against the MPfN plans

MPfN plan	Elements rated as strong	Overall evaluation
Overall evaluation of delivery against the MPfN PMP	132/133 (99%)	Strong
Overall evaluation of delivery against the MPfN CEP	22/24 (92%)	Strong
Overall evaluation of delivery against the MPfN MEP	35/42 (83%)	Strong
Overall stakeholder rating of planning, monitoring and reporting	4.2 (n=34)	Strong
Overall evaluation of delivery against the MPfN plans (average rating)	91%	Strong

The level of program outputs registered in the M&E database far exceeded those planned in the CEP, and internal stakeholders rated the project planning, monitoring and delivery as highly effective

(average 4.2, n=34), and the administrative support provided as highly effective (average 4.2, n=26), with generally positive comments supporting these ratings.

While the evaluation of the PMP and CEP focussed on the delivery of planned activities and outputs, the evaluation of the MEP performance indicators included stakeholder feedback on the effectiveness of the activities and outcomes in achieving program objectives. *Part 2* provides more detail on this by reviewing the effectiveness of the MPfN delivery against program objectives.

PART 2: EVALUATION OF DELIVERY AGAINST MPfN OBJECTIVES

Building on the evaluation of delivery of activities and outputs in *Part 1. Evaluation of delivery against program plans*, *Part 2* evaluates the MPfN Program success in achieving its primary and secondary objectives.

Primary objectives:

- Generate greater knowledge and understanding of the factors that influence NUE across the four industries.
- Identify new NUE strategies and technologies, or update or validate existing NUE strategies and technologies to inform NUE resources across the four industries.

Secondary objectives:

- Support the establishment and fostering of industry and research collaborations that form the basis for ongoing innovation and growth of Australian agriculture.
- Support strengthened pathways to extend the results of rural R&D, including understanding the barriers to adoption.

To evaluate the MPfN primary and secondary objectives, feedback was collected quantitatively and qualitatively across internal and external groups.

Generate knowledge and understanding

For each of the three key research areas, stakeholders were asked to rate the extent to which the MPfN Program achieved its primary objective of increasing industry knowledge and understanding of factors affecting NUE across the four industries.

Overall, respondents rated the MPfN highly for generating increased knowledge across each of the individual MPfN research activity areas (overall average 3.9, n=62) (Table 10). This is an improvement on the stakeholder ratings from the mid-term evaluation, where stakeholders rated the MPfN as moderate for contributing to increased industry knowledge and understanding (average rating 3.4, n=31), which highlights the progression of the sub-projects in finalising research results and communicating the findings to industry.

Breaking down the responses into the two primary stakeholder groups, the research group rated the contribution to knowledge and understanding highly across all research activity areas (average 4.1, n=44), while the industry group rated the contribution to knowledge and understanding as moderate (average rating 3.6, n=18).

Table 10. Stakeholder rating of MPfN Program contribution to NUE knowledge and understanding

Contribution to increased industry knowledge and understanding				
Stakeholder group	EEFs (activity B4)	Interplay of N factors (activity B5)	Mineralisation and N budgets (activity B6)	Average
RDC	3.6 (n=5)	3.9 (n=6)	4.1 (n=5)	3.9 (n=6)
Research leader	4.0 (n=10)	4.2 (n=10)	4.2 (n=11)	4.1 (n=12)
Research team member	4.1 (n=17)	4.1 (n=19)	4.1 (n=17)	4.1 (n=21)
Research partner	4.1 (n=5)	4.2 (n=5)	3.5 (n=4)	3.9 (n=5)
Industry service provider	3.7 (n=9)	3.4 (n=10)	3.8 (n=11)	3.6 (n=11)
Producer / grower	3.7 (n=5)	3.7 (n=5)	3.8 (n=6)	3.7 (n=7)
Industry group				
Sugarcane	3.9 (n=20)	3.6 (n=18)	3.7 (n=15)	3.7 (n=20)
Dairy	3.9 (n=16)	3.9 (n=18)	4.1 (n=17)	4.0 (n=18)
Cotton	3.8 (n=13)	3.7 (n=10)	3.7 (n=11)	3.8 (n=13)
Mango	3.3 (n=3)	4.0 (n=10)	4.2 (n=10)	3.8 (n=10)
Cherry	3.7 (n=3)	3.8 (n=4)	4.3 (n=6)	3.9 (n=6)
Stakeholder average	3.9 (n=51)	3.9 (n=55)	4.0 (n=54)	3.9 (n=62)

Stakeholder comments on the MPfN contribution to increased knowledge and understanding of NUE closely reflected the ratings provided, with overall comments being generally positive (Table 11).

Stakeholders recognised a strong contribution to knowledge across the three research areas and across all industries, with the MPfN addressing previous knowledge gaps particularly at a research level. Across most industries, stakeholders commented that the research findings often confirmed or reinforced existing knowledge or practice, which was an important process in increasing industries confidence in N management, and a primary objective to validate existing N practices. The exception to this was mango, reflecting the previous lack of existing N management recommendations for the northern mango industry and highlighting the importance of the MPfN research in addressing this gap.

EEFs generated the highest number of specific comments, with respondents noting the contribution of the research to understanding the interplay of EEFs with different soils and climate, but also recognising that there is still a lot of uncertainty surrounding the effectiveness of different EEF products in relation to these other factors. These comments on EEFs support the lower ratings for knowledge and understanding of EEFs identified above.

Table 11. Stakeholder comments on MPfN contribution to NUE knowledge and understanding

Sub-theme	Sample quotes	Sugar	Cotton	Dairy	Mango	Cherry	Total
Mineralisation knowledge: addressed data gap for tree litterfall and mineralisation / increased understanding of the long life-cycle of N in orchards / clarified N application in Autumn	<i>The MPfN project has enabled more accurate values to be placed on N dynamics, such as mineralisation and the reason for seasonality in N response, which will provide industry with greater knowledge for decision making around N nutrition (dairy)</i>	2 10%	4 27%	8 42%	6 60%	4 44%	23 33%
EEF knowledge: Addressed a lot of assumptions relating to EEFs, soil, and SOC / better understanding of cost effectiveness of EEFs	<i>Our project contributed to further understanding of the implications of DMPP upon N release from urea-based fertiliser and how this affects desorption of SOC (cotton)</i>	6 29%	4 27%	5 26%	4 40%	3 33%	21 30%
Interplay of soils, climate, and management knowledge: Filled a huge knowledge gap / water influence on N use was a big gap / climate is the most significant factor in N losses	<i>We had very little knowledge on the seasonal dynamics of nitrogen use in cherry orchards up until we commenced these trials. The ¹⁵N trial facilitated new knowledge and understanding of NUE in this context for both researchers and industry (cherry)</i>	2 10%	5 33%	8 32%	4 40%	3 33%	21 30%

Re-enforced and refined current NUE knowledge / clarified unsubstantiated assumptions, recommendations, and practice	<i>Confirms practices you have been doing for years. Gives the confidence on when, why, how much (dairy)</i>	3 14%	2 13%	7 37%	0	2 22%	14 20%
Highlighted the importance of considering varying seasonal conditions and soil types when considering EEFs.	<i>One recommendation was to consider and understand seasonal potential. If they have a prediction of seasonal rainfall then this may influence the application of EEFs. This was not necessarily previously considered (sugar)</i>	3 14%	0	3 16%	1 10%	0	7 10%
Still a lot of uncertainties about EEFs / different products and factors / could not find savings in N losses from EEFs / variable responses to EEFs / trials were affected by weather conditions and residual soil N.	<i>Still a lot of uncertainty around EEFs (dairy)</i>	1 5%	2 13%	3 16%	0	0	6 9%

Inform NUE resources

Across each of the key research areas, stakeholders were asked to rate the extent to which the MPfN achieved its secondary objective to identify new NUE strategies and technologies, or update or validate existing NUE strategies and technologies to inform NUE resources across the four industries.

On average across all research areas, respondents rated the MPfN moderately for informing NUE resources (overall average 3.6, n=60) (Table 12). This is consistent with the ratings from the mid-term evaluation (average rating 3.6, n=33).

Breaking down the responses into the two primary stakeholder groups, both the research group and the industry group rated the MPfN as moderate for contributing to NUE resources across all research activity areas (research group average 3.6, n=43; industry group average 3.4, n=17).

Table 12. Stakeholder rating of MPfN Program contribution to NUE resources

Contribution to NUE resources				
Stakeholder group	EEFs (activity B4)	Interplay of N factors (activity B5)	Mineralisation and N budgets (activity B6)	Average
RDC	4.0 (n=4)	3.5 (n=6)	3.4 (n=5)	3.6 (n=6)
Research leader	3.4 (n=10)	3.8 (n=8)	3.5 (n=10)	3.6 (n=11)
Research team member	3.6 (n=15)	3.9 (n=19)	3.6 (n=16)	3.7 (n=21)
Research partner	3.6 (n=5)	3.8 (n=3)	4.3 (n=2)	3.9 (n=5)
Industry service provider	3.3 (n=8)	3.4 (n=9)	3.9 (n=10)	3.5 (n=10)
Producer / grower	3.1 (n=4)	3.6 (n=5)	3.3 (n=5)	3.3 (n=7)
Industry group				
Sugarcane	3.6 (n=17)	3.5 (n=15)	3.3 (n=12)	3.5 (n=19)
Dairy	3.6 (n=15)	4.0 (n=17)	4.1 (n=15)	3.9 (n=17)
Cotton	3.4 (n=11)	3.3 (n=8)	3.1 (n=9)	3.2 (n=12)
Mango	1.0 (n=1)	3.9 (n=8)	3.8 (n=8)	2.9 (n=8)
Cherry	3.0 (n=2)	4.0 (n=3)	3.6 (n=5)	3.5 (n=5)
Stakeholder average	3.5 (n=46)	3.7 (n=50)	3.6 (n=48)	3.6 (n=60)

In contrast to the moderate ratings, stakeholder comments on the MPfN contribution to NUE resources were mostly positive (Table 13).

Across all industries, the most common theme (14 comments, 20% of stakeholders) was a recognition of the positive contribution of the MPfN to the development of new or updated resources in the latter phase of the program, or as the next step for the individual industries. Consistent with the ratings, the

most comments on this were from dairy industry stakeholders (7 comments, 37% of dairy stakeholders), which reflected on the effective integration of the research findings into industry resources including updated Fert\$mart Nitrogen Guidelines, an NUE Pocket Guide and an NUE calculator. Cotton industry stakeholders also had a relatively high level of positive comments (4 comments, 27% of cotton stakeholders) on the work to integrate the findings into the 2021 Australian Cotton Production Manual, which is a key production resource for the cotton industry.

Across all four industries, stakeholders also commented that the development of resources was not the primary objective of the MPfN, but that the program had delivered clear R&D outputs and made them available to industry for inclusion in NUE resources going forward (6 comments, 9% of stakeholders).

Table 13. Stakeholder comments on MPfN Program contribution to NUE strategies and technologies

Sub-theme	Sample quotes	Sugar	Cotton	Dairy	Mango	Cherry	Total
New / improved resources have been / are being developed	<i>The integration of dairy R&D findings into industry BMPs was a highly effective means of focussing interpretation and a path to next and end users of knowledge (dairy)</i>	1 5%	4 27%	7 37%	1 10%	1 11%	14 20%
Mineralisation: dairy mineralisation calculator was useful / relationship between litterfall and N mineralisation will improve N budgeting.	<i>It has become apparent that there is a lot of carryover N in the soil of high-yielding cotton farms that is not being accounted for in N fertiliser recommendations (cotton)</i>	2 10%	0	4 21%	2 20%	2 22%	10 14%
EEFs: MPfN program generated new tools and recommendations relating to EEF products / blends which result in increased NUE under a range of soil, climatic and system conditions	<i>Developed a practical tool. Depending on different harvest dates, applications, weather, it helps guide which combination of N to use, including EEF (sugar)</i>	4 19%	0	2 11%	0	2 22%	8 12%
Developing resources is industries job going forward / research was mostly foundational / more practical tools are required for industry	<i>The research was more focussed on fundamentals, so there is a need now to support this with specific tools and strategies (Sugar)</i>	2 10%	2 13%	1 5%	1 10%	1 11%	6 9%
Interplay of soils, climate, and management: Good resources and recommendations relating to seasonal demand / N supply and fruit quality / good rules of thumb on the interaction of soils and climate and N.	<i>Some of the recommendations about timing of application were good as it confirmed what we had heard from overseas that uptake efficiency is greater in spring rather than post harvest (cherry)</i>	2 10%	0	1 5%	1 10%	2 22%	6 9%

Support research collaboration

Feedback was sought from internal stakeholders to assess how effectively the MPfN Program achieved its secondary objective of supporting research collaboration. Across 9 collaboration activities (Figure 3), stakeholders gave average ratings of between 3.4 (moderately effective in supporting collaboration) to 4.5 (highly effective at supporting collaboration). On average, stakeholders rated the MPfN activities highly for supporting collaboration (average rating 4.0, n=33), which is comparable to the high rating of 4.1 (n=28) from the Mid-Term Evaluation.

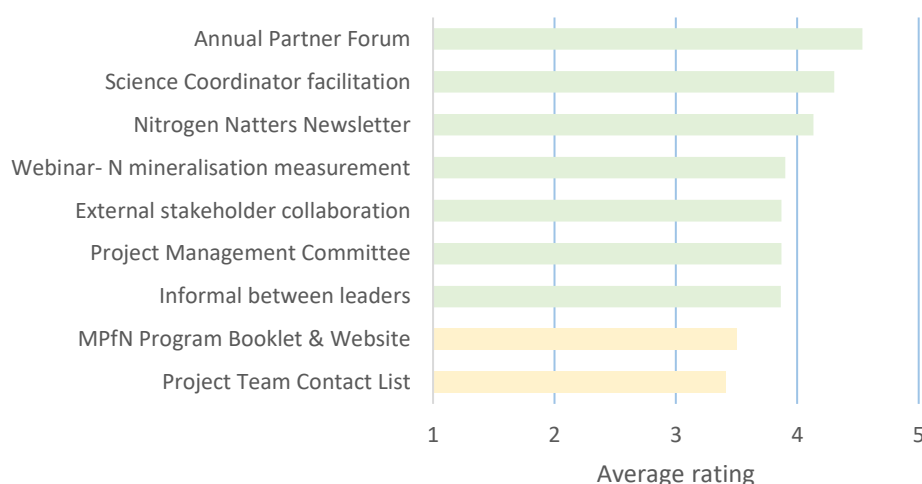


Figure 3. Rating of the effectiveness of MPfN activities in supporting collaboration

Stakeholder comments on MPfN research collaboration were mostly positive, with five main themes (Table 14). Stakeholders focussed on the overall effectiveness of MPfN activities in supporting inter and intra-industry collaboration, and singled out the Annual Partner Forums and Nitrogen Natters for particular praise. A small number of sugar and cotton industry stakeholder commented that more could have been done to support collaboration through more integrated research objectives and synthesis of results; however, MPfN planning time-constraints reduced the focus on this area.

