Rural R&D for Profit Program

More Profit from Nitrogen

RRDP1716 (July 2016 – November 2020)

Quantifying the whole farm systems impact of nitrogen best practice on dairy farms

Final Report

30 November 2020

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Project team details

Provide details of all personnel involved in the project.

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

Contents

Plain English Executive Summary

Standard nitrogen (N) fertiliser best management practice (BMP) guidelines were first developed in 1996, then updated again in 2001 based on outcomes of the project "Best management practices for N in intensive dairy production systems (Project no DAV413)". While most of these BMPs were based on well-established local and international research, they had not been evaluated across the range of soil types, climates, farm systems and forage types in the Australian dairy industry.

This project aimed to use whole farm systems modelling to test if the current best practices for N management on dairy farms improve productivity and limit environmental impacts across a wide range of bioclimates, soils and common pasture species used in the grazing based dairy industries of southern Australia.

Objectives

- To quantify current recommended best practices for N management on dairy farms, through farm systems modelling, providing farmers and industry with confidence to improve productivity and limit potential environmental impacts.
- To identify limitations in the models used and propose improvements to these models.
- To further develop modelling capability and capacity as part of a succession plan for farm systems modelling in the dairy industry.

Methods

The project used the DairyMod whole farm systems model to evaluate a range of rate, source, timing and formulations of N fertiliser, over an 18 to 20 year period in each case, across multiple sites from northern NSW through to Tasmania and South Australia.

Outcomes

Overall, the project team conducted 13 separate modelling studies, evaluating current BMPs for improving N fertiliser use efficiency in dairy pasture systems in south eastern Australia. These studies have been written up in 6 peer reviewed journal papers, with a further 4 papers in preparation, 1 Masters thesis, 8 conference papers, 3 popular articles and 2 guidelines for farmers and their advisers.

The existing BMPs for N fertiliser use on dairy pastures were largely validated as being widely applicable and appropriate. However, this study demonstrated the benefits of developing site and seasonal-specific N fertiliser BMPs guidelines that are both economical and environmentally beneficial. There were also instances identified where these BMPs could be further refined.

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. These BMPs were published in a Guidelines and Pocket Guide format, plus four case studies using data from the MPfN dairy projects. We recommend the promotion and adoption of these guidelines to the dairy industry.

Benefits of the research for industry

The dairy industry can have confidence in promoting these BMPs to farmers and farm advisors as the best approach to maximising productivity while minimising environmental losses. Likewise this gives farmers confidence in applying the BMPs on farm. The updated guidelines and case studies are now hosted on the Dairying for Tomorrow web site and will continue to be promoted by Dairy Australia, through their regional coordinators, through the FertCare network and by farm consultants.

Key recommendations for the industry

The Dairy Australia continue to promote the Fert$mart BMPs for N fertiliser use on dairy pastures, through hosting the guidelines on the Dairying for Tomorrow web site, but also promoting these to the industry through the Regional Coordinator networks, through FERTCARE and other networks.

That Dairy Australia consider their commitment to the future of DairyMod, a model built largely through investment by Dairy Australia. This model has proven valuable for numerous projects well beyond the current project, but would now be considered outdated, no longer maintained and soon to be redundant.

Conclusions

The updated BMPs for N fertiliser use on dairy pastures are now well validated for use across the southern Australian grazing-based dairy industry and can be promoted to dairy farmer and the advisory sector.

Further research is still needed on understanding the interplay between fertiliser additions and soil N mineralisation, as the evidence suggests that apply N fertiliser may be essential to prime N mineralisation. This could mean that the N being taken up by the plant may be from soil organic matter, but may only be released if N fertiliser was applied. These mechanisms require further understanding to enable our models to capture these effects.

Further research is also needed to fully understand the interactions between rainfall, stored soil moisture and plant N response. This may help develop predictive tools for farmers to better use data from the Bureau of Meteorology, together with soil moisture sensor data, to predict the likely response to N fertiliser, particularly at the autumn break and at the end of the winter rainfall season. This information could be captured in a Rapid Climate Decisions Framework being developed in a related project, Forewarned is Forearmed.

The project highlighted that, while BMPs can minimise N losses from N fertiliser, the largest input of N into dairy farm systems is from urine, which is largely a function of stocking rate. Further research is required to understand options to manage the total N loading on dairy farms and the consequent catchment scale implications for the dairy industry. This could link with an extensive research programme in New Zealand – the Low N Livestock program.

The last major update to the DairyMod model was in 2016, with a minor update in 2018. this project found a number of aspects in the model that need updating to match the new research and our associated understanding of processes. The software is also now outdated. As DairyMod was largely funded by and for the benefit of the Dairy industry, through funding from Dairy

Australia, the future of the model should be decided through consultation with the model custodians, as there is a risk the model becomes redundant and the investment no longer serves the industry.

Funding Acknowledgements

More Profit from Nitrogen: enhancing the nutrient use efficiency of intensive cropping and pasture systems was supported by funding from the Australian Government Department of Agriculture, Water and Environment and as part of its Rural R&D for Profit program, Dairy Australia, the Tasmanian Institute of Agriculture and the University of Melbourne.

Abbreviations and glossary

Provide a list of abbreviations and description of key words if used frequently throughout the report.

APSIM - The Agricultural Production Systems sIMulator, is an internationally recognised platform for modelling and simulation of agricultural systems.

BMP(s) = Best Management Practice(s)

DairyMod - a multi-paddock, biophysical simulation model developed for Australian grazing-based dairy systems.

DayCent - a daily time series biogeochemical model used in agroecosystems to simulates fluxes of carbon and nitrogen between the atmosphere, vegetation, and soil. It is a daily version of the CENTURY biogeochemical model.

N = Nitrogen

N_2O = nitrous oxide

NO_3 = Nitrate

NH_3 = Ammonia

NH_4 = Ammonium

TIA = Tasmanian Institute of Agriculture

UoM = University of Melbourne

1 Project rationale

Standard nitrogen (N) fertiliser best practice (BMP) guidelines were first developed in 1996, then updated in 2001 based on outcomes of the project "Best management practices for N in intensive dairy production systems (Project no DAV413)". More recently these BMPs where updated as part of the Fert$mart 'Dairy soils and Fertiliser manual', providing the industry with an agreed and consolidated list of recommended best practices.

While most of these BMPs are based on well-established local and international research, they had not been evaluated across the range of soil types, climates, farm systems and forage types in the Australian dairy industry. Modelling is well placed to confirm the efficacy of each of these BMPs, across the range of soils, climates and pasture types typical in the dairy industry, while also quantifying the likely benefit productivity and environmental benefits from adopting each practice.

It is well established, that N losses rise exponentially as N inputs approach diminishing returns, meaning that N losses from these high input dairy systems could already be well above international benchmarks of acceptable environmental impact. This is a large risk to the dairy industry given the clear trend towards greater N inputs with further intensification.

The key question posed by this project was to use whole farm systems modelling to test if the current best practices for N management on dairy farms improve productivity and limit potential environmental impacts across a wide range of bioclimates, soils and common pasture species used in the grazing based dairy industries of southern Australia.

This project therefore provides the industry with evaluated BMPs to demonstrate self-regulation and improvements in sustainability reporting.

2 Method and project locations

The project used the DairyMod whole farm systems model to evaluate a range of rate, source, timing and formulations of N fertiliser, over an 18 to 20 year period in each case, across multiple sites from northern NSW through to Tasmania and South Australia. These studies and the specific methodology of each are detailed further in the Technical Report.

Overall, the project team conducted 13 separate modelling studies, evaluating current BMPs for improving N fertiliser use efficiency in dairy pasture systems in south eastern Australia. The specific sites modelled are listed Table 1 and the specific methodology for each modelling study is detailed in the publications based on each study (see References and Technical Report). Note that some sites (e.g. Ellinbank, Taree etc) have been used in multiply modelling studies so these sites are listed with two active site periods.

Table 1. Location and details of each site included in the More Profit from Nitrogen, DairyMod modelling simulations

Research Site Type	Name	Location	Coordinates	Active Site Period	Experimental treatments
Modelling	TIA, Dairy Research Centre	Elliott, TAS	41.08° S, 145.78° E	1997-2017 1999-2019	Modelling studies comparing a range of N rate and N timing over 20 years.
Modelling	Ellinbank Dairy Research Farm	Ellinbank, VIC	38.24° S, 145.94° E	1997-2017 1999-2019	Modelling studies comparing a range of N rate and N timing over 20 years.
Modelling	Commercial Farm	Mt Gambier, SA	37.90° S, 140.79° E	1997-2017	Modelling studies comparing a range of N rate and N timing over 20 years.
Modelling	Commercial Farm	Taree, NSW	31.92° S, 152.56° E	1997-2017 1999-2019	Modelling studies comparing a range of N rate and N timing over 20 years.