Table 14. Qualitative feedback summary: program collaboration activities

Sub-theme	Sample quotes	Sugar	Cotton	Dairy	Mango	Cherry	Total
MPfN supported collaborative research across all participating industries / you can piggy-back on what other researchers are doing and learn a lot.	<i>There are enough commonalities between the different industries and the underlying science. Having the workshops and formats have enabled me to avoid some pitfalls based on other industry research (sugar)</i>	5 24%	6 40%	3 16%	2 20%	3 33%	18 26%
MPfN supported collaborative research within the same industry group / Grouping of the industry relevant teams together strengthens industry specific research collaboration.	<i>The MPfN program has been very productive, and the national coordination provides great opportunities for collaboration and information exchange. Grouping the industry teams together also strengthens industry specific research collaboration (dairy)</i>	3 14%	1 7%	2 11%	0	2 22%	8 12%
Annual meetings very effective / Partner Forum worked really well / great opportunity to interact with MPfN community / workshops were a great opportunity to share knowledge and gain feedback.	<i>Really enjoyed the partner forums, and being able to have conceptual discussion about NUE and mineralisation and how to present that (cherry)</i>	1 5%	2 13%	3 16%	0	1 11%	7 10%
Nitrogen Natters was really useful to understand other research / a go-to cross-industry read.	<i>Nitrogen Natters has been my go-to cross industry read (mangos)</i>	1 5%	3 20%	0	1 10%	1 11%	5 7%
MPfN planning time constraints limited the identification of specific cross sectoral activities and integrated objectives / More could have been done to allow cross-industry synthesis of results.	<i>Could have better identified the objectives and more specific cross project activities that would have improved collaboration. There was cross sectoral collaboration, but more time to build that component. The opportunity is to value add with more explicit cross sectoral activities. (cotton)</i>	2 10%	1 7%	0	0	0	3 4%

Support extension pathways

As identified in *Part 1*, program delivery against the CEP was evaluated as strong, with 150% of planned activities and outputs delivered. This section builds on that assessment by evaluating the effectiveness of the MPfN extension and communication in line with the MPfN secondary objective to support R&D extension pathways.

Overall, stakeholders rated the MPfN extension and external communication activities as being moderately effective at communicating the outcomes of the program and demonstrating industry opportunities for greater production and profit through increased NUE (average rating 3.6, n=61) (Table 15). This is lower than the mid-term evaluation rating of 3.8 (n=41), potentially reflecting the cancellation or modification of some planned activities in the last two years of the program as a result of COVID restrictions. On average research level stakeholders provided a high rating (average rating 3.7, n=42) while industry level stakeholder provided a moderate rating (average 3.6, n=19).

Stakeholders were also asked to rate the effectiveness of individual MPfN extension and communication activities at disseminating relevant project information to industry (Figure 4). Individual activities were rated from moderate to high (average rating 3.7, n=63), with in-person events viewed as the most effective at disseminating the project information. On average, research level stakeholders rated the extension activities highly (average 3.7, n=44), while industry level stakeholders rated extension activities as moderate (average 3.5, n=19).

Table 15. Stakeholder rating of MPfN Program extension and external communication

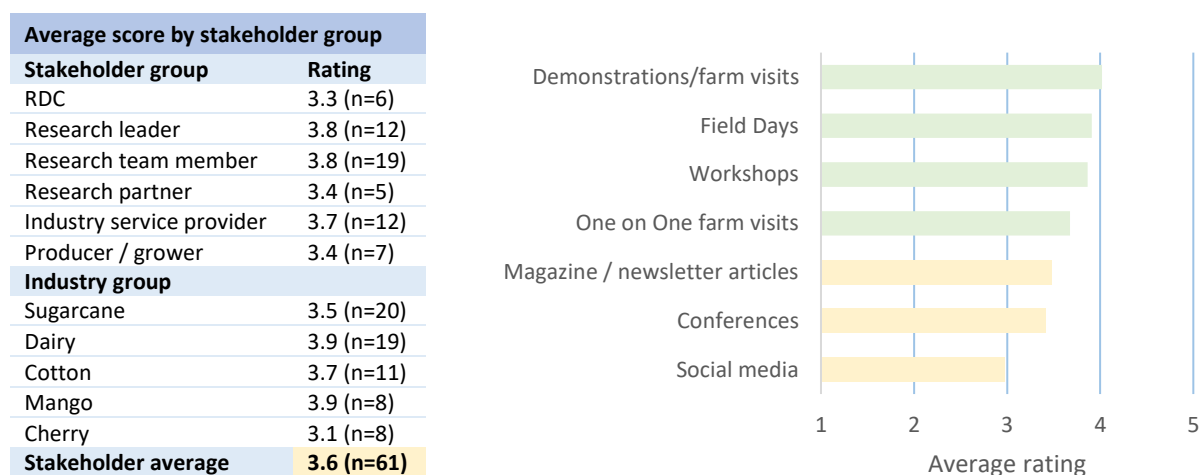


Figure 4 Stakeholder rating of individual extension and comms

Stakeholders commented extensively on the effectiveness of MPfN extension and communication activities at conveying the research findings (Table 16). Comments were mostly positive, with the highest level of feedback relating to the effectiveness of the in-person extension activities (23 comments), consistent with the ratings in Figure 4. Stakeholders also identified the effectiveness of targeting service providers to generate a multiplier effect, including through collaborations with Fertilizer Australia. The MPfN success in this area directly aligns with the RRD4P intent to focus on the growing role of private service delivery in industry RD&E and adoption³.

Across all industries with the exception of cotton, there were 16 comments that there had not been enough extension to effectively convey or re-enforce the research findings and recommendations. Of note, industry level stakeholders commented on this perceived lack of extension at a higher rate (7 comments, 30% of industry stakeholders) compared to research level stakeholders (9 comments, 20% of research stakeholders), and at the same time, research level stakeholders in all industries recognised that extension of the MPfN final recommendations was not a primary MPfN objective, but

³ Grosvenor Management Consulting, 2017, *Evaluation of the Rural Research & Development (R&D) for Profit Program Final Report*, Canberra, 15 December 2017.

was instead primarily the responsibility of industries going forward. As such, the industry stakeholder perception of a lack of extension was likely linked to their lack of awareness of the MPfN's primary focus on research, and the ongoing work to integrate the MPfN findings into industry resources and extension programs.

COVID was widely noted (12 comments) as having disrupted the extension of results through the preferred use of face-to-face events; however, online communications were identified by some respondents as being effective at partially mitigating this disruption. These COVID impacts in the latter part of the MPfN program potentially contributed to the perceived lack of extension by some stakeholders, and also, as previously identified, the lower rating of extension activities compared to the Mid-Term Evaluation.

Demonstrating the economics was highlighted as a key focus area for extension to support producer confidence in the research (6 comments). The importance of this was recognised in the MPfN planning, and as a result the program has delivered, or is in the process of delivering, at least two economic case studies for each industry group that highlight the farm level economic benefits of applying the MPfN recommended strategies.

Table 16. Stakeholder comments on effectiveness of MPfN extension and external communication

Theme	Sample quotes	Sugar	Cotton	Dairy	Mango	Cherry	Total
In person extension was the most effective / allowed practical discussion with researchers and other growers	<i>Feedback from field days was always very positive and small group discussions at workshops were very targeted and cited as useful by the growers involved (cotton).</i>	8 38%	5 33%	4 21%	4 40%	3 33%	23 33%
There hasn't been enough extension to convey / re-enforce the message / address barriers	<i>They have done an ok job at conveying the research but the frequency of communication has been lacking (cherry)</i>	5 24%	0	4 21%	2 20%	6 67%	16 23%
Extension has been really well done / coordination between researchers improved extension / engagement with growers and industry has been really successful	<i>Industry had great interaction with researchers so we are much more aware and prepared to manage N over the entire season and have benefited greatly from direct interaction with research staff (dairy)</i>	5 24%	1 7%	4 21%	1 10%	2 22%	13 19%
Coordination with industry extension programs was effective	<i>There has been good collaboration with CottonInfo (cotton).</i>	1 5%	5 33%	2 11%	4 40%	0	12 17%
COVID really impacted the number or effectiveness of extension activities	<i>COVID was very disruptive. We lost the face-to-face which made effective made communication harder (sugar)</i>	4 19%	0	2 11%	2 20%	4 44%	12 17%
Extension was effective at tailoring the message / language to the audience / "farmer language" / practical recommendations.	<i>The fact that the research was thorough, and was translated into meaningful outcomes that farmers could understand and implement in their own business (dairy)</i>	0	2 13%	7 37%	0	3 33%	12 17%
Extension wasn't really part of the project / wasn't explicitly written into the program / is industries job going forward	<i>Next step is identifying the best extension approach, which wasn't explicitly build into the program, so its industries job going forward (cotton)</i>	3 14%	4 27%	2 11%	1 10%	1 11%	10 14%
Targeting service providers / agronomists and retailers generated an impact multiplier	<i>Service providers are increasingly more influential, so targeting them is a more effective pathway for getting industry adoption (dairy).</i>	3 14%	0	4 21%	0	0	7 10%
A lack of simple, easily accessible, practical extension and communications / needs to be condensed into simple message / farmer language for extension	<i>What does it mean in 'real terms' and what can growers do in 'practical application' — provide growers with 'usable' information (sugar).</i>	2 10%	0	3 16%	1 10%	1 11%	6 9%

Collaborations with the fertilizer industry was useful when engaging with service providers	<i>Collaborations with the fertiliser Australia very good (dairy).</i>	3 14%	1 7%	2 11%	1 10%	3 33%	6 9%
Demonstrating the economics clearly is important to give growers confidence	<i>Economic analysis of the N impact on mangoes will provide basis for our extension activities after the project (mango).</i>	1 5%	0	4 21%	1 10%	0	6 9%
Online material and events were done well / social media was effective / helped to manage disruptions from COVID	<i>Farmers responded well to online videos. Great analytics on social. Social media are the best supporting material for the research, providing short, targeted messages (dairy).</i>	1 5%	0	3 16%	1 10%	0	5 7%
Activities could be more spread out / could have started earlier / greater consideration of seasonal farming conditions and priorities that impact attendance and cut-through	<i>The seasonality is also a challenge. Especially in drought conditions when farmers are thinking of survival its really difficult to cut through some of those messages. You need to pick the time when farmers are most likely to want to hear the message and adopt, right time and head-space (dairy).</i>	1 5%	0	3 16%	0	0	4 6%

Concluding remarks on the evaluation of delivery against program objectives

Overall, delivery of the MPfN against the program objectives was evaluated as strong (Table 17).

Table 17. Summary of evaluation of program delivery against the MPfN objectives

Evaluation of successful delivery against the project objectives		Average stakeholder rating	Overall evaluation
Primary objectives	Generate knowledge and understanding	3.9 (n=62)	Strong
	Inform NUE resources	3.6 (n=60)	Moderate
Secondary objectives	Support collaboration (internal stakeholders only)	4.0 (n=33)	Strong
	Support extension pathways	3.6 (n=61)	Moderate
Overall evaluation of delivery against the MPfN objectives (average rating)		3.8	Strong

Across the MPfN objectives, the perceived effectiveness against research level outcomes (research level knowledge and fostering collaboration) was strong, reflecting the delivery of a high level of research outcomes for what was fundamentally a research program.

While the perceived effectiveness against industry level outcomes (industry level resources, extension, and changes in industry level knowledge) was moderate, the lower ratings were consistent with these being primarily secondary objectives of the program. In particular, comments recognised that while the MPfN delivered clear R&D outputs to inform industry resources (a primary objective), responsibility for integrating the findings into industry resources and extending these to growers lay primarily with the individual industries and would continue beyond the completion of the MPfN. In addition, while all industries had begun to integrate the MPfN recommendations into industry resources, or had plans to do so, the comments indicated that service providers and producers were not as aware of this ongoing process, which likely contributed to their lower scores in this area.

PART 3. EVALUATION OF IMMEDIATE AND LEGACY IMPACT

This section includes an evaluation of the immediate and legacy impact of the project upon industry nitrogen management practices. Based on feedback from MPfN stakeholders, this section assesses the extent to which the MPfN has resulted, or will over time result in greater confidence to adopt the NUE strategies and recommendations; the barriers that might affect the rate and level of adoption; and the potential economic and environmental impact areas that could result from adoption.

Confidence to adopt the NUE strategies and recommendations

Stakeholders were asked to rate the extent to which the MPfN program has resulted, or will result in greater producer confidence to adopt the strategies and recommendations relating to the three NUE research areas. Overall, stakeholders rated the MPfN moderately for influencing producer confidence to adopt the NUE strategies (average rating 3.7, n=65) (Table 18). Across the three individual research areas, stakeholders singled out the MPfN for being the most effective at increasing producer confidence to adopt NUE strategies relating to N mineralisation. The lower rating for confidence to adopt the research findings on EEF products reflects the stakeholder comments that there remained a lot of uncertainties around EEFs (see *Part 2. Evaluation of program delivery against MPfN objectives*).

Table 18. Stakeholder rating of the extent to which the MPfN Program will result in greater confidence to adopt NUE strategies across the three research areas

Average score by stakeholder group				
Stakeholder group	EEFs (activity B4)	Interplay of N factors (activity B5)	Mineralisation and N budgets (activity B6)	Average
RDC	4.0 (n=4)	3.2 (n=5)	3.0 (n=5)	3.4 (n=5)
Research leader	3.3 (n=9)	4.1 (n=10)	4.0 (n=12)	3.8 (n=12)
Research team member	3.4 (n=18)	3.5 (n=19)	3.9 (n=20)	3.6 (n=22)
Research partner	4.0 (n=5)	2.8 (n=4)	4.2 (n=5)	3.7 (n=5)
Industry service provider	3.5 (n=10)	3.7 (n=11)	4.0 (n=11)	3.7 (n=11)
Producer / grower	3.5 (n=6)	3.7 (n=7)	3.8 (n=8)	3.6 (n=8)
Industry group				
Sugarcane	3.6 (n=19)	2.8 (n=12)	3.6 (n=17)	3.3 (n=19)
Dairy	3.7 (n=15)	3.8 (n=17)	4.1 (n=18)	3.8 (n=18)
Cotton	3.5 (n=13)	3.9 (n=15)	3.8 (n=13)	3.7 (n=15)
Mango	2.3 (n=3)	3.6 (n=9)	3.7 (n=10)	3.2 (n=10)
Cherry	3.3 (n=6)	3.4 (n=8)	3.5 (n=8)	3.4 (n=8)
Stakeholder average	3.5 (n=52)	3.6 (n=56)	3.8 (n=61)	3.7 (n=65)

In support of the ratings on producer confidence to adopt the MPfN recommendation, stakeholders also provided comments on the extent to which adoption was already taking place, was likely to occur, or was unlikely or unknown (Table 19). Across all industries the comments were net positive (adoption has already occurred or is likely to occur with time) with the exception of the cotton industry, where there were more comments that adoption was unlikely or unknown.

Table 19 Qualitative feedback summary: intent of industry to adopt MPfN recommendations

Sub-theme	Sample quotes	Sugar	Cotton	Dairy	Mango	Cherry	Total
Already identified industry adoption	<i>Very interesting the findings for the industry, especially with the findings of N left in leaf litter. So we have changed our management and don't add as much nitrogen now (mango).</i>	2 10%	3 20%	4 21%	3 30%	0	12 17%
Likely to see adoption with time / with further extension	<i>Full impact of the new knowledge generated by the MPfN project will occur over time (not straight away) as it is incorporated into industry extension/literature and is it becomes known by the wider industry (dairy).</i>	4 19%	0	4 21%	1 10%	3 37%	12 17%
Unlikely / unknown	<i>Research is not necessarily dealing with the drivers for N use on cotton farms. They have produced great information, very practical results, and they are communicating well, but it's not translating into impact (cotton).</i>	2 10%	4 27%	3 16%	1 10%	2 22%	11 16%

When asked to comment on the barriers that currently affect or are expected to affect the speed or level of producer adoption of MPfN program outputs, 75% of stakeholders responded, which was the highest response rate for all open-ended questions. Comments were aligned to themes covering economic, social, and practical factors (Table 20). In addition, stakeholders identified a lack of extension of the program recommendations as a potential barrier. As previously discussed (*Part 2. Support Extension Pathways*), extension was not a primary objective of the MPfN, so this potential barrier presents a key risk and challenge to participating industries going forward, but one that can be managed with the effective integration of the MPfN findings and recommendations into industry resources and extension programs.

Table 20. Stakeholder comments on issues and barriers that will affect the speed or level of adoption

Theme	Sample quotes	Sugar	Cotton	Dairy	Mango	Cherry	Total
N is cheap insurance / Risk averse / Too risky to lose potential production	<i>Secure crop production and cane supply is often an overriding consideration given the cost of production and sugar price - N in urea form is considered 'cheap insurance' (sugar).</i>	4 19%	6 40%	4 21%	3 30%	5 56%	21 30%
There hasn't been enough extension to convey / re-enforce the message / address barriers	<i>They have done an ok job at conveying the research but the frequency of communication has been lacking (cherry)</i>	5 24%	0	4 21%	2 20%	6 67%	16 23%
Alternative sources of N are too expensive	<i>EEF has potential, but cost inhibitive. If the economics were there I'm sure people would use them (cotton)</i>	7 33%	3 20%	1 5%	1 10%	3 33%	11 16%
More regionalised trials and recommendation (climate / soil) would support greater long-term adoption	<i>I think the major issue that might affect the speed or level of producer adoption is the validation of the results under uncertain climatic conditions (mango)</i>	6 29%	0	4 21%	1 10%	0	11 16%
Practicalities of farming (labour, cashflow, time, technology) may limit the ability to adopt	<i>Best practice is best practice if you have the cashflow to support it. Labour is also a factor, for best nitrogen use you want to get application spot on, but you cant always get labour in when you need it (dairy)</i>	1 5%	4 27%	2 11%	0	0	7 10%
N is not a large input cost / is not a primary issue of concern for farmers	<i>For horticulture, the big ticket items is labour. So a little bit of nitrogen is very small. Grower motivation is not to save money on nutrition but to maximise yield/quality (cherry).</i>	0	0	1 5%	3 30%	2 22%	6 9%
PCU residue a potential environmental concern	<i>Still questions about some of the EEF products. The PCU stays in the soil and can be washed away. Would be better if biodegradable. Environmental impact which comes back to haunt the industry (sugar).</i>	3 14%	0	0	0	0	3 4%
Needs more information on the longer term implications of N management	<i>Concern about longer term lost productivity if holding back on N — demonstration of projects longer term would alleviate this (cherry)</i>	1 5%	1 7%	0	0	1 11%	3 4%

Potential impact areas

Stakeholders commented on several MPfN impact areas that had already been identified as a result of adoption, or were expected following adoption (Table 21). These included research impacts (9 comments), profitability impacts (45 comments), and environmental impacts (27 comments). In addition, there were 19 comments across all industries that profitability or environmental impacts were unknown, unlikely, or minor.

Table 21. Stakeholder comments on observed or expected impacts as a result of adoption

Theme	Sample quotes	Sugar	Cotton	Dairy	Mango	Cherry	Total
Research impacts							
Furthering N research areas / capacity building through PhDs / identified new research methods	<i>Some fabulous student projects in both mangoes and cherries who've made a great impact on the growers/farms they worked on and the industry. Good to see capacity building as a strong output in this sort of project (mango)</i>	3 14%	2 13%	3 16%	1 10%	0	9 13%
Profitability impacts							
Increased application efficiency (timing, meeting crop needs)	<i>Over the long term it will definitely be a better fertilizer recovery from more efficient timing application. We haven't improved yield but we have reduced N application to improve productivity (cotton)</i>	4 19%	4 27%	5 26%	4 40%	0	17 25%
Reduced rates of applied N	<i>We are not going to get more revenue/yield necessarily, but we can achieve a much more efficient approach to nitrogen use with less application (mango)</i>	4 19%	3 20%	2 11%	6 60%	2 22%	16 23%
Profit impact is unlikely / unknown / minor	<i>Not sure. The cost of N is very minimal within the overall cost of production for cotton. So, it's challenging better NUE with improved profits (cotton)</i>	2 10%	2 13%	2 11%	2 20%	2 22%	10 14%
Improved yield / quality	<i>Increases in cane yields in wetter farms (sugar)</i>	2 10%	0	3 16%	2 20%	0	7 10%
Increased profits in some seasons / soils from EEFs	<i>Productivity and environmental benefits that can stem from the use of EEFs are not observed in all years. It is highly dependent on the interaction of different factors (soil x climate x harvest time) (sugar)</i>	5 19%	1 7%	0	0	0	5 7%
Environmental impacts							
Reduced system losses / leaching / run-off / emissions	<i>Keeping the N where it needs to be (in the rootzone), reducing off site impacts through runoff and deep drainage (cotton)</i>	7 33%	6 40%	4 21%	5 50%	3 33%	24 35%
Environmental impact is unlikely / unknown / minor	<i>Cannot see this in short-term in the systems examined (dairy)</i>	1 5%	0	5 26%	2 20%	1 11%	9 13%
PCU residue a potential environmental concern	<i>Still question marks about some of the products. The polymer coat stays in the soil and can be washed away. Would be better if biodegradable. Environmental impact which comes back to haunt the industry or fertilizer company (sugar)</i>	3 14%	0	0	0	0	3 4%

Concluding remarks on the evaluation of immediate and legacy impact

While stakeholders rated producer confidence to adopt as moderate; it is important to note that the timeframe for practice change within an agricultural R&D context can take years (or decades). It is rare for industry adoption of R&D to occur rapidly following the completion of the underlying research, but rather, adoption occurs in stages depending on the overlapping of a range of underlying factors including the strength of extension pathways and stakeholders' appetite for risk and change (social aspects), and underlying market conditions relating to the commodity and the innovation (economic aspects). A wide range of social and economic barriers were identified by MPfN stakeholders, with the

primary impediments being the perceived risk of missing out on lost productivity with reduced N application, combined with the low cost of traditional N sources such as urea. Together, these factors support a culture in many industries where N is applied as a form of cheap insurance to maximise productivity.

The identified social and economic factors present potential barriers to practice change, reducing the rate or level of overall adoption of new practices and technologies. Understanding and addressing these barriers to change where possible, and reinforcing the key research messages through industry specific resources and extension becomes critical to achieving incremental practice change and industry impact. While this process can be supported with communication and extension throughout the R&D process (as the MPfN has done through the delivery of 150% of planned communication and extension activities and outputs), it's success is ultimately dependent on extension of the final research results in the longer term following the completion of the research phase, with this responsibility falling to the industry research organisations and supporting industry bodies. Importantly, the significance of this ongoing process was clearly recognised by research level stakeholders through their feedback, and across all stakeholders, adoption was considered likely to occur over time as the MPfN recommendations are integrated into industry resources and extension programs. Promisingly, stakeholders commented that adoption was already evident in all industries, with demonstrated potential for economic and environmental benefits including yield or quality improvements, reduced N inputs, and reduced losses of N to the environment.

Considering the above, the MPfN's 1) strong contribution to generating knowledge and understanding; 2) identification of NUE strategies or technologies that were made available for inclusion (and in some cases already included) in industry NUE resources; and 3) contribution to a moderate (borderline high) industry confidence to adopt the NUE strategies, are together assessed to generate a strong immediate research impact, and a strong foundation supporting potential future adoption of NUE practices resulting in improved profitability and reduced environmental impact (Table 22). Importantly, it is up to individual industry research and extension bodies to convert this potential into realised NUE practice change and industry impact by continuing the process of integrating the MPfN recommendations into industry resources and extension programs, and understanding and addressing industry specific barriers to NUE practice change.

Table 22. Summary of evaluation of immediate and legacy impact to improve on-farm NUE

Evaluation of immediate and legacy impact to improve on-farm NUE	Average stakeholder rating	Overall evaluation
Generate knowledge (from Part 2)	3.9 (n=62)	Strong
Inform NUE resources (from Part 2)	3.6 (n=60)	Moderate
Confidence to adopt MPfN strategies and recommendations	3.7 (n=65)	Moderate
Overall evaluation of immediate and legacy impact (average rating)	3.7	Strong

Appendix A. MPfN sub-project details

The eleven projects under the MPfN program are presented in Table A1.

Table A1 MPfN project details

CRDC Agreement Code	Project Title	Research Organisation	Final reporting date	MPfN Final Evaluation stage
RRDP1712	More profit from nitrogen – Enhancing nutrient use efficiency in cotton	NSW DPI	30-Jun-21	2
RRDP1713	More Profit from Nitrogen – Optimising nitrogen and water interactions in cotton	USQ	30-Jun-18	1
RRDP1714	More Profit from Nitrogen – Increasing nitrogen use efficiency in dairy pastures	QUT	30-Nov-19	1
RRDP1715	More Profit from Nitrogen – Improving dairy farm nitrogen efficiency using advanced technologies	UoM	31-May-20	1
RRDP1716	More Profit from Nitrogen – Quantifying the whole farm systems impact of nitrogen best practice on dairy farms	UoM	30-Dec-20	1
RRDP1717	More Profit from Nitrogen – Improved nitrogen use efficiency through accounting for deep soil and mineralisable N supply, and deployment of Enhanced Efficiency Fertilisers to better match crop N demand	NSW DPI	31-May-20	1
RRDP1718	More Profit from Nitrogen – Smart blending of enhanced efficiency fertilisers to maximise sugarcane profitability	QDES	30-Apr-20	1
RRDP1719	More Profit from Nitrogen – New technologies and managements: transforming nitrogen use efficiency in cane production.	QDAF	30-Jun-21	2
RRDP1720	More Profit from Nitrogen – Optimising nutrient management for improved productivity and fruit quality in mangoes	NTDPIR	30-Jun-21	2
RRDP1721	More Profit from Nitrogen – Optimising nutrient management for improved productivity and fruit quality in cherries	TIA	30-Jun-21	2
RRDP1901	More profit from Nitrogen – Nitrogen use efficiency indicators for the Australian cotton, sugar, dairy and horticulture industries	CSIRO	30-Jun-19	Not individually evaluated

Appendix B. Key evaluation questions

Seven key evaluation questions (KEQ) were identified in the TOR (Table B1), and integrated into the project scope (Table B2).

Table B1. Key evaluation questions

Item	Key evaluation question
1	To what extent did the activities of MPfN contribute to increased understanding and knowledge of the factors which influence NUE across the four industries (both at a research and service provider/ producer level)?
2	To what extent did the activities of the Program identify new or update / validate existing NUE strategies/ technologies across the four industries (both at a research and service provider/ producer level)?
3	To what extent are key stakeholders confident that the MPfN activities have/ will over time result in greater confidence to apply NUE strategies resulting in more consistent profit and reduced environmental impact gains for primary producers of the four industries?
4	What evidence is there (anecdotal & outputs) that the research activities have effectively demonstrated opportunities for each industry to improve NUE without production loss or increased production and profit?
5	To what extent are key stakeholders confident that the MPfN planning, monitoring and reporting instruments assisted to effectively deliver upon the research, communication and extension objectives of the program?
6	What, if any, unintended outcomes (positive or negative) resulted from the MPfN (whole-of-program, research and service provider/ producer levels)?
7	What changes in implementation/processes could have improved effectiveness and/or impact?