Research Site Type	Name	Location	Coordinates	Active Site Period	Experimental treatments
Modelling	Demo Dairy Demonstration Farm	Terang, VIC	38.24° S, 142.92° E	1997-2017	Modelling studies comparing a range of N rate and N timing over 20 years.
Modelling	Commercial Farm	Casino, NSW	28.81° S, 152.98° E	1999-2019 2000-2017	Modelling studies comparing a range of N rate and N timing over 20 years, including benefits of nitrification inhibitors. Modelling seasonal soil N mineralisation using three models.
Modelling	Elizabeth Macarthur Agricultural Institute	Camden, NSW	34.12° S, 150.71° E	1999-2019	Modelling studies comparing a range of N rate and N timing over 20 years. Modelling seasonal soil N mineralisation using three models.
Modelling	Commercial Farm	Mepunga West, Vic	38.25° S, 142.38° E	1999-2019 2000-2017	Modelling studies comparing a range of N rate and N timing over 20 years, including benefits of nitrification inhibitors.
Modelling	Wye	South Australia	38°01′ S, 140°55′ E	Au: 1-26/5 2014; Sp: 30/9-27/10 2014	Modelling studies at 50 kg N-urea/ha on Perennial ryegrass.

Research Site Type	Name	Location	Coordinates	Active Site Period	Experimental treatments
Modelling	Murroon	Western VIC	38°26′ S, 143°47′ E	Au: 12/4-10/5 2010; Sp: 27/9-21/10 2010	Modelling studies on Perennial ryegrass at 40 kg N-urea/ha.
Modelling	Kyabram	Northern VIC	36°20′ S, 145°04′ E	Au: 29/3-6/4 2004	Modelling studies on Paspalum, perennial ryegrass, white clover at 50 kg N-urea/ha.
Modelling	Tamworth	Northern NSW	31°16’ S, 150°97’ E	Wi: 1/6-21/6 2011	Modelling studies on Rhodes grass at 100 kg N-urea/ha.
Modelling	Gatton	Southern QLD	27.54° S, 152.34° E	Su: 23/11-12/12 2013	Modelling studies on Queensland bluegrass at 50 kg N-urea/ha.
Modelling	Samford	Southern QLD	27°22′ S, 152°53′ E	Su: 21/2-8/3 1978 Au: 24/5-21/7 1978 Wi: 21/8-19/10 1978	Modelling studies on *Setaria sphacelate* cv. Nandi at 94 kg N-urea/ha.
Modelling	Milla Millaa	Northern QLD	17°32′ S, 145°38′ E	Sp: 9/9-24/9 1993	Modelling studies on *Setaria sphacelate* cv. Nandi at 115 kg N-urea/ha.
Modelling	Hamilton	Western VIC	37.7° S, 142.0° E	1998-2018	Modelling perennial ryegrass, Phalaris and subclover at 100 kg N/ha in Aug or Dec.
Modelling	Vasse	Southern WA	33.7° S, 115.3° E	2000-2019	Modelling two varying feedbases; low N fertiliser and maize silage

Research Site Type	Name	Location	Coordinates	Active Site Period	Experimental treatments
					vs high N fertiliser and grass silage.
Modelling	Myponga	Southern SA	35.5° S, 138.5° E	2000-2019	Modelling two varying feedbases; low N fertiliser and maize silage vs high N fertiliser and grass silage.
Modelling	Maffra	Eastern VIC	38.0° S, 146.9° E	2000-2019	Modelling two varying feedbases; low N fertiliser and maize silage vs high N fertiliser and grass silage.
Modelling	Montague	North-western TAS	40.8° S, 144.9° E	2000-2019	Modelling two varying feedbases; low N fertiliser and maize silage vs high N fertiliser and grass silage.
Modelling	Deloraine	Central TAS	41.5° S, 146.6° E	2000-2019	Modelling two varying feedbases; low N fertiliser and maize silage vs high N fertiliser and grass silage.
Modelling	Scottsdale	North-eastern TAS	41.1° S, 147.5° E	2000-2019	Modelling two varying feedbases; low N fertiliser and maize silage vs high N fertiliser and grass silage.
Modelling	Bega	Southern NSW	36.7° S, 149.8° E	2000-2019	Modelling two varying feedbases; low N fertiliser and maize silage vs high N fertiliser and grass silage.
Modelling	Bellingen	Northern NSW	30.5° S, 152.8° E	2000-2019	Modelling two varying feedbases; low N fertiliser and maize silage

Research Site Type	Name	Location	Coordinates	Active Site Period	Experimental treatments
					vs high N fertiliser and grass silage.
Modelling	Gympie	Southern QLD	26.2° S, 152.6° E	2000-2019	Modelling two varying feedbases; low N fertiliser and maize silage vs high N fertiliser and grass silage.
Modelling	Malanda	Northern QLD	17.5° S, 145.6° E	2000-2019	Modelling two varying feedbases; low N fertiliser and maize silage vs high N fertiliser and grass silage.
Modelling	Noorat	SW VIC	38.2° S, 143.0° E	2000-2019	Modelling seasonal soil N mineralisation using three models.

3 Project Outcomes

The key findings from the project are that:

- 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 that 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 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-NH_3) 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 NO_3, NH_4, 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 N_2O 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.

Recommendations

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 in a Guidelines and Pocket Guide format.

We recommend that Dairy Australia continue to promote the Fert$mart BMPs for N fertiliser use on dairy pastures, through hosting the guidelines on the Dairying for Tomorrow web site, but also promoting these to the industry through the Regional Coordinator networks, through FERTCARE and other networks.

The publications are as follows:

- Dairy Australia (2020) FERT$MART NITROGEN - POCKET GUIDE. Prepared by Karen Christie, Graeme Ward, Richard Eckard, Helen Suter, David Rowlings, Cath Lescun for the More Profit from Nitrogen Program. ISBN 978-1-925347-87-6
- Dairy Australia (2020) FERT$MART NITROGEN GUIDELINES. Prepared by Karen Christie, Graeme Ward, Richard Eckard, Helen Suter, David Rowlings, Cath Lescun for the More Profit from Nitrogen Program. ISBN 978-1-925347-83-8 (Print), ISBN 978-1-925347-82-1 (Digital/PDF).
- Dairy Australia (2020) Improving dairy farm nitrogen use efficiency, using soil moisture monitoring. Economic Case Study Allansford (Victoria). Dairy Australia Limited.
- Dairy Australia (2020) Quantifying the whole farm systems impact of nitrogen. Best practice on an irrigated dairy farm. Economic Case Study - Elliot (Tasmania). Dairy Australia Limited
- Dairy Australia (2020) Quantifying the whole farm systems impact of nitrogen. Best practice on an irrigated dairy farm. Economic case study Taree (New South Wales). Dairy Australia Limited
- Dairy Australia (2020) Quantifying the whole farm systems impact of nitrogen. Best practice on a rainfed dairy farm. Economic case study Terang (Victoria). Dairy Australia Limited

We recommend that Dairy Australia consider their commitment to the future of DairyMod, a model built largely through investment by Dairy Australia. This model has proven valuable for numerous projects well beyond the current project, but would now be considered outdated, no longer maintained and soon to be redundant.

3.1 Project level achievements

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

KPI no. and description	**KPI Due Date**	**Relevant CRDC FRP Milestone Number/s.**	**Summary of final outcome of the reserarch concluded by this KPI**
KPI 2.12 – Provide commentary on the outcomes to date of whole farm system modelling at both a systems and component level	July 2017	1.1 1.2	☒ Achieved ☐ Partially achieved ☐ Not achieved • Dr Andrew Smith and Dr Karen Christie were employed by the project as the key modellers. • A modelling workshop was held jointly with DairyNZ on the 27th and 28th February 2018. • First N modelling workshop held on 4th and 5th May 2017. • A project website was established on both www.piccc.org.au/MPfN and www.dairyingfortomorrow.com.au/tackling-specific-issues/soils/more-profit-from-nitrogen-dairy/ • Articles were published in the Gippsdairy How Now Gippy Cow magazine, delivered to all dairy farmers in Gippsland. Loaded onto the MPfN database. • Two journal papers and a MODSIM conference paper were submitted for publication.
KPI 3.10 – Provide commentary on the outcomes of whole farm system modelling (Output 5(i)).	February 2018	1.2	☒ Achieved ☐ Partially achieved ☐ Not achieved • A second N modelling workshop was conducted in collaboration with Dairy NZ, held in Christchurch, NZ on 27th and 28th February 2018. • A further two modelling studies were identified and commenced.