Table B2. Alignment the KEQs to project scope

Project scope	Key evaluation question alignment						
	KEQ 1	KEQ 2	KEQ 3	KEQ 4	KEQ 5	KEQ 6	KEQ 7
Part 1. Evaluate program delivery against MPfN plans					✓		✓
Part 2. Evaluate program delivery against MPfN objectives	✓	✓		✓	✓	✓	✓
Part 3. Evaluate MPfN immediate and legacy impact	✓	✓	✓			✓	✓

Appendix C. Stakeholder consultation

The stakeholder register for the survey and interviews was confirmed with research project leads and the MPfN Science Coordinator. Table C1 shows the breakdown by stakeholder type of the 69 stakeholders engaged for the final evaluation.

Table C1. Stakeholder engagement by stakeholder type, industry, and project

Stakeholders group		Cotton		Dairy			Sugar			Mango	Cherry	All projects
		NSW DPI	USQ	QUT	UoM	UoM	NSW DPI	QDES	QDAF	NTDPIR	UTAS / TIA	
		1712	1713	1714	1715	1716	1717	1718	1719	1720	1721	
Research group	RDCs	2	2	1	1	1	2	2	2	1	1	6
	Research Project Leaders	2	1	1	1	1	1	1	1	2	1	10
	Research team	3	2	1	2	2	1	3	2	6	3	24
	Research Project Partners	1	0	0	0	0	1	4	2	0	0	7
Industry group	Industry Programs / Service Providers	3	3	2	6	6	2	1	1	1	2	12
	Producers/ Growers	2	0	1	1	0	1	2	0	1	2	10
Total stakeholders by project		13	8	6	11	10	8	13	8	11	9	69
Total stakeholders by industry		16		19			21			18		

* Note: some stakeholders were involved in multiple projects and industries, so stakeholder totals do not equal the sum of underlying stakeholders.

Appendix D. Survey and interview questions

The seven KEQs identified in the TOR were aligned to appropriate survey and interview questions based on the Mid-Term Evaluation (where appropriate, to provide consistency and continuity), as well as the Performance Indicators from the Program Logic Framework in the MEP (shown in Appendix H). Table D1 details the survey and interview questions, showing alignment the KEQs.

Not all M&E Performance Indicators were appropriate for survey and interview questions. Those Performance Indicators not directly tied to a survey and interview question instead informed a desktop review of program and project outputs. This approach ensured that all appropriate M&E Performance Indicators were addressed to understand the specifics of the research outcomes, with all information aggregating to be summarised against the KEQs.

The developed questionnaire was delivered through an online format (using Survey Monkey®). Follow up telephone interviews of approximately 30 minutes duration were undertaken with key stakeholders as appropriate for clarification or additional comment. Internal stakeholders (research staff and RDCs) received a full questionnaire across all KEQs, while external stakeholders received a reduced questionnaire excluding project planning and delivery questions (KEQ 5).

Table D1. Survey and interview questions, showing alignment the KEQs

KEQ	Q #	Question
0	1	Respondent name
0	2	Respondent role (select single most relevant):
		A) Research and Development Corporation (RDC)
		B) Research project leader
		C) Research project team member
		D) Research project partner
		E) Industry Programs/ Service Providers
0	3	F) Producer / Grower
		Related industry:
		A) Sugar
		B) Cotton
		C) Dairy
		D) Mango
0	4	E) Cherry
		Given the research project you have been involved with has now been completed, how satisfied are you with:
		(A) your specific project/activities? (rating 1=low, 5=high)
		(B) overall program progress to date? (rating 1=low, 5=high)

1	5	Overall, how much have the program/project activities contributed towards changes in knowledge and understanding of the factors which influence Nitrogen Use Efficiency (NUE) (rating 1=low, 5=high).
1	6	The following question relates to MPfN research on <i>the interplay of soil, weather, climatic and farm management factors to optimise nitrogen N formulation, rate and timing across industries, farming regions and irrigated/ non-irrigated situations (Activity B5 — optimising NUE in irrigated systems).</i> How much have the program/project activities contributed towards changes in knowledge and understanding of this area of research (rating 1=low, 5=high).
1	7	The following question relates to MPfN research on <i>the contribution (quantifying rate and timing) of mineralisation to a crop or pasture's N budget (Activity B6 — better understanding N supply through mineralisation).</i> How much have the program/project activities contributed towards changes in knowledge and understanding of this area of research (rating 1=low, 5=high).
1	8	The following question relates to MPfN research on <i>how enhanced efficiency fertiliser (EEF) formulations can better match a crop or pasture's specific N requirements (Activity B4 — extracting value from EEFs).</i> How much have the program/project activities contributed towards changes in knowledge and understanding of this area of research (rating 1=low, 5=high).
1	9	Please provide any comments regarding your answers to Qs 5–8 (MPfN contribution to changes in knowledge and understanding of NUE)
2	10	The following question relates to MPfN research on <i>the interplay of soil, weather, climatic and farm management factors to optimise nitrogen N formulation, rate and timing across industries, farming regions and irrigated/ non-irrigated situations (Activity B5 optimising NUE in irrigated systems).</i> How much have the program/project activities in the above research area contributed towards new or improved NUE resources (such as strategies, tools, and technologies) (rating 1=low, 5=high).
2	11	The following question relates to MPfN research on <i>the contribution (quantifying rate and timing) of mineralisation to a crop or pasture's N budget (Activity B6 — better understanding N supply through mineralisation).</i> How much have the program/project activities in the above research area contributed towards new or improved NUE resources (such as strategies, tools, and technologies) (rating 1=low, 5=high).
2	12	The following question relates to MPfN research on <i>how enhanced efficiency fertiliser (EEF) formulations can better match a crop or pasture's specific N requirements (Activity B4 — extracting value from EEFs).</i> How much have the program/project activities in the above research area has contributed towards new or improved NUE resources (such as strategies, tools, and technologies) (rating 1=low, 5=high).
2	13	Please provide any comments regarding your answers to Qs 10–12 (MPfN contribution to new or improved NUE resources)
3	14	To what extent do you think that the MPfN program will result in the greater producer confidence to apply the recommended NUE strategies relating to: A) Addressing significant N loss pathways for improved management of NUE on irrigated farms. B) The appropriate source, rate, timing and placement of N fertiliser. C) The potential for Enhanced Efficiency Fertilizers to better match a crops specific N requirements.

3	15	How confident are you, that adoption of the MPfN NUE strategies will result in more consistent profitability for primary producers and reduced negative environmental impact?
4	16	How would you rate the effectiveness of the following extension and external communication activities to disseminate relevant research project information? Please only rate those activities with which you were involved.
		A) Demonstrations/farm visits
		B) Field Days
		C) Workshops
		D) Conferences
		E) Industry magazine / newsletter articles
		F) Social media
		G) One on One farm visits
		H) Other, please specify.
4	17	For extension and external communication activities, please comment on what did, or did not work well and why.
4	18	Overall, how effective do you think the extension and communication activities have been at demonstrating industry opportunities for greater production and profit through increased Nitrogen Use Efficiency (NUE)?
4	19	Please provide any evidence to support your answers to question 18.
4	20	What examples can you provide where, as a result of MPfN project activities, primary producers and/or service providers are already starting to see or are on the way to seeing:
		A) Gains in profitability?
		B) Environmental impacts?
4	21	What issues / barriers have you identified that you expect will affect the speed or level of producer adoption of MPfN program outputs? And what could be done to minimise these?
5	22	Overall, how confident are you that MPfN's planning, monitoring and reporting instruments effectively support the delivery of research, communication and extension objectives?
5	23	Please provide any comments regarding your answers to question 22.
5	24	How would you rate the effectiveness of the following communication activities?
		A) Website for central sign-posting
		B) Articles in industry newsletters
		C) Information Sheet/MPfN Booklet - annual update
		D) Project Branding
		E) Templates for guidance
5	25	What issues or opportunities have arisen in your experience of MPfN to date that have impacted on the completion of activities or outputs and deliverables? (e.g. Budget/ industry issues/ resources/ research setup etc). And if relevant how have these been addressed?

5	26	How would you rate effectiveness of the following collaboration activities between MPfN program partners?
		A) Project Management Committee
		B) Annual Partner Forum
		C) Project Team Contact List
		D) Quarterly Nitrogen Natters Newsletter
		E) Webinar- N mineralisation measurement
		F) MPfN Program Booklet & Website
		G) Informal email conversations between leaders
5	27	H) Collaborations facilitated by the Science Coordinator
		While conducting your research activities, how effective have you found the support you've received from the:
		A) Science Coordinator
		B) Research and Development Corporation (RDC) Partners
5	28	C) Project Manager (CRDC)
		How satisfied are you that the MPfN communications plan, and assistance provided by the Science Coordinator, effectively supports your project/ industry to promote its research activities/ outcomes / potential benefits to producers?
6	29	What unexpected outcomes (positive or negative) are you aware of that resulted from MPfN activities (at all levels including program level, research projects, producers/service providers)? Please provide any examples.
7	30	What changes could have improved:
		A) Research and development effectiveness
		B) Extension effectiveness
		C) Adoption impact
7	31	Please make any other comments about the MPfN program

Appendix E. Document register

Table E1 provides a list of the key documents reviewed for the Final Evaluation.

Table E1. Key documents reviewed

MPfN document details
MPfN Program Management Agreement December 2016
MPfN Program Management Agreement Variation December 2017
MPfN CEP March 2017
MPfN MEP April 2017
MPfN PMP February 2017
MPfN M&E Database: 161 extension activities and outputs; 154 media communication activities and outputs; 46 project material outputs; 75 collaboration activities and outputs. As at April 2021.
MPfN Mid-Term Evaluation Survey Report August 2018
MPfN websites (CRDC, Dairy Australia, SRA, TIA, NT Gov)
MPfN Milestone Reports (x9), and supporting sub-project updates.
Nitrogen Natters quarterly newsletter (x15)
MPfN Program Booklet January 2018
MPfN Project Updates (1 per sub-project)
MPfN Final Reports (projects 1901, 1713, 1714, 1715, 1716, 1717, 1718)
MPfN Technical Reports (projects 1714, 1717)
MPfN project 1715 Mineralisation Calculator
Moody, PW, 2019, <i>Characterising the soil organic carbon and nitrogen pools and the mineralisable soil nitrogen at MPfN field trial sites</i>

Appendix F. MPfN Activities, outputs and KPIs

Table F1 shows the MPfN activities, outputs, KPIs, milestones as per the Deed of Variation (DoV) (Dec 2017) to the Commonwealth Grant Agreement (CGA), and the evaluated status of each.

Table F1. Evaluation of the MPfN activities, outputs, KPIs, milestones

Industry	Activity	Output	Output description	KPI	Milestone Due	Status
All	B1	1 (a)	Engage a project manager (Science Leader) for the duration of the Activity.	KPI 1.1 – Confirm engagement of a project manager (Science Leader)	30/11/2016	Achieved
All	B1	1 (b)	Establish a project management committee responsible for oversight of the Activity. The project management committee will agree its terms of reference which will set out its membership, governance arrangements and responsibilities.	KPI 1.2 – Provide the agreed membership, governance arrangements and terms of reference for the project management committee	30/11/2016	Achieved
All	B1	1 (c)	Execute agreements with partner organisations	KPI 1.3 – Provide a list of all partner organisations and the status of partner agreements, including the date signed or the date expected to be signed.	30/11/2016	Achieved
All	B1	1 (d)	Advise on the yearly breakdown of the cash and in-kind contributions to be provided by partner organisations for the duration of the Activity.	KPI 1.4 – Provide a list of cash and in kind contributions for each partner, for each financial year of the Activity and the total amount of funding and in kind contributions	30/11/2016	Achieved
All	B1	1 (e)	Establish appropriate industry steering / reference groups for each relevant industry.	KPI 1.5 – Provide a list of industry steering/reference groups established	30/11/2016	Achieved
All	B2	2 (a)	Prepare a project plan, setting out the schedule for activities, and the human resources and financial resources required. Prepare a risk management plan as part of the project plan.	KPI 1.7 – Provide a draft project plan.	30/11/2016	Achieved
All	B2			KPI 2.1 – Provide the project plan endorsed by the project management committee.	3/07/2017	Achieved
All	B2	2 (b)	Prepare a communication and extension plan, setting out the schedule for communication and extension activities, and the human resources and financial resources required.	KPI 2.2 – Provide the communication and extension plan.	3/07/2017	Achieved
All	B2	2 (c)	Prepare a monitoring and evaluation plan, setting out timeframes for activities to be delivered, and the human resources and financial resources required. The evaluation plan should address the Project's three key aims:	KPI 2.3 – Provide the monitoring and evaluation plan.	3/07/2017	Achieved

All	B2	2 (d)	Provide a progress report on the evaluation of the project, delivered at the mid-point of the project.	KPI 4.1 – Provide a mid-term evaluation report.	13/08/2018	Achieved
All	B2	E2	Final Report mandatory inclusions.	KPI 10.1 – Provide the final evaluation of the activity	30/09/2021	On track
All	B3	3 (a)	Identify target audiences and establish appropriate contacts with them, including peak industry bodies, growers in target regions, industry extension agents and crop consultants / agronomists.	KPI 2.4 – Provide an update on communication and extension activities	3/07/2017	Achieved
All	B3			KPI 3.1 – Provide an account of completed communication and extension activities	1/02/2018	Achieved
All	B3			KPI 4.2 – Provide an account of completed communication and extension activities	13/08/2018	Achieved
All	B3			KPI 5.1 – Provide an account of completed communication and extension activities	4/02/2019	Achieved
All	B3			KPI 6.1 – Provide an account of completed communication and extension activities	15/07/2019	Achieved
All	B3			KPI 7.1 – Provide an account of completed communication and extension activities	24/01/2020	Achieved
All	B3			KPI 8.1 – Provide an account of completed communication and extension activities	30/06/2020	Achieved
All	B3			KPI 9.1 – Provide an account of completed communication and extension activities	5/02/2021	Achieved
All	B3			KPI 10.2 – Provide a summary of completed communication and extension activities	30/09/2021	On track
All	B3			KPI 2.4 – Provide an update on communication and extension activities	3/07/2017	Achieved
All	B3	3 (b)	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.	KPI 3.1 – Provide an account of completed communication and extension activities	1/02/2018	Achieved
All	B3			KPI 4.2 – Provide an account of completed communication and extension activities	13/08/2018	Achieved
All	B3			KPI 5.1 – Provide an account of completed communication and extension activities	4/02/2019	Achieved
All	B3			KPI 6.1 – Provide an account of completed communication and extension activities	15/07/2019	Achieved
All	B3			KPI 7.1 – Provide an account of completed communication and extension activities	24/01/2020	Achieved
All	B3			KPI 8.1 – Provide an account of completed communication and extension activities	30/06/2020	Achieved
All	B3			KPI 8.1 – Provide an account of completed communication and extension activities	30/06/2020	Achieved

All	B3	3 (b) (cont...)		KPI 9.1 – Provide an account of completed communication and extension activities	5/02/2021	Achieved
All	B3			KPI 10.2 – Provide a summary of completed communication and extension activities	30/09/2021	On track
All	B3	3 (c)	Prepare articles for publication in local media outlets and/or industry-specific magazines, newsletters, journals and websites; and prepare abstracts for presentation at industry-specific conferences. Publish research findings.	KPI 2.4- Provide an update on communication and extension activities	3/07/2017	Achieved
All	B3			KPI 3.1 – Provide an account of completed communication and extension activities	1/02/2018	Achieved
All	B3			KPI 4.2 – Provide an account of completed communication and extension activities	13/08/2018	Achieved
All	B3			KPI 5.1 – Provide an account of completed communication and extension activities	4/02/2019	Achieved
All	B3			KPI 6.1 – Provide an account of completed communication and extension activities	15/07/2019	Achieved
All	B3			KPI 7.1 – Provide an account of completed communication and extension activities	24/01/2020	Achieved
All	B3			KPI 8.1 – Provide an account of completed communication and extension activities	30/06/2020	Achieved
All	B3			KPI 9.1 – Provide an account of completed communication and extension activities	5/02/2021	Achieved
All	B3			KPI 10.3 – Provide a list of prepared, submitted and published research	30/09/2021	On track
All	B3			KPI 3.1 – Provide an account of completed communication and extension activities	1/02/2018	Achieved
All	B3			KPI 4.2 – Provide an account of completed communication and extension activities	13/08/2018	Achieved
All	B3	E1 (h)	A list of all planned or completed media, communications and extension activities or materials. Where appropriate, photographs of Activity work should be provided. Imagery should be high resolution (at least 5 megapixels), along with caption and credit information.	KPI 5.1 – Provide an account of completed communication and extension activities	4/02/2019	Achieved
All	B3			KPI 6.1 – Provide an account of completed communication and extension activities	15/07/2019	Achieved
All	B3			KPI 7.1 – Provide an account of completed communication and extension activities	24/01/2020	Achieved
All	B3			KPI 8.1 – Provide an account of completed communication and extension activities	30/06/2020	Achieved
All	B3			KPI 9.1 – Provide an account of completed communication and extension activities	5/02/2021	Achieved
All	B3					

Sugar	B4	4 (a)	'Next generation fertiliser formulation': investigate sorption and desorption processes. This may include diffusion and kinetics studies relative to the rates of plant uptake and competing processes; undertaking laboratory studies on optimising inhibitor protection; and screening trials for formulations and rainfall simulation.	KPI 2.5 – Provide an update on 'Next generation fertiliser formulation' sorption and desorption process investigations.	3/07/2017	Achieved
Sugar	B4	4 (a)	'Next generation fertiliser formulation': investigate sorption and desorption processes. This may include diffusion and kinetics studies relative to the rates of plant uptake and competing processes; undertaking laboratory studies on optimising inhibitor protection; and screening trials for formulations and rainfall simulation.	KPI 2.5b – Provide an update on 'Next generation fertiliser formulation' sorption and desorption process investigations.	1/02/2018	Achieved
Sugar	B4			KPI 2.5c – Provide an update on 'Next generation fertiliser formulation' sorption and desorption process investigations.	4/02/2019	Achieved
Sugar	B4	4 (b)	'Next generation fertiliser formulation': establish small plot fertiliser and inhibitor field trials, employing valid factorial or partial factorial design.	KPI 4.3 – Provide an update on 'Next generation fertiliser formulation' fertiliser and field trials outcomes.	24/01/2020	Achieved
Sugar	B4	4 (c)	'Next generation fertiliser formulation': evaluate nutrient capture using replicated rainfall and simulation. This may include flume evaluation using a statistically valid design and enhanced filter strips studies using a statistically valid design.	KPI 4.4 – Provide an update on the evaluation of nutrient capture.	24/01/2020	Achieved
Sugar	B4	4 (d)	'Next generation fertiliser formulation': establish field trials (at least two sites) to integrate agronomic measures and key loss pathways, including identifying links to other key research teams and using mathematical modelling to tailor the fertiliser formulations to crop requirements.	KPI 6.2 – Provide an account of established 'Next generation fertiliser formulation' field trials.	30/06/2020	Achieved
Sugar	B4	4 (e)	'Next generation fertiliser formulation': construct the apparatus to manufacture formulations for field trial and estimate the cost of manufacturing the formulation.	KPI 6.3 – Provide brief commentary on the construction of a formulation manufacturing apparatus and related cost.	30/06/2020	Achieved
Sugar	B4	4 (f)	'Next generation fertiliser formulation': identify products that can decrease vulnerability to leaching, and stabilise nitrogen transformations.	KPI 8.4 – Provide a brief and final account of the identification of products that decrease vulnerability to leaching and the stabilisation of nitrogen transformations.	30/09/2021	On track
Sugar	B4	4 (g)	'Smart Blends': conduct field trials in four to five cane regions to investigate the optimum combination(s) of fertiliser blending ratio and fertiliser application rate.	KPI 2.6 – Provide an update on 'Smart Blends' experiments	3/07/2017	Achieved
Sugar	B4			KPI 4.5- Provide an update on 'Smart Blends' experiments	13/08/2018	Achieved
Sugar	B4			KPI 6.4 – Provide an update on 'Smart Blends' experiments	15/07/2019	Achieved

Sugar	B4	4 (g) (cont...)		KPI 8.5 – Provide a brief and final account of the ‘Smart Blends’ experiments.	30/06/2020	Achieved
Sugar	B4	4 (h)	‘Deep soil Nitrogen’: draft a technical report for the use of EEFs in cane at the two year growth mark; and estimates to calculate soil and fertiliser nitrogen (N) supply. Report findings and agro-economic modelling at an industry workshop.	KPI 4.6 – Provide brief commentary on the planning for a sugar industry EEFs workshop.	15/07/2019	Achieved
Sugar	B4	4 (h)	‘Deep soil Nitrogen’: draft a technical report for the use of EEFs in cane at the two year growth mark; and estimates to calculate soil and fertiliser nitrogen (N) supply. Report findings and agro-economic modelling at an industry workshop.	KPI 6.5- Provide brief commentary regarding the drafting of a technical report for the use of EEFs at the sugar industry workshop.	30/06/2020	Achieved
Horticulture	B4	4 (i)	Next generation fertiliser formulation’: conduct fertigation (irrigation by fertilisation) trials using biologicals or EEFs.	KPI 2.7 – Provide an update on the outcome of the fertigation trials.	3/07/2017	Achieved
Horticulture	B4			KPI 2.7b – Provide an update on the outcome of the fertigation trials.	13/08/2018	Achieved
Horticulture	B4	4 (j)	Conduct experiments to assess fruit quality and productivity under EEF (mangos)/biological (cherries) fertiliser treatments.	KPI 4.7 – Provide an update on the results from fruit quality and productivity experiments.	15/07/2019	Achieved
Horticulture	B4	4 (k)	Evaluate the best performing EEF (mangos)/biological fertiliser (cherries) from the experiments conducted in Output 4(j).	KPI 6.6 – Provide an update on the evaluation of best performing EEFs in mango and cherry crops.	30/06/2020	Partially achieved
Horticulture	B4			KPI 8.6 – Provide a brief and final account of the evaluation of best performing EEFs in mango and cherry crops.	30/09/2021	On track
Horticulture	B4	4 (l)	Develop recommendations for the timing, rate and placement of EEFs and any potential EEF blends to reduce nitrogen losses; and optimise Nitrogen Use Efficiency (NUE) both at a plot and farm scale level.	KPI 8.7 – Provide the department with the EEF recommendations and a brief account of optimising NUE at both plot and farm-scale level.	30/09/2021	On track
Dairy	B4	4 (m)	Test different EEF blends at two locations in NSW, (likely Casino and Camden, to: identify optimal timing of different EEF; any potential EEF blends to reduce nitrogen losses; and optimise NUE	KPI 4.8 – Provide an update on the EEF blend test outcomes in NSW	4/02/2019	Achieved
Dairy	B4			KPI 6.7 - Provide an update on the EEF blend test outcomes in NSW	24/01/2020	Achieved
Cotton	B5	5 (a)	Conduct cotton experiments on the core research site at Narrabri to investigate fertiliser by irrigation interactions.	KPI 2.8 – Provide an update on cotton experiments at the core research site, and planning for satellite sites.	3/07/2017	Achieved
Cotton	B5			KPI 4.9 – Provide an update on cotton experiments at the satellite and core research sites	13/08/2018	Achieved

Cotton	B5	5 (a) (cont...)		KPI 6.8 – Provide an update on cotton experiments at the satellite and core research sites	15/07/2019	Achieved
Cotton	B5			KPI 8.8 – Provide an update on cotton experiments at the satellite and core research sites	30/06/2020	Achieved
Cotton	B5			KPI 10.4 – Provide a complete and final account of cotton experiments at the satellite and core research sites	30/09/2021	On track
Cotton	B5	5 (b)	Conduct cotton experiments on two satellite sites, informed by findings of Output 5(a) and any	KPI 2.8 – Provide an update on cotton experiments at the core research site, and planning for satellite sites.	3/07/2017	Achieved
Cotton	B5	5 (b)	Conduct cotton experiments on two satellite sites, informed by findings of Output 5(a) and any specific local influences or factors.	KPI 4.9 – Provide an update on cotton experiments at the satellite and core research sites	13/08/2018	Achieved
Cotton	B5			KPI 6.8 – Provide an update on cotton experiments at the satellite and core research sites	15/07/2019	Achieved
Cotton	B5			KPI 8.8 – Provide an update on cotton experiments at the satellite and core research sites	30/06/2020	Achieved
Cotton	B5			KPI 10.4 – Provide a complete and final account of cotton experiments at the satellite and core research sites	30/09/2021	On track
Horticulture	B5	5 (c)	Conduct N15 research trials under irrigation in mango and cherry crops.	KPI 2.9 – Provide an update on N15 research trials and NUE in horticulture tree crops.	3/07/2017	Achieved
Horticulture	B5			KPI 2.9b – Provide an update on N15 research trials and NUE in horticulture tree crops.	13/08/2018	Achieved
Horticulture	B5			KPI 4.10 – Provide an update on N15 research trials and NUE in horticulture tree crops	15/07/2019	Achieved
Horticulture	B5			KPI 6.9 – Provide an update on N15 research trials and NUE in horticulture tree crops.	30/06/2020	Achieved
Horticulture	B5	5 (d)	Determine seasonal and inter-annual cherry and mango plant nitrogen (N) demand, quantify N losses, uptake and calculate NUE.	KPI 8.9 – Provide a brief and final account of calculating NUE for cherry and mango nitrogen use.	30/09/2021	On track
Horticulture	B5	5 (e)	Develop and test algorithms for remote sensing of leaf N content (mangos) based on the results of Outputs 5(c) and 5(d).	KPI 8.10 – Provide a brief and final account of the developed and tested algorithms for remote sensing of leaf N content.	30/09/2021	On track
Horticulture	B5	5 (f)	Develop NUE benchmarks for the horticulture industry to target.	KPI 8.11 – Provide a brief and final account of the NUE benchmarks developed for the horticulture industry.	30/09/2021	On track
Dairy	B5	5 (g)	Conduct N15, N loss and irrigation trials on irrigated dairy farms at two locations in NSW (Casino and Camden)	KPI 2.10 – Provide an update on N15, N loss and irrigation trials in NSW.	3/07/2017	Achieved
Dairy	B5			KPI 2.10b – Provide an update on N15, N loss and irrigation trials in NSW.	1/02/2018	Achieved

Dairy	B5	5 (g) (cont...)		KPI 4.11 – Provide an update on N15, N loss and irrigation trials in NSW.	4/02/2019	Achieved
Dairy	B5	5 (h)	Determine the impact irrigation management has on soil N processes and losses on dairy farming systems and calculate agronomic efficiency of N and water use.	KPI 2.10 – Provide an update on N15, N loss and irrigation trials in NSW	3/07/2017	Achieved
Dairy	B5			KPI 2.10b – Provide an update on N15, N loss and irrigation trials in NSW.	1/02/2018	Achieved
Dairy	B5			KPI 4.11 – Provide an update on N15, N loss and irrigation trials in NSW	4/02/2019	Achieved
Dairy	B5	5 (i)	Undertake whole farm systems modelling of interactions between water and N application and soil N mineralisation.	KPI 2.11 – Provide commentary on the outcomes to date of whole farm system modelling at both a systems and component level	3/07/2017	Achieved
Dairy	B5			KPI 4.12 – Provide commentary on the outcomes to date of whole farm system modelling at both a systems and component level	13/08/2018	Achieved
Dairy	B5	5 (j)	Identify best combinations of irrigation, fertiliser timing and EEF type and development of NUE Best Management Practices (BMPs) for the dairy industry. This may include integrating mineralisation algorithms into N decision tools; and modelling the practicality, cost-effectiveness and adoptability of dairy nitrogen management practices.	KPI 2.11 – Provide commentary on the outcomes to date of whole farm system modelling at both a systems and component level	3/07/2017	Achieved
Dairy	B5			KPI 4.12 – Provide commentary on the outcomes to date of whole farm system modelling at both a systems and component level	13/08/2018	Achieved
Dairy	B5			KPI 4.13 – Provide commentary on the development of Best Management Practices for the dairy industry and the outcome of sharing these findings at workshops and field days.	4/02/2019	Achieved
Dairy	B5			KPI 6.10 – Provide commentary on the development of Best Management Practices for the dairy industry and the outcome of sharing these findings at field days.	24/01/2020	Achieved
Dairy	B5	5 (k)	Conduct field days at each trial site for dairy farmers demonstrating project findings	KPI 4.13 – Provide commentary on the development of Best Management Practices for the dairy industry and the outcome of sharing these findings at workshops and field days.	4/02/2019	Achieved
Dairy	B5			KPI 6.10 – Provide commentary on the development of Best Management Practices for the dairy industry and the outcome of sharing these findings at field days	24/01/2020	Achieved
Cotton	B6	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.	1/02/2018	Achieved