KPI 4.12 and 4.13 - Provide commentary on the outcomes to date of whole farm system modelling at both a systems and component level for the dairy industry and sharing these findings at planned dairy workshops and field days.	August 2018	2.1 3.1	☒ Achieved ☐ Partially achieved ☐ Not achieved • The dairy industry BMP listing from Fert$mart was updated to reflect the new data from the modelling, particularly autumn N management. This revised list was circulated to all delegates attending the Allansford field day and the new findings presented at the event. • Findings to date were presented at 3 field days and 2 workshops. • The project team competed 5 modelling studies, focused on combinations of N fertiliser rate, N timing and strategies, N by irrigation interaction - Output 5 (j). • The studies were written up in 5 peer reviewed journal papers and 8 conference papers, including reporting on the practicality, cost-effectiveness and adoptability. • The key findings from the modelling were incorporated into a draft update of the N BMPs published in the Australian Dairy Farmer magazine and How Now Gippy Cow. • The team completed a comprehensive review of N mineralisation, which will inform incorporating N mineralisation into algorithms for future N decision tools - Output 5 (i).
KPI 6.9 and 6.10 – Provide commentary on the development of BMPs for the dairy industry and the outcome of sharing these findings at workshops and field days (Outputs 5(j) and 5(k)).	30 November 2019	4.1	☒ Achieved ☐ Partially achieved ☐ Not achieved • The project team competed 13 modelling studies in total, evaluating current BMPs for improving N fertiliser use efficiency in dairy pasture systems in south eastern Australia. • These studies have been written up in 10 peer reviewed journal papers to date, 8 conference papers and 3 articles in publications for farmers. • The MPfN Dairy projects team, in collaboration with Dairy Australia, produced a practical, farmer friendly 'Fert$mart N Pocket Guide' and a detailed fact sheet for the Dairy Australia website. The project team contributed to 4 economic case studies published by Dairy Australia. These publications have been communicated directly to industry via a series of Webinars hosted by Dairy Australia, the MPfN and Hunter LLS NSW. This addresses the KPI 6.10 – Provide commentary on the development of BMPs for the dairy industry and the outcome of sharing these findings at workshops and field days (incorporating Outputs 5(j) and 5(k)). • The project results and BMPs for N fertiliser use on dairy have been updated, based on the modelling to date, and have now been presented to dairy farmers and farm advisers through field days, presentations, webinars and a number of industry training events, as listed in Sections 7 and 9. This addresses the KPI 6.9 and 6.10 –

			Provide commentary on the development of BMPs for the dairy industry and the outcome of sharing these findings at workshops and field days (incorporating Outputs 5(j) and 5(k)). • The studies have modelled the rate, source, timing, placement and formulations across a range of sites in south eastern Australia, addressing Output 5(j) – Identify best combinations of irrigation, fertiliser timing and EEF type and development of NUE BMPs for the dairy industry. These studies and their status are detailed in the Technical report with publications listed in Section 7. • The team value-added to the research through hosting a number of students and post-doctoral fellows. ○ A masters student from Wageningen University - Esmee de Loof. ○ A Horizon 2020 Marie Curie post-doctoral fellowship in partnership with Bangor University, Dr Karina Marsen for 2 years. ○ A CLIFFS/GRAD PhD student from Brazil, Camila Dos Santos.

3.2 Contribution to MPfN program objectives

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

- The project has greatly enhanced the dairy industries knowledge on the use of N fertiliser for improved profitability while reducing N losses to the environment.
- The whole farm systems modelling approach was able to analyse the rate, timing and formulation of N fertiliser across the varying soils, pasture types, climates and regions, under irrigated and dryland systems, capturing this knowledge in updated BMPs for the dairy industry.
- Due to the DairyMod model being a whole farm systems modelling approach, this research captured the interplay between a broad range of climatic, edaphic and management influences.
- The modelling project also improved our knowledge of the interplay between N fertiliser use an maximising mineralisation of soil N towards the overall pasture budget.
- The improved BMPs have been promoted to the dairy industry and published in updated guidelines, the adoption of which will lead to improved profitability enhanced N use efficiency and greater sustainable use of N fertiliser.

3.3 Demonstrable more profit from nitrogen

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

- The project has captured all the new knowledge in updated BMPs for the dairy industry. These publications are listed in section 7.3.
- The research results were used in 4 case studies that demonstrated the potential productivity and profitability of adopting these BMPs.
    - Dairy Australia (2020) Improving dairy farm N use efficiency, using soil moisture monitoring. Economic Case Study Allansford (Victoria). Dairy Australia Limited
    - Dairy Australia (2020) Quantifying the whole farm systems impact of nitrogen. Best practice on an irrigated dairy farm. Economic Case Study - Elliot (Tasmania). Dairy Australia Limited
    - Dairy Australia (2020) Quantifying the whole farm systems impact of nitrogen. Best practice on an irrigated dairy farm. Economic case study Taree (New South Wales). Dairy Australia Limited
    - Dairy Australia (2020) Quantifying the whole farm systems impact of nitrogen. Best practice on a rainfed dairy farm. Economic case study Terang (Victoria). Dairy Australia Limited

4 Collaboration

As a result of this project, the team were able to attract a masters student, a post-doctoral fellow and an exchange student internationally.

- A masters student from Wageningen University 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 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 post-doctoral fellowship was secured in partnership with Prof David Chadwick, Bangor University. Dr Karina Marsen joined the project team for 2019 and 2020 and will return to the UK in November 2020. Karina was able to value-add to all 3 dairy projects under MPfN, 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 we have already submitted a UK Research Innovation, Future Leader Fellowships proposal to continue the collaboration with Dr Marsden and Prof Chadwick.
- As a result of the Marie Curie Fellowship, we 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.

5 Extension and adoption activities

5.1 Extension of the research to the end-user

- The BMPs for N fertiliser use on dairy pastures were updated based on the new knowledge generated by this project, together with research from the parallel MPfN dairy projects (Led by Dr Helen Suter and Dr David Rowlings).
- These BMPs were published in a Guidelines and Pocket Guide format, together with 4 economic case studies.
- The project results and BMPs for N fertiliser use on dairy have been updated, based on the modelling to date, and have now been presented to dairy farmers and farm advisers through field days, presentations, webinars and a number of industry training events, as listed in Section 7 and the appendices.
- The BMPs will be hosted and promoted by Dairy Australia, as part of the Fert$mart program, leading to on-going and increased adoption over time.

5.2 Recommendations to industry on adoption of the research outcomes.

- Dairy Australia will continue to promote the updated BMPs as part of the Fert$mart program, leading to on-going and increased adoption over time. “Fert$mart” is the dairy industry’s central repository of soil and fertiliser knowledge and best practice information and is held and maintained by Dairy Australia. The manual can be accessed on the “Dairying for Tomorrow” website. Similarly, “Fert$mart” farmer courses run by the Regional Development Programs of Dairy Australia will be an important vehicle in extending the results and recommendations to the farmer level.
- These updated guidelines were developed in consultation with the national FERTCARE team who have also recognised these and will continue to promote these as part of their FERTCARE accreditation training.
- The research has been promoted to Dairy Australia’s regional coordinators, who will continue to promote the BMPs on-going.
- The 2 Guidelines documents and 4 case studies are hosted on the “Dairying for Tomorrow” website (www.fertsmart.dairyingfortomorrow.com.au/).

6 Lessons learnt

6.1 Research level

- 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 an unachievable with the resources available.
- The research was able to generate 10 peer reviewed papers within a 3 year project, which would be almost impossible with field-based research.
- The on-going maintenance and support of these models should be a priority for the dairy industry, as they are able to address a far wider spectrum of questions for the industry at a component through to farm system and catchment scale. It was noted that the DairyMod model has not been maintained since 2016 and is at risk of redundancy.

6.2 Industry level

- The project was able to evaluate the current BMP's for N fertiliser use on dairy pastures, demonstrating that these are effective at improving efficiency while minimising environmental impacts. This is an important message for the industry as a whole in demonstrating efficient use of fertilisers and demonstrating best practise for managing environmental impacts.

6.3 Service Provider/ Primary Producer Level

With the whole farm systems modelling was able to demonstrate applicability of the Fert$mart BMP's across a wide range of climatic, edaphic and management conditions, thus providing confidence to service providers to promote these to primary producers.

7 Appendix - additional project information

7.1 Project material and intellectual property

7.1.1 Journal Papers published

Christie, K. M., Smith, A. P., Rawnsley, R. P., Harrison, M. T., & Eckard, R. J. (2018). Simulated seasonal responses of grazed dairy pastures to nitrogen fertiliser in SE Australia: Pasture production. *Agricultural Systems* **166**, 36-47. doi: https://doi.org/10.1016/j.agsy.2018.07.010

Christie, KM, Smith, AP, Rawnsley, RP, Harrison, MT, Eckard, RJ (2020) Simulated seasonal responses of grazed dairy pastures to nitrogen fertiliser in SE Australia: N loss and recovery. *Agricultural Systems* **182**, 102847. https://doi.org/10.1016/j.agsy.2020.102847

Rawnsley R. P., Smith A. P., Christie K. M., Harrison M. T., Eckard R. J. (2019) Current and future direction of nitrogen fertiliser use in Australian grazing systems. *Crop and Pasture Science* **70**, 1034-1043. https://doi.org/10.1071/CP18566

Smith, AP, Beale, P, Fulkerson, BJ, Eckard, RJ (2019) Managing the nitrogen status of subtropical dairy pastures for production, efficiency and profit. *Agricultural Systems* **176**, 102677. https://doi.org/10.1016/j.agsy.2019.102677

Smith, A. P., Christie, K. M., Rawnsley, R. P., & Eckard, R. J. (2018). Fertiliser strategies for improving nitrogen use efficiency in grazed dairy pastures. *Agricultural Systems*, **165**, 274-282. doi: https://doi.org/10.1016/j.agsy.2018.06.017

Smith, AP, Johnson, IR, Schwenke, G, Lam, SK, Suter, HC, Eckard, RJ (2020) Predicting ammonia volatilization from fertilized pastures used for grazing. *Agricultural and Forest Meteorology* **287**, 107952. https://doi.org/10.1016/j.agrformet.2020.107952

7.1.2 Journal Papers in preparation and review

Bilotto F., Harrison M.T., De Antoni Migliorati M., Christie K.M., Rowlings D., Grace P., Smith A., Rawnsley R.P., Thorburn P., Eckard R.J. (2020) Modelling soil nitrogen with APSIM, DairyMod and DayCent: can seasonal N mineralisation trends be leveraged to enhance pasture growth? *Science of the Total Environment* (in review).

Marsden K.A., Ward G., Martin B., Jones D.L., Gleeson D., Suter H.C., He J., Eckard R.J., Chadwick D.R. (2020) Nitrous oxide emissions and N cycling functional gene abundance in dairy pasture soils with contrasting degrees of impact by livestock. *Paper in preparation.*

Marsden K.A., Ward G., Jones D.L., Suter H.C., He J., Eckard R.J., Chadwick D.R. (2020) Targeting farm scale features for nitrification inhibitor application: an effective N_2O mitigation strategy? *Paper in preparation.*

Smith A. P., Christie K.M., Harrison M.T., Eckard R.J. (2020) Ammonia volatilisation from grazed, pasture based dairy farming systems. *Agricultural Systems* (in review)

7.1.3 MSc Thesis

de Looff E. (2019) A model to predict the effect of excess dietary nitrogen on milk production and its implications for reducing nitrogen inputs on pasture-based dairy farms. March 5, 2019. Supervisors: C. van Middelaar, R. Eckard, A. Smith. MSc Thesis], Animal Production Systems group, Wageningen University. APS-80436

7.1.4 Conference Papers

Christie, K., Rawnsley, R., Eckard R. (2018) Modelling nitrogen fertiliser by irrigation interaction for southern Australian dairy farms. *Australasian Dairy Science Symposium*, November 2018, Palmerston North, New Zealand.

Christie, K.M., Rawnsley, R.P., Smith, A.P., Eckard, R.J. (2017) Simulated seasonal nitrogen fertiliser responses for diverse dairy regions of Australia. In: Syme, G., Hatton MacDonald, D., Fulton, B. and Piantadosi, J. (eds) MODSIM2017, 22nd International Congress on Modelling and Simulation. Modelling and Simulation Society of Australia and New Zealand, December 2017, p 60. ISBN: 978-0-9872143-7-9. https://www.mssanz.org.au/modsim2017/documents/MODSIM2017_book_abstracts.pdf

Harrison M., De Antoni M., Eckard R. (2019) Soil nitrogen: can pasture yields be increased by capitalising on seasonal trends in mineralisation and immobilisation? 19th Australian Agronomy Conference, 25-29 August 2019. Wagga Wagga. http://agronomyaustraliaproceedings.org/images/sampledata/2019/2019ASA_Harrison_Matthew_316.pdf

Harrison M.T., Rawnsley R.P., Eckard R.J. (2018) Modelling nitrogen mineralisation in pasture-based systems: a comparison of three agro-ecosystem models. Australasian Dairy Science Symposium, November 2018, Palmerston North, New Zealand. https://static.sched.com/hosted_files/adss2018/82/87691.pdf

Harrison, M.T., Christie, K.M., Smith, A.P., Rawnsley R.P., Eckard, R.J. (2018). Modelling nitrogen mineralisation in pasture-based systems: a comparison of three agro-ecosystem models. *Report prepared for the More Profit from Nitrogen, Project Leadership Group.*

Marsden K.A., dos Santos C.A, Friedl J., Rowlings D., Suter H.C., Eckard R.J., Chadwick D.R. (2019). Targeting farm scale features for nitrification inhibitor application: an effective N_2O mitigation strategy? Proceedings of the 2019 Greenhouse Gas and Animal Agriculture conference, August 2019, Igazu, Brazil.

Smith, A.P., Christie, K.C., Rawnsley, R.P., Eckard R.J. (2018) Fertiliser strategies to improve NUE in grazed dairy pastures. 20th N Workshop and Side event, June 25-27, 2018, Rennes, France. https://workshop.inrae.fr/nitrogenworkshop2018/content/download/4995/57403/version/1/file/20th+Nitrogen+Workshop_2018_Final+Proceedings.pdf

Smith, A.P., White, M. (2018) More profit from nitrogen in Australian agriculture. 20th N Workshop and Side event, June 25-27, 2018, Rennes, France. https://workshop.inrae.fr/nitrogenworkshop2018/content/download/4995/57403/version/1/file/20th+Nitrogen+Workshop_2018_Final+Proceedings.pdf

7.1.5 Intellectual property

The 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. There were no material upgrades made to the DairyMod model through this project.

7.2 Equipment and assets

No assets or equipment was purchased by the project – note that computers and accessories were purchased as part of essential equipment. However, as these would be considered redundant by the end of the project, the University of Melbourne does not consider these as assets.

7.3 Media and communications material

A total of 11 YouTube videos and 1 podcast were recorded, as listed in Section 10.

Christie K., Rawnsley R., Smith A., Eckard R. (2018) Do the Best Management Practices for Nitrogen stack up? The Australian Dairy Farmer July-August 2018. pp 34-35.

Eckard R.J. (2017) Summer Nitrogen Fertiliser Responses. How Now Gippy Cow. Issue 226, November 2017.

Eckard R.J. (2018) Use nitrogen fertiliser best practice. The Australian Dairy Farmer May-June 2018 pp. 29-31.

Dairy Australia (2020) FERT$MART NITROGEN - POCKET GUIDE. Prepared by Karen Christie, Graeme Ward, Richard Eckard, Helen Suter, David Rowlings, Cath Lescun for the More Profit from Nitrogen Program. ISBN 978-1-925347-87-6

Dairy Australia (2020) FERT$MART NITROGEN GUIDELINES. Prepared by Karen Christie, Graeme Ward, Richard Eckard, Helen Suter, David Rowlings, Cath Lescun for the More Profit from Nitrogen Program. ISBN 978-1-925347-83-8 (Print), ISBN 978-1-925347-82-1 (Digital/PDF).