Cotton	B6	6 (a) (cont...)		KPI 5.2 – Provide an update on cotton field mineralisation experiments in Queensland.	4/02/2019	Achieved
Cotton	B6	6 (b)	Investigate the potential impact of long-term phosphorous (P) decline and/or stratification on the nitrogen cycle in cotton farming systems.	KPI 3.3 – Provide an update on investigations into the potential impact of long-term P decline and/or stratification on the nitrogen cycle in cotton farming systems.	1/02/2018	Achieved
Cotton	B6			KPI 5.3 – Provide an update on investigations into the potential impact of long-term P decline and/or stratification on the nitrogen cycle in cotton farming systems.	4/02/2019	Achieved
Cotton	B6	6 (b)	Investigate the potential impact of long-term phosphorous (P) decline and/or stratification on the nitrogen cycle in cotton farming systems.	KPI 7.2 – Provide an update on investigations into the long-term P decline and/or stratification on the nitrogen cycle in cotton farming systems.	24/01/2020	Achieved
Cotton	B6			KPI 8.12 – Provide an update on investigations into the potential impact of long-term P decline and/or stratification on the nitrogen cycle in cotton farming systems.	30/06/2020	Achieved
Cotton	B6			KPI 10.5 – Provide a brief and final account of the investigations into the potential impact of long-term P decline and/or stratification on the nitrogen cycle in cotton farming systems.	30/09/2021	On track
Horticulture	B6	6 (c)	Quantify the timing and amount of N released in tree crop residues.	KPI 3.4 – Provide an update on the investigations to quantify the timing and amount released in mango crop residues.	13/08/2018	Achieved
Horticulture	B6			KPI 5.4 – Provide an update on the investigations to quantify the timing and amount of N released in tree crop residues.	15/07/2019	Achieved
Horticulture	B6			KPI 7.3 – Provide an update on the investigations to quantify the timing and amount of N released in tree crop residues.	30/06/2020	Achieved
Horticulture	B6			KPI 8.13- Provide a brief and final account of the investigations to quantify the timing and amount of N released in mango crop residues.	30/09/2021	On track
Horticulture	B6	6 (d)	Quantify the N mineralisation from soil organic matter (SOM) in key cherry and mango soils.	KPI 8.14 – Provide a brief and final account of quantifying N mineralisation from soil organic matter.	30/09/2021	On track

Sugar	B6	6 (e)	'Deep soil N': conduct sampling and analysis of up to 30 cane paddocks in Queensland and NSW to determine deep soil N content / mineralisable N (supply of N by soil).	KPI 3.5 – Provide an update on 'Deep soil N' experiments.	13/08/2018	Achieved
Sugar	B6	6 (f)	'Deep soil N': conduct incubations to estimate mineralisable N in the same locations as outlined in Output 6(e).	KPI 3.5 – Provide an update on 'Deep soil N' experiments.	13/08/2018	Achieved
Sugar	B6			KPI 5.5 – Provide an update on 'Deep soil N' experiments.	15/07/2019	Achieved
Sugar	B6	6 (g)	'Deep soil N': conduct experiments on three field trial sites (including micro-plots) in Northern NSW cane sites for N fertiliser rates response investigations. Data to be collected includes crop yield, crop biomass/N15 uptake and leaching levels.	KPI 3.5 – Provide an update on 'Deep soil N' experiments.	13/08/2018	Achieved
Sugar	B6			KPI 5.5 – Provide an update on 'Deep soil N' experiments.	15/07/2019	Achieved
Sugar	B6	6 (g)	'Deep soil N': conduct experiments on three field trial sites (including micro-plots) in Northern NSW cane sites for N fertiliser rates response investigations. Data to be collected includes crop yield, crop biomass/N15 uptake and leaching levels.	KPI 7.4 – Provide a brief and final account of the 'Deep soil N' experiments and the definition of N response curves for farm scale N stocks.	5/02/2021	Achieved
Sugar	B6	6 (h)	'Deep soil N': define N response curves for farm-scale N stocks (mineralisable and deep soil N) for cane at two year growth mark; develop equations for mineralisable N against Near Infra Red/Mid Infra Red methodologies; and develop a standard operating practice for commercial application.	KPI 5.5 – Provide an update on 'Deep soil N' experiments.	15/07/2019	Achieved
Sugar	B6			KPI 7.4 – Provide a brief and final account of the 'Deep soil N' experiments and the definition of N response curves for farm scale N stocks.	5/02/2021	Achieved
Dairy	B6	6 (i)	Identify, establish and monitor zero N and N15 plots for apparent and total N recoveries in irrigated dairy systems at two locations in NSW (Casino and Camden)	KPI 3.6 – Provide an update on the N experiments on irrigated dairy farms in NSW.	13/08/2018	Achieved
Dairy	B6			KPI 5.6 – Provide an update on the N experiments on irrigated dairy farms in NSW.	15/07/2019	Achieved
Dairy	B6	6 (j)	Establish technical reference groups and hold field days, workshops and knowledge exchange for the dairy industry including one workshop to refine a N mineralisation RD&E program.	KPI 1.6 – Provide brief commentary on dairy workshop and knowledge exchange preparations	30/11/2016	Achieved
Dairy	B6			KPI 3.7 – Provide brief commentary on the planning for the technical reference groups, field days and workshops	13/08/2018	Achieved
Dairy	B6			KPI 5.10 – Provide an update on the development of the mineralisation calculator, the workshop to refine the mineralisation RD&E program and the planning for a dairy workshop to demonstrate the mineralisation calculator.	15/07/2019	Achieved
Dairy	B6			KPI 5.7 – Provide brief commentary on technical reference groups established, field days held and the outcomes of the dairy knowledge exchange workshops held.	15/07/2019	Achieved

Dairy	B6	6 (j) (cont...)		KPI 7.5 – Provide brief and final commentary on the technical reference groups established, field days held and the outcome of the dairy knowledge exchange workshops.	24/01/2020	Achieved
Dairy	B6	6 (k)	Conduct field trials to determine N dynamics rain-fed and irrigated dairy systems in south west Victoria; and to predict N cycling and losses. This includes isolation of key drivers of mineralisation and testing mineralisation prediction mechanisms once sufficient data is generated.	KPI 3.8 – Provide an update on the N experiments on irrigated and rain-fed dairy farms in south west Victoria	13/08/2018	Achieved
Dairy	B6			KPI 5.8 – Provide an update on the N experiments on irrigated and rain-fed dairy farms in south west Victoria	15/07/2019	Achieved
Dairy	B6			KPI 7.6 – Provide a brief and final account on the N experiments on irrigated and rain-fed dairy farms in south west Victoria.	24/01/2020	Achieved
Dairy	B6	6 (l)	Conduct laboratory studies on nitrogen and nitrous oxide emissions to inform field findings from Output 6(k).	KPI 3.8 – Provide an update on the N experiments on irrigated and rain-fed dairy farms in south west Victoria	13/08/2018	Achieved
Dairy	B6	6 (l)	Conduct laboratory studies on nitrogen and nitrous oxide emissions to inform field findings from Output 6(k).	KPI 5.9 – Provide brief commentary on laboratory study outcomes.	15/07/2019	Achieved
Dairy	B6	6 (m)	Develop a mineralisation calculator and convene a workshop for dairy farmers demonstrating the findings and the mineralisation calculator.	KPI 5.10 – Provide an update on the development of the mineralisation calculator, the workshop to refine the mineralisation RD&E program and the planning for a dairy workshop to demonstrate the mineralisation calculator.	15/07/2019	Achieved
Dairy	B6			KPI 7.7 – Provide brief and final commentary on the development of the mineralisation calculator and the dairy workshop held to demonstrate it.	24/01/2020	Achieved

Appendix G. Evaluation of delivery against MPfN Communication and Extension Plan tools

Appendix G details the evaluation of delivery against individual tools within the MPfN Communication and Extension Plan (CEP). An evaluation was undertaken for each of the planned internal (Table G1) and external (Table G2) communication and extension tools.

Delivery of the planned communication and extension tools have been evaluated based off a combination of document review (were the communication and extension tools delivered as identified) and stakeholder engagement (did stakeholders view the tools as effective). The tools have been evaluated based on a three colour system with green reflecting strong performance, yellow showing moderate performance, and red showing weak performance.

Table G1. MPfN Communication and Extension Plan — evaluation of internal tools

Communication tool	Purpose	Planned Audience	Planned Frequency	Evaluation (colour) and comment
Program Management Committee (PMC)	Oversee implementation and monitoring of the communication & extension plan.	Sector partners	At least twice annually at PMC meetings. Each year: Q2 & Q4	• 9 PMC meetings held to date.
	Information exchange on strategic communication strategies and adherence with Commonwealth Grant Agreement requirements.	Research partners		
Science Coordinator	Establish an appreciation and understanding between partners of the cross-sector and cross-project sharing and learning conduits offered by the project with an aim to increase Program efficiencies, reduce duplication of effort and create new opportunities for the current and future collaborative projects.	Sector partners	Ongoing	• Internal stakeholders rated the science coordinator as highly effective in supporting internal collaboration and communication activities between MPfN program partners (average rating 4.3, n=23).
		Research partners		
		Project collaborators		
Program partner forums	Provide forum for updates on Program progress and delivery and opportunity for representatives from sector partners, research partners and project collaborators to raise strategic issues for the PMC to consider and Science Coordinator to action.	Sector partners	Annually Approximate: December 2016 August 2017 September 2018 July 2019 December 2019	• Partner Forums held in 2017, 2018, 2019, and 2020 (online due to COVID disruption), and 1 partner forum planned after this report (2021).
	Provide a platform for robust partner and cross sector exchange of information. The opportunity to discuss, share and debate allows research partners to identify synergies between partner activities, resulting in reduced duplication and improved Program outcomes which have multi sector relevance.	Research partners		
		Project collaborators		

Research project steering committees	Provide guidance, input and feedback to specific research projects, including communication and extension activities. Note: Not all research projects have committed to forming steering committees.	Research lead agency representatives	As specified in research partner communication & extension plan tables (Appendix C of CEP)	• Held for QUT, UTAS/TIA, QDES, NSW DPI.
		Project Collaborators		
		Farm advisors		
		Industry program extension representatives		
		Farmer/ industry group representatives		
Dairy Industry Forums	Knowledge exchange for the dairy industry and technical reference group for N mineralisation RD&E projects.	Dairy Australia	Annual	• Multiple annual dairy industry collaborations in the development of industry resources.
		Dairy research partner teams		
Program partner e-newsletter	Technical knowledge exchange between the extended research project teams and progress updates. To be coordinated and prepared by the Science Coordinator. Hosted on CRDC MPfN Program webpage. Contributions to be made from all research partners and project contributions on project progressive findings and activities, including sharing tips and recommendations.	Sector partners	Quarterly Each year: March June September December	• 15 Nitrogen Natters e-newsletters completed (100% of planned).
		Research partners & research peers		
		Project collaborators		
Partner webinars/ professional development	General and specific technical knowledge exchange/ development platform for the 10 project research teams. These sessions are aimed at highlighting one or two of the projects in-depth and also inviting external researchers/ experts to upskill the researchers on identified emerging methodology or findings of aligned research (both national & international).	Industry extension program staff	Quarterly Each year as identified & assisted by the research partners.	• Two online workshops held but in discussion with project leaders it was decided there were insufficient topics that covered the interest of all teams at that frequency. Professional development was incorporate into annual forums instead, which included guest speakers/ skills development sessions.
		Sector partners		
Email	The main vehicle for notifications and requests for information amongst Program stakeholders. An email tree approach has been agreed whereby the Science Coordinator will email sector & research partner primary contacts only, for further distribution to the research teams/ research collaborators as deemed appropriate.	Research partners	Ongoing	• Internal stakeholders rated internal email use as a highly effective means of collaboration (average rating 3.9, n=22).
		Appendix A- Notification Distribution List.		
Workshops	Certain research projects will be conducting professional development training on specific modelling tools and calculators for extension to their relevant industries. These workshops will also be open to researchers from MPfN Program sectors so that the technology and extension learnings can be shared and potentially transferred to other sectors.	Sector partners Research partner teams Project collaborator teams Industry extension program staff	Primarily annually As scheduled by RP (Appendix C of CEP)	• 60 industry workshops held (273% of planned) across all industries.