Dairy Australia (2020) Improving dairy farm nitrogen use efficiency, using soil moisture monitoring. Economic Case Study Allansford (Victoria). Dairy Australia Limited

Dairy Australia (2020) Quantifying the whole farm systems impact of nitrogen. Best practice on an irrigated dairy farm. Economic Case Study - Elliot (Tasmania). Dairy Australia Limited

Dairy Australia (2020) Quantifying the whole farm systems impact of nitrogen. Best practice on an irrigated dairy farm. Economic case study Taree (New South Wales). Dairy Australia Limited

Dairy Australia (2020) Quantifying the whole farm systems impact of nitrogen. Best practice on a rainfed dairy farm. Economic case study Terang (Victoria). Dairy Australia Limited

7.4 Resource outputs for industry

Title	Authors	Date finalised	Host platform for ongoing use
FERT$MART Nitrogen - Pocket Guide	Karen Christie, Graeme Ward, Richard Eckard, Helen Suter, David Rowlings, Cath Lescun	October 2020	https://fertsmart.dairyingfortomorrow.com.au/ ISBN 978-1-925347-87-6
FERT$MART Nitrogen Guidelines	Karen Christie, Graeme Ward, Richard Eckard, Helen Suter, David Rowlings, Cath Lescun	October 2020	https://fertsmart.dairyingfortomorrow.com.au/ ISBN 978-1-925347-83-8 (Print), ISBN 978-1-925347-82-1 (Digital/PDF).
Improving dairy farm nitrogen use efficiency, using soil moisture monitoring. Economic Case Study Allansford (Victoria).	Karen Christie, Graeme Ward, Richard Eckard, Helen Suter, David Rowlings, Cath Lescun, George Revell	October 2020	https://fertsmart.dairyingfortomorrow.com.au/
Quantifying the whole farm systems impact of nitrogen. Best practice on an irrigated dairy farm. Economic Case Study - Elliot (Tasmania)	Karen Christie, Graeme Ward, Richard Eckard, Helen Suter, David Rowlings, Cath Lescun, George Revell	October 2020	https://fertsmart.dairyingfortomorrow.com.au/
Quantifying the whole farm systems impact of nitrogen. Best practice on an irrigated dairy farm. Economic case study Taree (New South Wales)	Karen Christie, Graeme Ward, Richard Eckard, Helen Suter, David Rowlings, Cath Lescun, George Revell	October 2020	https://fertsmart.dairyingfortomorrow.com.au/
Dairy Australia (2020) Quantifying the whole farm systems impact of nitrogen. Best practice on a rainfed dairy farm. Economic case study Terang (Victoria). Dairy Australia Limited	Karen Christie, Graeme Ward, Richard Eckard, Helen Suter, David Rowlings, Cath Lescun, George Revell	October 2020	https://fertsmart.dairyingfortomorrow.com.au/

8 Appendix – Project technical report

8.1 Summary of Objectives

The project was established with 3 main objectives:

8.1.1 Objective 1:

To quantify current recommended best practices for N management on dairy farms, through farm systems modelling, providing farmers and industry with confidence to improve productivity and limit potential environmental impacts.

This was the main objective of the project. The project established a sequence of modelling studies aimed at validating the BMPs listed in the 'Nitrogen and Nitrogen Fertilisers' section of the 'Dairy soils and Fertiliser' Fert$mart manual, over a wide range of climates, soils, pasture types and management across the pasture-based dairy industry. This required working sequentially through the recommended N rate, source, timing and formulation (N source was not covered as the main N source was assumed to be urea or DAP).

These modelling studies, and associated field work, are detailed in the Section 8 below. This modelling, together with data from the other two dairy MPfN projects, led to the updating of the Fert$mart BMPs, with a pocket booklet and updated Fert$mart guidelines for N use being published. These documents along with 4 case studies are now hosted on the Dairying for Tomorrow web site.

8.1.2 Objective 2:

To identify limitations in the models used and propose improvements to these models.

As part of the modelling under Objective 1, it was assumed that limitations would be identified in DairyMod to conduct these studies. These limitations were documented in the various milestone reports. In most cases the project team were able to work around these limitations, even though not ideal. An example would be how the model could simulate a nitrification inhibitor on urine but not on fertiliser specifically. In some cases, this required going back to earlier version of the model, where these processes were better addressed.

However, as there is no mechanism currently in place to maintain the DairyMod model and there is also no proposed pathway to address these limitations (the original model developer Dr Ian Johnson has now retired and, while the project team has the model source code, there is no one funded to understand, maintain or develop this code further. The model is now close to being redundant, as it has not been upgraded since 2016). This remains a priority recommendation, well beyond the current project, for Dairy Australia to consider their role in the future of this model.

8.1.3 Objective 3:

To further develop modelling capability and capacity as part of a succession plan for farm systems modelling in the dairy industry.

The project engaged 7 early and mid-career researchers in the modelling, fostering collaboration between these modellers through online platforms, regular meetings and a number of workshops. During the project it became obvious that DairyNZ had similar priorities, so the workshops and the online platforms were expanded in scope to include these collaborators. The project also identified a number of farm consultants that wanted to use the DairyMod model as part of their advisory work.

The first N modelling workshop was held on the 4th and 5th May 2017. Day 1 of the workshop focused on various groups presenting their recent experiences with modelling N in grazing systems, from component to catchment scale. Day 1 of the workshop was attended by 26 delegates from 14 research providers, including universities, state governments, CSIRO and DairyNZ. Day 2 of the workshop focused on providing training in the use of DairyMod to both researcher and farm consultants. Around 25 delegates attended each day, mainly research teams on day 1 and half research half consultants on day 2.

A second modelling workshop was held jointly with DairyNZ in February 2018, Christchurch, New Zealand. An Australasian Dairy Modelling Community of Interest group was established between the project team and DairyNZ (David Chapman, Pierre Beukes, Simon Woodward) as of February 2018. This team continue to use the Loomio collaboration portal to exchange ideas and develop new project concepts.

8.2 Detailed studies conducted

8.2.1 Simulated seasonal pasture responses of grazed dairy pastures to nitrogen fertiliser in SE Australia: Pasture production

Reference

Christie, K. M., Smith, A. P., Rawnsley, R. P., Harrison, M. T., & Eckard, R. J. (2018). Simulated seasonal responses of grazed dairy pastures to nitrogen fertiliser in SE Australia: Pasture production. *Agricultural Systems* **166**, 36-47. doi: https://doi.org/10.1016/j.agsy.2018.07.010

Highlights

- Cutting defoliation underestimated responses at low N fertiliser rates
- Seasonal and site variation in dry matter response to N fertiliser
- Updated site and seasonal-specific BMP recommendations
- Grazing system included recycled N not present in cutting system

Abstract

Many N fertiliser recommendations for grazing livestock enterprises are based on cutting experiments, excluding the influence of recycled N in excreta. Grazing experiments are expensive to conduct, and so compromise on variables such as number of N fertiliser rates, replication and number of years of investigation. Biophysical modelling provides an efficient and effective approach to address many of the complexities of field studies. Our study, using the biophysical whole-farm systems model DairyMod, examined the effect of a range of N fertiliser rates on pasture production for five dairy sites through south-eastern Australia over 18 years under both cutting and grazing regimes. The study aims were to highlight the variation in pasture N responses between cutting and grazing experiments and compare results to current BMP guidelines for N fertiliser management. Annual and seasonal maximum and optimum pasture production, defined as 90% of maximum production, N fertiliser rate to achieve optimum pasture production and the slope of the response rate curve between two fertiliser application rates were estimated. For all five sites, at the lower N rates, there was a divergence in annual pasture production between the grazing and cutting management regimes. However, once N was no longer limiting pasture production for the cutting regime, annual pasture production under cutting and grazing converged. For most sites and seasons, current BMPs of applying between 20 and 50 kg N ha^{-1} post grazing will ensure efficient use of N applied, assuming soil moisture is not first limiting growth. However, this study has refined these recommendations across all sites and seasons. For some seasons and sites, there was high variability in pasture N response rate between years that need to be taken into consideration. At Elliott in Tasmania, an irrigated site, there was merit in increasing N fertiliser rates above the current recommendation above 50 kg N ha^{-1} 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.

8.2.2 Simulated seasonal pasture responses of grazed dairy pastures to nitrogen fertiliser in SE Australia: Nitrogen loss and N recovery

Reference

Christie, KM, Smith, AP, Rawnsley, RP, Harrison, MT, Eckard, RJ (2020) Simulated seasonal responses of grazed dairy pastures to nitrogen fertiliser in SE Australia: N loss and recovery. *Agricultural Systems* **182**, 102847. https://doi.org/10.1016/j.agsy.2020.102847

Highlights

- Environmental N loss was closely linked to N fertiliser inputs.
- N loss at 90% maximum pasture yield was greatest in spring & summer for most sites.
- N recovery in pasture biomass generally greatest in spring at all sites.
- Volatilization was the greatest source of N loss for most sites and seasons.

Abstract

Evidence from farm level studies indicates that there is potential to improve N fertiliser efficiency of Australian dairy farms. Increasing N fertiliser application rates to drive pasture dry matter production beyond an agronomic or economical optimum has the potential to result in detrimental environmental outcomes. Our study, using the biophysical whole-farm systems model DairyMod, modelled a range of N fertiliser rates on total N loss for five dairy sites through south-eastern Australia, using 18 years of historical climate. Nitrogen accumulation in plant biomass and soil N accumulation within and below the rootzone were estimated. Total N loss, in the form of volatilization, leaching, runoff and denitrification lost to the environment were also estimated. 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. Nitrogen recovery (proportion of N recovered in biomass relative to N fertiliser applied) exceeded 100% with lower N fertiliser rates (< 30 kg N ha^{-1} $month^{-1}$) for most sites and seasons. Demand for N was high during spring due to high pasture growth and this was supported via N mineralization and legacy N build-up in winter. Nitrate leaching risk was highest in winter for the four temperate sites and autumn at the subtropical site. This study demonstrated the benefits of developing site and seasonal-specific N fertiliser BMP guidelines that are both economical and environmentally beneficial. When considering whether to add more fertiliser, the value of additional pasture production needs to be weighed up against environmental N losses and the cost of additional N fertiliser to achieve this. The relationship between seasonal soil and climatic conditions and N loss and recovery were also examined for one rainfed site. As this study does not consider the externalities associated with N loss, recommendations need to be considered and amended in the context of location specificity and seasonal climatic conditions.

8.2.3 Simulated seasonal responses of grazed dairy pastures to nitrogen fertiliser in SE Australia: N fertiliser by irrigation interaction

Reference #1

Christie, K.M., Rawnsley, R.P., Smith, A.P., Eckard, R.J. (2017) Simulated seasonal nitrogen fertiliser responses for diverse dairy regions of Australia. In: Syme, G., Hatton MacDonald, D., Fulton, B. and Piantadosi, J. (eds) MODSIM2017, 22nd International Congress on Modelling and Simulation. Modelling and Simulation Society of Australia and New Zealand, December 2017, p 60. ISBN: 978-0-9872143-7-9. https://www.mssanz.org.au/modsim2017/documents/MODSIM2017_book_abstracts.pdf

Abstract

There is an ongoing challenge for Australian dairy farms to increase production, improve input resource efficiency and farm profitability in the face of climatic, price and regulatory requirements. The consumption of home-grown forage is widely recognized as a key metric to ensuring farm profitability. Optimal soil N management is critical to improving quantity and quality of pasture produced on-farm. Reviews have highlighted that despite many years of field research, the production responses of pasture to varying rates of N fertiliser (kg dry matter/kg N applied) remains highly variable and uncertain for a range of contexts (i.e. soil, climate, and farming system (FS) interactions). Of the experimental data available, virtually all are from cutting studies. Such studies exclude N returns through the grazing animal, a critical component to the N cycle, thereby increasing the uncertainty in pasture responses to recommended rates of fertiliser. Biophysical modelling is considered an effective approach to assessing the complex interaction that exist between climatic, edaphic and management factors that influence pasture production response to varying N fertiliser rates within a FS.

Using a biophysical modelling (DairyMod) approach, we derived the pasture production responses to varying rates of N inputs using both a cutting and grazing simulation. These simulations were undertaken for two varying temperate locations. At both sites, N fertiliser was applied monthly, at incremental rates of 10kg N/ha.month, post-defoliation and were conducted for 18 years of climatic data (winter 1999 to autumn 2017 inclusive). Figure 1 shows the spring-time perennial ryegrass growth rate (kg DM/ha.day) at an irrigated site in NW Tasmania (a) and a rainfed site in SW Victoria (b) under cut and grazed conditions. At the irrigated site, there was disparity in average daily growth rates between the cut and grazed systems for rates up to 80kg N/ha.month. This difference highlights the impact on the soil-plant system of the animal sources of excretal N. In contrast at the rainfed site, the variation in daily growth rates between the cut and grazed system was minimal for rates above 40kg N/ha.month. The amount of N fertiliser required to achieve 90% of maximum pasture production under cutting conditions averaged ~ 75 and 50 kg N/ha.month at the irrigated and rainfed sites, respectively, reducing to an average of ~ 52 and 35 kg N/ha.month under grazing at the irrigated and rainfed sites, respectively.

These results suggest that the grazing N fertiliser recommendation of between 20 and 50 kg N/ha is appropriate for both sites but does demonstrate that a greater level of N input is required for the NW Tasmanian site that the SW Victoria site, highlighting the importance of examining the complex interactions that exist in a grazing system. Also of note is the comparatively large interannual variation in the response at the rainfed site (Figure 1b)

indicating that year to year N management should be adjusted according to current conditions. This information, along with assessments of N loss, will be used to validate and, where appropriate, update current dairy industry best management practices.

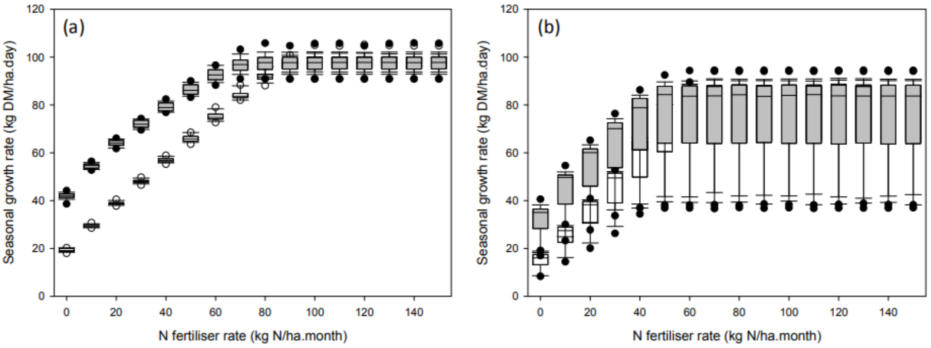

Fig 1. Average spring daily growth rate (kg DM/ha.day), at an irrigated site in NW Tasmania (a) and at a rainfed site in SW Victoria (b) under cut (open boxplots) and grazed (solid boxplots) conditions over 18 years.

Reference #2

Christie, K., Rawnsley, R., Eckard R. (2018) Modelling nitrogen fertiliser by irrigation interaction for southern Australian dairy farms. *Australasian Dairy Science Symposium*, November 2018, Palmerston North, New Zealand.

Abstract

Using the biophysical whole farm systems model DairyMod, we examined the effect of four N fertiliser regimes, combined with four irrigation regimes, on the variability of pasture production and N loss via leaching at two sites in southern Australia. The N fertiliser regimes represented varying levels of decision sophistication while the irrigation regimes represented ranges of accuracy in scheduling water application in response to rainfall deficit. Improving the level of sophistication in N fertiliser decision making, from a flat rate (i.e 40 kg N/ha after each grazing event) to applying in response to plant demand, resulted in a 5 and 8% decline in annual dry matter (DM) production at Elliott and Mt Gambier, respectively. However, leached N losses were reduced by 36 and 46%, respectively. Relative to over-watering, irrigating to match rainfall deficit reduced N loss by 30 and 44% at Elliott and Mt Gambier, respectively, but with no effect on DM production.

8.2.4 Fertiliser strategies for improving nitrogen use efficiency in grazed dairy pastures

Reference

Smith, A. P., Christie, K. M., Rawnsley, R. P., & Eckard, R. J. (2018). Fertiliser strategies for improving nitrogen use efficiency in grazed dairy pastures. *Agricultural Systems*, **165**, 274-282. doi: https://doi.org/10.1016/j.agsy.2018.06.017

Highlights

- Strategic fertiliser strategies were more efficient than flat rate strategies.
- Precision strategies were most valuable for N use efficiency in autumn.
- Periodic soil based strategies had high N losses.
- Smart sensors should be focussed on pasture rather than soils.

Abstract

Evidence from farm level studies indicates that there is potential to improve N use efficiency of the predominately pasture-based dairy farms in Australia. This is possible via several ways which includes modifying the timing and rates of N fertiliser applied to pasture. Traditionally fertiliser strategies have been based on a “recipe” approach where N fertiliser, primarily urea, is applied a set rate following grazing. The aim of this study was to compare the pasture dry matter response, N loss and response rate of fertiliser strategies which used increasing knowledge of plant and soil conditions in different ways. The study was conducted under grazing conditions using the biophysical model, DairyMod and repeated at several locations and farming systems in the dairy regions of Australia. In comparison to set rates this study showed that strategic approaches to N fertiliser have the potential to be more efficient in N use and lower both N inputs and N losses with little impact of pasture production. This was evident across all seasons and locations studied. Strategies that used the plant N status to trigger fertiliser timing and rates were more efficient and had lower environmental N losses than those that used fixed rates or soil N information. Fertilising per plant N requirements was the most efficient – and therefore should be the priority for development – particularly in view of the greater expense of fertilisers that are slow release. Precision fertiliser management strategies have the value in terms of reducing fertiliser use and loss during autumn and to a lesser extent in summer, with the least value in winter. However, for the strategies to be properly evaluated for pasture based dairy farms with grazing, a whole farm analysis needs to be conducted that incorporates other sources of feed. This is a necessary inclusion in any subsequent studies.