Table G2. MPfN Communication and Extension Plan — evaluation of external tools

Tool	Purpose	Audience	Frequency	
Science Coordinator	Responsibility for communicating and extending the technical research and production/profit/ environmental advancements being investigated and achieved through the collaborative approach of the MPfN Program.	All audiences identified as external in Table 1.	Ongoing via presentations, meeting attendance, field day attendance, conference proceedings.	Internal stakeholders were highly satisfied that the CEP, and assistance provided by the Science Coordinator, effectively supported the projects / industries to promote research outcomes to producers (average rating 4.2, n=30).
	Responsibility for communicating and extending the plain English intra and inter sector learning and practice outcomes of the MPfN Program to producers and service providers. These will be focused upon optimising NUE through:			
	o Efficient irrigation practices;			
	o Managing N fertiliser vs mineralisation;			
	o EEFs;			
	o Developing new products and optimising existing products; and			
Website Pages	1) A simple MPfN Program page will be established on the existing CRDC website to provide a centralised portal for Program information and sign-posting for project specific information.	- External agencies and commercial companies - Media outlets - Potential Program collaborators - Industry specific stakeholders - Industry specific farmers & service providers - Potential research project collaborators - Industry extension staff	Project Duration Live Website Page- May 2017 Live partner webpages- July 2017	- MPfN Program webpage established as planned. - MPfN sector partner organisation webpages established as planned. 29 website content activities reported across all industries as part of media communications. - Final website update being undertaken with final project outputs and updates.
	2) Each of the sector partner organisations will be encouraged to host a dedicated web page on their relevant industry website (See Appendix A) for the research projects of their sector. These may include:			
Industry Extension Programs	- Integration of research findings and outcomes into new and existing industry best practice NUE & WUE materials, resources and programs. - Extension of key production, profitability and environmental benefit messages associated with adoption of NUE practices, including use of developed tools and resources.	- Industry extension staff - Industry specific farmers & service providers - Nutrient and irrigation advisors.	Resources updated upon release of research outcomes As scheduled by RP (Appendix A of CEP) to deliver upon MPfN Program Outputs.	New or updated industry resources for all industries (see Resource Materials / Tools on p5 of Annex G).

Social Media	Many project partners have existing Facebook, Twitter and Instagram pages which will be utilised to promote Program & project achievements, research findings, updates, activities, forums and meetings and share relevant links to websites. Utilising existing accounts, by providing content to project partner communications teams, ensures that existing audiences already engaged with those pages are communicated with effectively. Dedicated MPfN Program accounts would not have the content volume required to satisfy followers (at least 4 updates weekly). In addition, other industry networks such as farmers groups and commercial companies also have existing pages for which content could be prepared.	Existing and new partner social media followers	Ongoing Social media availability stocktake- April 2017 Social media protocols agreed & approved- June 2017 Ongoing content preparation	• 15 communication and extension activities identified as specifically social media (all videos with distribution across Facebook, twitter, Instagram, and YouTube). However, it is noted that many other communications activities would likely include a social media aspect, including through industry social media external to the MPfN program with reduced oversight or ability to track.
Industry Circulars (magazines, e-newsletters, newsletters, email campaigns)	Existing key industry communication channels will be used to engage industry audiences in the progress and findings of individual projects, overall MPfN Program progress and achievements and key NUE practice change messages.	Sector communication & media teams	Quarterly presence in at least 2 circulars for each industry (32)	• 78 industry circulars to date (244% of planned).
	Articles will be prepared by sector & research partner communication teams (project specific) and by the Science Coordinator (MPfN Program). Emails may be compiled for distribution to distribute information on key events.	Industry extension staff	Events promoted as planned	
		Industry specific farmers & service providers	Publications: Quarterly Magazines Fortnightly e-newsletters Preparation of material will coincide with publication dates with an aim to present MPfN Program information for each industry 8 times per year (32 total). As scheduled by RP (Appendix C of CEP)	
		Nutrient and irrigation advisors (private & commercial) Private farm business consultants		

Media Releases	MPfN Program research project achievements, outcomes and implications for agricultural production, environmental impact and community benefits.	General media outlets- food & fibre markets (television news, print, radio)	Program achievements- 4 annually	• 7 General media communications across all industries (44% of planned) including 6 agriculture specific media (75% of planned). • 19 media and communication activities providing updates on research activity achievements (95% of planned media on project progress findings).
	Promotion of cross sector advantages of participating in a collaborative Program, including translatable/ transferable outcomes to reduce duplication of effort across industries.	Agricultural specific media outlets (television news, print, radio)	Program findings/ outcomes- 2018 x 3, 2019 x 3, 2020 x 2	
	Releases will feature quotes from partners, investors, service providers and farmers as appropriate to the topic. Will include photo, video footage and interview opportunities.	Sector communication & media teams	Project progress & findings- two per research project annually (20)	
	Releases will be prepared in collaboration with Sector & research partner communication and media teams as applicable.	Research organisation communication & media teams	Promotion & coverage of Program/ project events- annually	
	Partner spokespersons will be briefed on communication protocol requirements should an “on the spot” interview be requested.		Project overview and awareness raising, April 2017 Monthly commencing April 2017 For partner: As per event requirements	
Program Booklet	Provide an overview of the MPfN Program goals, participating partners/ collaborators and insight into the aims, methodology and contacts of the 10 research projects. This high level publication is designed to stimulate audience interest in engaging further in the Program/ project activities. The Program Booklet provides flexibility for the partners in that it can be presented as a collective publication or can be segregated into individual project research pages. The Program Booklet is designed to be downloadable from websites or printed in hand-out format for use at communication and extension events.	All media outlets	Prepared 2017 & updated annually Program Booklet ready for distribution 10th February 2017. Annual update undertaken January	• Prepared in January 2017, updated January 2018. Not subsequently updated as it was identified that this was not a key resources for stakeholders, and updates would be more effective at the project level.
		Researchers		
		Service Providers		
		Industry extension staff		
		Nutrient and irrigation advisors (private & commercial)		
		Farmers		

Communication Templates	Create an identifiable image for the MPfN Program and develop an easy to use method for preparing/ presenting event flyers and press releases for the partners of the Program.	Research Partners	Ongoing- per event/ press release	• Communication templates provided for researchers and research partners.
	The MPfN Program templates will provide a format in which the MPfN “brand” and Commonwealth acknowledgement obligations are ready installed within the document. The partners will be required to infill the relevant promotional/ communication text and logos only.	Event audiences & media outlets		
Resource material/ tools	All research projects will either prepare new resource material for industry extension programs or contribute to updating or amending current resources.	Service Providers	At least one resource material/ tool prepared for industry extension per research project (10) As scheduled by RP (Appendix C of CEP)	• Industry resources delivered to date and ongoing for 8 research projects: – Cotton (1712) Cotton Production Manual update. – Dairy (All) Fert\$mart Nitrogen Guidelines and NUE Pocket Guide. – Dairy (1716) industry Mineralisation Calculator. – Sugarcane (1717) Six Easy Steps N budgeting model – Sugarcane (1718) Smart Blending booklet. – Mango (1720) BMPs – Cherry (1721) Recommended practice factsheet • No industry resources identified for project(s): – Cotton (1713) – Sugarcane (1719)
	Resources are designed to enhance the confidence of farmers to adopt best practices for NUE by providing science based facts & evidence, advising on practice options for their farm and promoting the business performance benefits in changing current practice.	Nutrient and irrigation advisors (private & commercial)		
	Resources will be prepared in collaboration with industry extension programs. Distribution will be through existing Industry extension program channels- websites, processors, farm visits, events	Farmer Groups		
		Individual Farmers		
Field Days/ Walks/ Workshops	MPfN Program activities and outcomes, including the benefits for the relevant industry of participating in cross sector collaborations.	Farmers	As specified in the KPIs of individual research projects.	• 34 field days / walks held across all industries (179% of planned). • 60 workshops held to date across all industries (273% of planned). • 13 Farmer discussion groups held across all industries (186% of planned). • 5 industry training events held across all industries (500% of planned).
	Farmer & service provider participatory learning, input and feedback opportunities into individual research trials or development of tools.	Nutrient and irrigation advisors (private & commercial).	Each project will use key milestones within research activities to engage with potential adopters to seek input and feedback.	

Field Days/ Walks/ Workshops (continued)	Demonstration to trial outcomes in real life scenarios.	Private farm business consultants	2019/2020 emphasis will be on advocating benefits of adopting research outcomes.	(See above)
	Communication of research findings and resultant recommendations for optimal N fertiliser formulations, timing, placement and rates, including associated irrigation management.	Service Providers	As scheduled by RP (Appendix C of CEP)	
	Skill development in use of decision support tools (ie. mineralisation calculator), BMP guidelines and industry benchmarks.	Industry extension staff		
Technical Forums	Conduit for open discussion on specific technical knowledge/ resource gaps and industry needs relating to particular areas of NUE or associated support topics ie. modelling, EEFs, sensor technologies.	Sector partners	As need is identified- potential for 1 annually As scheduled by RP (Appendix C of CEP) or as deemed beneficial to the program outputs by PMC.	The PMC decided to incorporate technical forums into annual Partner Forums, which included attendance by Fertiliser Australia and other industry stakeholders.
	Research partners have identified that the MPfN Program may provide the conduit required to bring together key stakeholders on particular areas of technical need/ investigation, including potential investors.	Research partners		
		Project Collaborators		
		Service Providers		
		Advisors		
		Public/ private technology developers		
Videos/ Case Studies	Communication of need for research into NUE and overview/ progress of research project methodology and hypothesis.	Farmers	Per research project: - 1 project overview video. - 1 video/ printable farm case study - Research project overviews by Dec 2017 - One Collaboration Case Study per year - 1 Case Study per RP by December 2019	1 project overview video completed as planned. 9 video case studies completed across sugar, dairy, cotton, cherries. 13 intra-industry collaborative economic case studies completed (4 for dairy, 2 each for other industry groups), and an additional case study on long term economic impacts. - Final videos being developed for each project as of June 2021.
	Extension of key production, profitability and environmental benefit messages associated with adoption of NUE practices, including use of technology and resources developed by the MPfN Program.	Nutrient and irrigation advisors (private & commercial).		
	Resources will be prepared in collaboration with industry extension programs and farmers hosting trial sites. Distribution will be through existing Industry extension program websites.	Private farm business consultants		
		Service Providers		

Research interim & final technical reports	Communication of research progress and findings of a technical nature.	Full Reports:	As per contracted KPIs as scheduled by CEP (Appendix C of CEP)	• Final and technical reports submitted and accepted to date: – Cotton (1713) – Dairy (1714) – Dairy (1715) – Dairy (1716) – Sugarcane (1717) – Sugarcane (1718) – All industries (1901) • Final and technical reports ongoing: – Cotton (1712) – Sugarcane (1719) – Cherry (1721) – Mango (1720)
	Distribution methodology will be decided with sector and research partners on a report by report basis. Report plain English summaries may be provided for broader distribution through industry networks.	Sector partners Research partners Researchers Project Collaborators Summaries: Service Providers Advisors Public/ private technology developers Early adopting farmers		
Conferences	Promotion of MPfN Program activities and outcomes, especially the benefits of cross sector collaboration effort via proceedings, presentation and posters.	Australian Government	Emphasis in 2018-2020	• 33 conferences held across all industries (194% of planned).
		National and international researchers	MPfN Program- 2018 x 2, 2019 x 2, 2020 x 2	
	Communication on project research findings and outcomes via proceedings, presentation and posters.	Industry program developers/ funders	As specified in research partner communication & extension plan tables (Appendix C of CEP)	
	Demonstration of new technologies and decision support tools via proceedings, presentation and posters.	Commercial product/ service developers	As deemed beneficial to the Program outputs.	
Science Journals	Publication of peer reviewed research findings	Early farm adopters/ innovators		• 31 Scientific papers / journal articles identified across all industries (148% of planned).
		Australian Government	Emphasis 2019-2020	
		National and international researchers	As specified in research partner communication & extension plan tables (Appendix C of CEP)	
		Program developers/ funders	As scheduled by RP (Appendix C of CEP)	
		Public/ private technology developers		

Appendix H. MPfN MEP Performance Indicators

Table H1 shows the MPfN Program M&E performance indicators as per the M&E Logical Framework (table 2.4 of the MEP).

Performance indicators have been evaluated based off a combination of document review and stakeholder engagement (quantitative and qualitative responses). The performance indicators have been evaluated based on a three-colour system with green reflecting strong performance, yellow showing moderate performance, and red showing weak performance.

Table H1. Evaluation of the delivery of activities and outputs against the MPfN MEP Performance indicators

Initiation Activities (Project Management & Planning): Underpinning structures and process to guide and support activities and outputs — What will be managed and how?			
Program Evaluation Level	Research Project Detail	Performance indicator	Evaluation (colour) and Comment
Delivered activities of B1 & Activity B2 of the Commonwealth Grant Agreement	Execution of research partner contracting.	Contracting process undertaken. Signing of the Program Management Agreement (PMA) by all parties and completion of individual contracts with satisfactory Full Research Proposals (FRPs).	- Contracting completed as required under DoV outputs 1(c). - Cotton and sugarcane stakeholders commented on delays and conflicting organisational timelines causing difficulty during sub-project contracting (5 comments).
	Engagement of Science Coordinator	Recruitment process undertaken to select a suitably qualified and experienced person.	- Contracting completed as required under DoV output 1 (a). - Stakeholders rated the Science Coordinator as highly effective (average rating 4.7, n=26)
	Establishment of Project Governance (PMC). Representatives from the research partners & sectors. Two meetings annually.	Representation and conduct of PMC: meetings held and topics and decisions made; reaction by participants to meetings and evidence of influence and actions taken by members as a result of participation.	- PMC established as required under DoV output 1 (c) - PMC members rated the PMC as highly effective (average rating 3.9, n=23)
	Adoption and execution of the MPfN Program Management Plan (PMP) by PMC.	Effectiveness of PMP as the primary tool for implementing the Program and execution of timely activities to deliver Outputs in accordance with the Commonwealth Grant Agreement. Effectiveness of PMP to monitor research partner progress and achieve KPIs within milestone dates.	131/132 (99%) of KPIs achieved or on track. 1/132 (1%) KPIs partially achieved.