8.2.5 Managing the nitrogen status of subtropical dairy pastures for production, efficiency and profit

Reference

Smith, AP, Beale, P, Fulkerson, BJ, Eckard, RJ (2019) Managing the nitrogen status of subtropical dairy pastures for production, efficiency and profit. *Agricultural Systems* **176**, 102677. https://doi.org/10.1016/j.agsy.2019.102677

Highlights

- Nitrogen management was compared in dairy systems with kikuyu/annual ryegrass.
- Fertiliser requirements at sowing were not very different between farming systems.
- Fertiliser on kikuyu was not profitable due to the need for cutting.
- Milk production and profit was increased by feeding more grain during summer.

Abstract

Pastures that contain winter-active annual ryegrass (ARG) in association with summer-active kikuyu are valuable for dairy production in subtropical regions. The two pasture phases have different challenges to increase production and profitability – for the kikuyu phase the management of soil fertility is challenging as it requires synchronization with soil, plant and animal demands for energy and protein. Unsure how best to manage the soil N during the kikuyu phase and deterred by the risk of a poor pasture dry matter response to N fertiliser; farmers tend to under-fertilize the kikuyu phase which was hypothesized to limit the potential productivity of not only the kikuyu, but adversely impact the N nutrition of the subsequent ARG phase. For the first-time different farming systems for a subtropical location were comprehensively compared using the mechanistic model DairyMod. The farming systems compared consisted of N fertiliser to only the ARG phase, N fertiliser throughout the year to both phases, N fertiliser only at the start of the kikuyu growth cycle or increased feed-grain supplementation during the kikuyu phase. An overall summary of the results is that although applying N fertiliser to the pasture all year lifted pasture productivity, particularly of the kikuyu, much of the extra herbage grown could not utilized by grazing cows and needed to be cut. At the period of establishment of ARG pasture in mid -autumn, the new finding was that soil mineral N did not differ significantly between the different systems, and therefore using N fertiliser to maintain soil and pasture N within an optimum range was shown to be expensive and inefficient. The major novel finding of the study was that the farming system was most profitably and productively managed by addressing deficiencies metabolizable energy of kikuyu with supplementary grain feeding, rather than using fertiliser.

8.2.6 Predicting ammonia volatilization from urea fertiliser applied to the surface of grazed pastures

Reference

Smith, AP, Johnson, IR, Schwenke, G, Lam, SK, Suter, HC, Eckard, RJ (2020) Predicting ammonia volatilization from fertilized pastures used for grazing. *Agricultural and Forest Meteorology* **287**, 107952. https://doi.org/10.1016/j.agrformet.2020.107952

Highlights

- Volatilization from urea applied to grazed dairy pastures was modelled with DairyMod.
- The complex process of volatilization was simulated by a simple modelling approach.
- DairyMod is versatile for use across a range of scenarios with overall low model errors.
- Modelling is attractive considering the difficulty, expense and uncertainty in field studies.

Abstract

Ammonia (NH_3) volatilization from fertilised agricultural soils is driven by complex interactions between edaphic, climatic and plant canopy factors that can be difficult to measure or predict. We developed a simplified approach using default parameters in the DairyMod model to predict daily NH_3 volatilization from urea applied to grazed dairy pastures. Several published datasets were used to validate the reliability of the model to reproduce key related soil processes in a whole farming systems framework. For the sites where monitoring for the experimental duration occurred, DairyMod simulated the main features of the observed NH_3 emissions, with an overall predicted median of 4.1 kg/ha or 7% of applied N, compared to the measured median of 6.1 kg/ha for 12% of applied N fertiliser. There was an overall root mean square error (RMSE) of 0.9 kg NH_3-N/ha/d and an overall mean prediction error (MPE) of 0.5 kg NH_3-N /ha/d. However, there was high uncertainty in several of the datasets used which made it difficult to be conclusive about the validation. The simulation accuracy was improved using daily wind speed (collected on-site in field campaigns) as input to the evapotranspiration calculations. In cases of high certainty in the volatilization data, it was concluded that the model was useful for the analysis of N cycling in situations used for dairy farming without the need for a more complex mechanistic method with difficult-to-obtain parameters. DairyMod presents a simple but readily reproducible prediction of NH_3 volatilization from urea application on pasture in intensive livestock farming systems compatible with the certainty of the model inputs and scale of model application. However, the collective understanding of NH_3 volatilization in pasture based dairy systems is currently based on a limited number of often uncertain, short term plot studies in the absence of animals.

8.2.7 Quantifying the impacts of farming system and climate on farm-scale ammonium losses from grazed dairy farms.

Reference

Smith A. P., Christie K.M., Harrison M.T., Eckard R.J. (2020) Ammonia volatilisation from grazed, pasture based dairy farming systems. *Agricultural Systems* (in review)

Abstract

A key pathway for N loss, which is poorly quantified in livestock farming systems with grazing, is the ammonia (NH3) volatilisation that occurs from fertilisers, soils, fresh and stored animal excreta. This study used farm systems modelling to understand, the likely losses of N via NH3 volatilisation from different farming systems in diverse locations throughout the geographical extent of the dairy industry in Australia. DairyMod was used to simulate daily water, energy and N cycles in commonly occurring farming systems. DairyMod simulated the flows of N through soils, pastures, feed, animals throughout the whole farm system in order to sensibly simulate the NH3 volatilisation from fertilisers, soil and animal excreta. Across 18 locations, average annual volatilisation for the years 2000-2019 was 40 kg N/ha but varied greatly from 10-97 kg N/ha depending on year, location and farming system. Across all locations, volatilisation was higher in Spring (Sp) > Winter (Wi) > Autumn (Au) > Summer (Su). Across the 18 locations annual volatilisation was, on average, 51 % greater from the livestock excreta source than from the fertiliser N source, which was 22 % greater than from soil N sources over the long term assess how N losses volatilised. Heterogeneity was a feature as the amount of volatilisation changed between seasons and N sources but with no obvious trends across all locations when averaged over all years. Supplemental forage feeding with grass silage made up between 10 ± 6% of total intake on a dry matter basis, but by substituting this for low protein maize silage, the overall diet N concentration was reduced from 3.0% to 2.4% which in turn caused a 47% reduction in volatilisation, from 56 to 30 kg N/ha/year, improvement in whole farm NUE by 65% from 31 to 60 g milk MS/g N-NH_3 volatilisation and milk production was uncompromised overall. The findings indicate if addressed at the whole farm scale, farm NUE can be improved significantly but this needs to be understood in the broader context of the farming system. Due to the highly heterogenous nature and responses of farming systems that include grazing animals, a pervasive and inflexible approach to modifying dairy systems in order improve environmental air quality is implausible.

8.2.8 Modelling nitrogen mineralisation in pasture-based systems: a comparison of three agro-ecosystem models.

Reference #1

Bilotto F., Harrison M.T., De Antoni Migliorati M., Christie K.M., Rowlings D., Grace P., Smith A., Rawnsley R.P., Thorburn P., Eckard R.J. (2020) Modelling soil nitrogen with APSIM, DairyMod and DayCent: can seasonal N mineralisation trends be leveraged to enhance pasture growth? *Science of the Total Environment* (in review).

Abstract

Soil N mineralisation is the process by which organic N is converted into plant-available forms, while soil N immobilisation is the transformation of inorganic soil N into organic matter and microbial biomass, thereafter becoming bio-unavailable to plants. These cyclical processes are known as "mineralisation-immobilisation turnover" and are governed by many factors, including soil N status, organic matter, clay content, soil biota, as well as soil moisture and temperature. Mechanistic models can be used to explore the contribution of mineralised N to pasture growth through simulation of plant, soil and environment interactions driven by management. Here, our objectives were (1) compare the performance of three agro-ecosystems models (APSIM, DayCent and DairyMod) in simulating soil N using the same experimental data collected in three diverse environments, and (2), to determine if tactical application of N in different seasons could be used to leverage seasonal trends in N mineralisation to influence pasture growth. We found that despite considerable variation in model sophistication, no model consistently outperformed the other models with respect to simulation of soil N, shoot biomass or soil water. Differences in the accuracy of simulated soil NH_4 and NO_3 were greater between sites than between models; overall, all models performed well in simulating cumulative N_2O. Further scenario analyses showed that while tactical N application had immediate effects on NO_3, NH_4, N mineralisation and pasture growth, no long-term relationship between mineralisation and pasture growth could be discerned. These results suggest that while superfluous N application generally stimulates immobilisation and a pulse of N_2O emissions, subsequent effects through N mineralisation on pasture growth are variable. We suggest that 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.