Delivered activities of B1 & Activity B2 of the Commonwealth Grant Agreement	Adoption and execution of the MPfN Communications & Extension Plan (CEP)	Effectiveness of CEP as the primary tool for executing Program communications and extension activities in accordance with conditions outlined in the Commonwealth Grant Agreement.	Internal stakeholder rated the CEP, and support provided by the Science Coordinator, as highly effective in supporting the promotion of research activities & outcomes (average rating 4.2, n=30)
		Effectiveness of CEP in engaging key stakeholders in the Program's activities to increase adoption of NUE best practices.	External stakeholders rated the extension and external communication activities as moderately effective at demonstrating industry opportunities for greater production and profit through increased NUE (average rating 3.6, n=19)
	Adoption and execution of the MPfN Monitoring and Evaluation Plan (MEP)	Effectiveness of the MEP in assisting the Program to monitor research partner KPI and Output obligations.	Stakeholders rated planning, monitoring, and reporting instruments as highly effective to support delivery of the MPfN objectives (average rating 4.2, n=34).
		Effectiveness of the MEP as a tool of the PMC in assessing progress towards final Program outcomes throughout project implementation.	
	Use and updating of an on-line M&E Data-base portal to engage with the project stakeholders and publish update and results from research work.	The details of the M&E Data-base (content, user-friendliness), access, downloads and other use statistics; feedback from users in usefulness and actions taken as a result of information gained.	- Stakeholders commented that the M&E database was a useful reporting tool for the program. - The Final Evaluation found the database fields did not directly align to planned outputs making assessment of plans difficult.

Program Materials (Products): Research and stakeholder adoption — What will the project produce?

Program Evaluation Level	Research Project Detail	Performance indicator	Evaluation (colour) and Comment
Developed resources relating to the Outputs listed under Activity B4- B6 of Commonwealth Grant Agreement.	Fertiliser formulations/ smart blends identified and tested under a combination of commercial farm management practices & site conditions.	Effectiveness of specific fertiliser formulations/ smart blends in reducing losses and maintaining or increasing production under particular field conditions.	21/22 (95%) of KPIs relating to fertiliser formulations / smart blends (activity B4) achieved. 1/22 KPIs partially achieved.
	Fertiliser formulations/ smart blends identified and tested under a combination of farm management practices & site conditions.	Cost effectiveness of EEFs under a range of management scenarios determined and extent to which findings are extended to producer programs/groups through resource materials & activities.	Producers and industry programs/service providers rated the MPfN research activities as moderate for their contribution towards changes in knowledge and resources relating EEF products & blends under a range of soil, climatic and system conditions (average rating 3.5, n=14)

Developed resources relating to the Outputs listed under Activity B4- B6 of Commonwealth Grant Agreement.	Decisions Support Tools to account for soil N mineralisation developed, trialled and extended.	Extent of change in confidence of advisors and producers to attend demonstration activities and likelihood of using developed NUE DSS when making N fertiliser decisions.	Producers and industry programs/service providers rated MPfN research activities as strong for their contribution to new or improved resources relating to soil mineralisation and N budgeting (average rating 3.7, n=15)
	Industry Extension Materials prepared and extended through existing industry programs.	Extent to which advisors and producers attend input/ feedback activities and access resultant extension materials from websites.	3085 farmers and 2998 service providers attended extension activities.
	NUE benchmarks developed for horticulture (Mango & Cherry).	Evidence that benchmarks / guidelines have been determined and are underpinned by research findings	NUE benchmarks and guidelines on track for development for both mango and cherries.
	NUE Best Practices determined and/ or validated, and integrated into existing industry programs.	Adoption of NUE recommendations by industry BMP Programs- Fert\$mart (dairy), Six Easy Steps (6ES) (Sugar) and CottonInfo (Cotton) resources.	- New or updated industry resources delivered to date or ongoing for 8 research projects across all industries: - Included in 2021 Cotton Production Manual update. - Included in updated Dairy Fert\$mart Nitrogen Guidelines and NUE Pocket Guide. - Made available to sugarcane Six Easy Steps N budgeting model and Smart Blending booklet ongoing. - Developed first Northern mango N BMPs. - Developed cherry N recommendations. - Overall, stakeholders rated the MPfN as moderate for contributing to new or updated industry resources.
	Reports prepared on research findings and extended to science audiences.	Number of peer reviewed research reports prepared as a result of the MPfN Program.	- Final and technical reports submitted and accepted to date: - Cotton (1713) - Dairy (1714) - Dairy (1715) - Dairy (1716) - Sugarcane (1717) - Sugarcane (1718) - All industries (1901) - Final and technical reports ongoing: - Cotton (1712) - Sugarcane (1719) - Cherry (1721) - Mango (1720)
	Journal articles on research findings prepared and peer reviewed.	Number of articles peer reviewed and published in science journals.	31 Scientific papers / journal articles identified across all industries (148% of planned).

Program Activities: *Research and stakeholder engagement outputs — What will the project deliver?*

Program Evaluation Level	Research Project Detail	Performance indicator	Evaluation (colour) and Comment
Delivered research activities of the Outputs listed under Activity B4- B6 of Commonwealth Grant Agreement.	- Field based trials established and operating at the identified locations. Investigations being conducted to monitor/measure, interpret/analyse, compare and evaluate against research hypothesis. - Laboratory based research established and operating to analyse field samples and validate field work. Water simulation, farm modelling and mathematical modelling research conducted to replicate field conditions/ management, determine effectiveness of potential practice options and inform decision support tools. - Industry Workshops/ field days conducted to seek input into research and to extend progressive research findings.	Extent to which the six research projects of Activity B4 deliver upon contracted Outputs: Sugar 4(a) to 4 (h), Horticulture 4 (i) to 4 (l) & Dairy 4 (m).	21/22 outputs achieved or on track for B4, 1/22 activities partially achieved.
		Extent to which the seven research projects of Activity B5 deliver upon contracted Outputs: Cotton 5(a) to 5 (b), Horticulture 5 (c) to 5 (f) & Dairy 5 (g) to 5 (k).	All activity B5 outputs achieved or on track.
		Extent to which the seven research projects of Activity B6 deliver upon contracted Outputs: Cotton 6(a) to 6 (b), Horticulture 6 (c) to 6 (d), Sugar 6 (e) to 6 (h) & Dairy 6 (i) to 6 (m).	All activity B6 outputs achieved or on track.
	Collaboration taking place	Extent to which field trials provide a certain level of relevance to local producers and service providers resulting in ongoing engagement during project duration and generation of greater NUE understanding.	Producers and industry programs / service providers rated demonstrations, farm visits, field days, and workshops as moderately effective to disseminate relevant information (average rating 3.6, n=17).
		Extent to which producers and service providers are increasing their knowledge on N dynamics under varying climatic/ management conditions and understand what this means to their farm business.	Producers and industry programs / service providers rated the MPfN program as having moderately contributed to increased knowledge and understanding of the interplay of N dynamics under varying climatic/ conditions and what this means to a farm business (3.5, n=15)
		Evidence that opportunities are provided for planned cross-sector collaboration on methodology approaches, shared information on progressive and final findings as well as key learnings. These opportunities are resulting in greater knowledge and understanding amongst the research partners/ collaborators.	75 collaboration activities registered in the MPfN database across all industries. - Stakeholders rated the MPfN's overall collaboration activities as highly effective (average rating 4.0, n=33). 23 stakeholders (33%) commented positively on the MPfN collaboration activities in enhancing their research and extension

Delivered research activities of the Outputs listed under Activity B4- B6 of Commonwealth Grant Agreement.	Collaboration taking place	The details of partner forums (location, topics, process), extent of representation of targeted stakeholders, stakeholder reactions, input received and actions taken as a result.	• Partner Forums held in 2017, 2018, 2019, and 2020 (online due to COVID disruption), and 1 partner forum planned after this report (2021). • Stakeholders rated the annual partner forums highly as an internal communication method that supported internal collaboration (average rating 4.5, n=28).
		Documented outcomes of both formal and informal collaborations taken place between research partners, project collaborators and further external stakeholders as a result of MPfN Program activities.	• Stakeholders rated the MPfN's overall collaboration activities as highly effective (average rating 4.0, n=33). • 23 stakeholders (33%) commented positively on the MPfN collaboration activities in enhancing their research and extension.
	Mid-term evaluation report	Evidence that the MPfN Program is progressing towards greater knowledge and understanding in relation to the three Intermediate Outcomes: • What knowledge and understanding gains have been made at this point? • What have been the enabling activities to stimulate greater knowledge and understanding? • Are there signs that greater knowledge and understanding will lead to adoption of future recommendations? • What are the current indications that there are profitability and production gains to be made from increased NUE?	• Delivered as planned.
	Deliver Outputs of Activity B3: Program Communications conducted in accordance with the MPfN Communications and Extension Plan (CEP).	Extent to which the Science Coordinator/ Program Manager meet requirements of Outputs 3 (a) to 3 (c).	• All activity B3 outputs achieved or on track (Appendix F).
		Extent to which the Science Coordinator appropriately organises research/ sector partner communication activities and delivers upon the requirements of the actions and schedule of Section 9 "Program Implementation Plan" of the CEP.	• Delivery of 20/24 tools (83%) of the CEP <i>Program implementation Plan</i> assessed as strong (Appendix G) • Internal stakeholder rated the CEP, and support provided by the Science Coordinator, as highly effective in supporting the promotion of research activities & outcomes (average rating 4.2, n=30)
		Extent to which planned communications have been undertaken; extent of reach to targeted stakeholders; level of awareness and interest in contents; actions taken as a result of communication activities including access and use of resource and engagement in project activities.	• Stakeholders rated the MPfN extension and communication activities as moderately effective at demonstrating industry opportunities for greater production, profit, or improved environmental outcomes through increased NUE (average rating 3.6, n=61).

Intermediate outcomes: Achievable within the life of the project—What will result from the project activities?

Program Evaluation Level	Research Project Detail	Performance indicator	Evaluation (colour) and Comment
Activity B4- A greater knowledge and understanding of how enhanced efficiency fertiliser (EEF) formulations can better match a crop or pasture's specific N requirements.	Question: What are the most suitable fertiliser product types or blends for a producer's individual circumstances?	Extent to which there is greater knowledge/ understanding of EEF products/ blends which result in increased NUE under a range of soil, climatic and system conditions across the four sectors.	- Stakeholders rated the MPfN highly for contributing to knowledge and understanding of EEF products/ blends (average rating 3.9, n=51). - Stakeholders rated the MPfN moderately for contributing to new or improved resources (such as strategies, tools, and technologies) relating to EEF products/ blends (average rating 3.5, n=46).
	Question: What is the cost effectiveness of Enhanced Efficiency Fertilisers, under a range of soil and climatic conditions, and product blends?	Extent to which knowledge/ understanding of the profitability and production benefits of EEF product/ blend use has been determined and extended across the four sectors.	
		Extent to which research has demonstrated increased knowledge/ understanding of how EEF use can reduce N loss from the farm system without impact to product yield or quality.	
	Question: Can better EEFs be developed that release nitrogen based on the demands of the crop?	Extent to which the potential for new EEF formulations and combinations of existing EEFs to better match nitrogen crop demand has been determined.	
	Question: Can polymer and / or sorber technology be used to improve the ability of vegetative buffer strips to remove nutrients and sediment from farm water run-off?	Extent to which the research demonstrates future potential for new EEF technology to reduce N loss from the farm system through simulation and modelling techniques.	
Activity B5- A greater knowledge and understanding of the interplay of factors to optimise nitrogen (N) formulation, rate and timing across industries, farming regions and irrigated/ non-irrigated situations.	Question: How can N be managed most effectively to make the most of available water and soil-N, to maximise productivity and quality, minimise losses to the environment and provide economic benefits to the producer?	Extent to which knowledge/ understanding of total losses of N from certain farming systems has increased.	Stakeholders rated the MPfN highly for contributing to increased knowledge and understanding relating to the interplay of factors to optimise NUE in irrigated systems (average rating 4.0, n=54).

Activity B5- A greater knowledge and understanding of the interplay of factors to optimise nitrogen (N) formulation, rate and timing across industries, farming regions and irrigated/ non-irrigated situations	Question: How can nitrogen and irrigation management be modified to minimise nitrogen losses and maintain or improve productivity?	Extent to which significant N loss pathways are understood and have resulted in targeted recommendations for improved management of NUE on irrigated farms.	- Stakeholders rated the MPfN highly for generating new or improved resources for understanding and managing the interplay of factors to optimise NUE in irrigated systems (average rating 3.7, n=50). - Stakeholders who have adopted or observed adoption of recommendations in irrigation systems had a high level of confidence that the MPfN NUE strategies will result in more consistent profitability and reduced negative environmental impact (average rating 4.2, n=10).
	Question: How effective are current BMPs for nitrogen management in improving nitrogen use efficiency, productivity, profitability and environmental impact on farm?	Extent to which profitability and production outcome knowledge/ understanding has increased on adopting identified practice modifications in N and irrigation management across the four sectors.	- New or updated industry resources delivered to date or ongoing across all industries. - Overall, stakeholders rated the MPfN as moderate for contributing to new or updated industry resources (average rating 3.6, n=60).
		Extent to which research has resulted in changed BMP recommendations or the preparation of new guidelines/ benchmarks for industry.	Stakeholders rated the MPfN extension and communication activities as moderately effective at demonstrating industry opportunities for greater production, profit, or improved environmental outcomes through increased NUE (average rating 3.6, n=61).
Activity B6- A greater knowledge and understanding of the contribution (quantifying rate and timing) of mineralisation to a crop or pasture's nitrogen budget	Questions: Can MIR/NIR be used to predict soil mineralisable N and how effective is it compared to current 'soil C' based methods for estimating N mineralisation index for soils?	Extent to which the effectiveness of MIR/NIR has been explored against other methods to predict soil mineralisable N.	- NSWDPI (sugar) reported that standard methodology of measuring potentially mineralizable N (PMN) across 7-300 days were correlated to laboratory MIR. MIR calibrations showed promise in the measurement of both short and long-term soil mineralisable N stocks. The cheap and rapid NIR test was under discussion with a commercial analytical provider as at Feb 2021, and further negotiation with the sugar industry and the 6ES will occur. - No other sub-projects reported researching the potential for MIR/NIR as a predictor of soil mineralisable N.
	Question: What tools can producers use to access better information regarding N dynamics and seasonal availability to inform their decisions for a better economic outcome?	Extent to which developed tools/ resources provide increased knowledge/ understanding for producers (and services providers) to make more informed decisions in source, rate, timing and placement of N fertiliser.	Producers and service providers rated the MPfN highly for contributing to increased knowledge and new or improved resources relating to N mineralisation (average rating 3.7, n=17).

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