Reference #2

Harrison M., De Antoni M., Eckard R. (2019) Soil nitrogen: can pasture yields be increased by capitalising on seasonal trends in mineralisation and immobilisation? 19th Australian Agronomy Conference, 25-29 August 2019. Wagga Wagga. http://agronomyaustraliaproceedings.org/images/sampledata/2019/2019ASA_Harrison_Matthew_316.pdf

Abstract

Decomposition of organic N into inorganic N is known as mineralisation. This process and its converse, immobilisation, occur simultaneously and continuously under the controls of soil temperature, moisture, texture and organic N content. As plants can only utilise inorganic N, the

rate of net mineralisation (the difference between gross mineralisation and gross immobilisation) may be a determinant of subsequent pasture growth. Here we examine how the timing of inorganic N fertilisation influences net N mineralisation and pasture growth. We simulated the long-term effects of spreading urea in August, when pasture growth was near its peak, or in December, when pasture growth was lowest; the latter treatment being deigned to test whether N would be immobilised and released from soil organic matter in the following growing season(s) and thus enhance plant growth. Application of 100 kg N/ha in December resulted in 7-14 kg N/ha.year greater net mineralisation within and across all years in the simulation relative to N fertiliser applied in August. These trends were consistent in both vertosol and chromosol soils, suggesting that time of year of fertilisation had a significant and sustained influence on subsequent net N mineralisation. N fertilisation in August partially relieved N stress and stimulated growth, much more so than N applied in December, but also reduced net N mineralisation relative to that applied in December. This may have been caused by either lower mineralisation or higher immobilisation in the August-fertilisation treatment. Overall these results suggest that N fertilisation timing has implications for the magnitude of mineralisation, yet linkages between mineralisation and pasture growth require further investigation.

<u>Reference #3 & 4</u>

Harrison M.T., Rawnsley R.P., Eckard R.J. (2018) Modelling nitrogen mineralisation in pasture-based systems: a comparison of three agro-ecosystem models. Australasian Dairy Science Symposium, November 2018, Palmerston North, New Zealand. https://static.sched.com/hosted_files/adss2018/82/87691.pdf

Harrison, M.T., Christie, K.M., Smith, A.P., Rawnsley R.P., Eckard, R.J. (2018). Modelling nitrogen mineralisation in pasture-based systems: a comparison of three agro-ecosystem models. *Report prepared for the More Profit from Nitrogen, Project Leadership Group.*

<u>Abstract</u>

Realistic simulation of soil N cycling is important for quantifying N loss pathways to the environment, as well as the influence of N on pasture productivity. Although several models have been evaluated for their ability to simulate pasture growth, few studies have compared the models APSIM and DairyMod. Here, our objectives were to examine the capability of each model in simulating field measurements of pasture biomass, soil water content, mineral N and N_2O emissions. For site one, DairyMod generally simulated mineral N, cumulative N_2O and soil water with lower residual error than that from APSIM, but APSIM produced better estimates of pasture biomass. At site two, DairyMod produced more precise estimates of mineral N, but APSIM simulations were more reliable in terms of cumulative N_2O. Overall this study demonstrated that both models produced satisfactory estimates of pasture biomass and soil water dynamics, but further research is necessary to diagnose reasons for the sometimes large discrepancies between simulated and measured mineral N and cumulative N_2O emissions. Part of this discrepancy is likely to be caused by heterogeneity of soil N in the field, spatially and temporally. Although both models produce temporal estimates of mineral N and N_2O, quantification of parameter uncertainty associated with spatial variation in mineral N would help improve model evaluation such as performed in this study.

8.2.9 A model to predict the effect of excess dietary nitrogen on milk production and its implications for reducing nitrogen inputs on pasture-based dairy farms

Research carried out from August 2018 until March 2019 under supervision of Richard Eckard and Andrew Smith of the University of Melbourne. The final thesis has been submitted and passed through Wageningen University.

Reference

de Looff E. (2019) 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. March 5, 2019. Supervisors: C. van Middelaar, R. Eckard, A. Smith. MSc Thesis, Animal Production Systems group, Wageningen University. APS-80436.

Thesis Summary

Intensification of pasture-based dairy systems is a global trend. As N sources are limited and the dairy industry is increasingly relying on N inputs for productivity through feed and fertiliser, high NUE is essential. Besides environmental impacts from N losses, there have also been an economic impact related to N losses as it costs a cow energy to metabolise dietary N in excess of requirement. This means there is less energy available for milk production, and therefore less production. As there has not been any studies published that specifically estimate the milk loss from excess dietary N, the aim of this research was to build a model to predict the effects of excess dietary N on milk production. It was hypothesised that milk losses would be highest for diets with high pasture inclusion and relative low pasture supplementation, mainly during spring when pasture CP contents are generally highest.

A major part of the research was the development of the model. For this, an energy and N balance at animal-level over the course of a year were developed based on literature. Energy was allocated to locomotion, gestation, maintenance (including body weight changes), and milk production. For N allocation, there was a distinction between N retention (for body weight changes of the cow and calf growth) and N excretion (through milk, faeces and urine). A diet component was added to the model and formed an input template for ME, CP and DMI data on pasture and pasture supplements (i.e. energy supplement, summer crop, hay and silage), which was used to calculate total weighted ME and N inputs for the energy and N balances, respectively. The model was applied for three diets of hypothetical pasture-based farming systems typical for south-west Victoria (Australia) with autumn calving at the 1st of April. Each case study diet was differentiated based on the level of pasture supplementation in the diet (in particular the use of energy supplement) and annual milk production (based on DairyMod output). Diets were formulated to meet energy requirements. The N supplied through each diet was compared with the N requirement for that particular farming system, leading to the excess dietary N used to calculate the energy cost for metabolising excess N. Using the energy density of milk for a certain fat- and protein-content, this led to an estimation of milk production lost.

The model outputs were best interpreted in terms of relative behaviour over time. On average, milk losses were relatively highest for the diet with low pasture supplementation in the diet (3.18%), followed by the medium (3.02%) and high (2.77%) pasture supplementation diets. In absolute terms, this would mean an average milk loss of approximately 175 litres/cow/year on an annual production of 5488 litres/cow for the low supplementation diet, 199 litres/cow/year on an annual production of 6582 litres/cow for the medium supplementation diet, and 207 litres/cow/year on an annual production of 7482 litres/cow for the high supplementation diet. Excess dietary N decreased and NUE increased when more pasture supplementation was included in the diet. These effects were most profound in April (at calving), May, July, August and September, when the effects of high pasture protein contents were diluted by pasture supplement inclusion.

It is recommended to balance the diet at times of the year when pasture CP contents are highest, by adding high-energy pasture supplements (like energy supplement) because they appeared to address most of the milk loss issues. This study showed the periods of the year when this can and should be redressed, both for economic and environmental outcomes. Possible model improvements could be the inclusion of the relation between fertiliser use and pasture CP contents and upscaling of the model to a farm-level approach (e.g. include herd composition). In addition, economic analysis could be of great value to translate the milk losses into profit loss estimations and define a tipping point at which it would be more profitable to either use more fertiliser to grow more home-grown feed (and accept environmental and economic consequences of excess dietary N), or buy-in high energy pasture supplements.

8.2.10 Assessment of DairyMod to model a nitrification inhibitor during autumn and spring at Casino

Research carried out from by Karina Marsden as part of a Horizon 2020 Marie Curie post-doctoral fellowship in 2019 and 2020. This joint fellowship in Australia was made possible due to the MPfN project funding. Karina was able to value-add to all 3 dairy projects under MPfN, working at the Allansford and Casino sites as well as on the modelling.

Reference

Not published as yet. Paper in preparation.

Introduction

Nitrification inhibitors (NIs) are compound that delay the nitrification process in soils that converts soil ammonium into nitrite and then nitrate by depressing the activity of Nitrosomonas bacteria, thus reduce N loss through nitrous oxide (N_2O) denitrification and nitrate (NO_3) leaching. Two commonly used NIs are 3,4-dimethylpyrazole phosphate (DMPP) and dicyandiamide (DCD). A review of studies from New Zealand found that NIs could be reduce NO_3 leaching and N_2O denitrification from under dairy cattle urine patches by the order of 50 and 57%, respectively (Di and Cameron, 2016). In some of these studies, pasture production was reported to also increased by 20 to 25%. Some studies in Australia have resulted in no significant reduction in N loss coupled with no increase in pasture production (Dougherty *et al.*, 2016). Where the NI has significantly reduced N_2O loss, the amount of retained N has not necessarily translate into additional pasture production (Kelly *et al.*, 2008; Suter *et al.*, 2016). Given the efficacy of NIs are temperature and soil moisture dependant (Chen *et al.* 2010; Di and Cameron, 2016), modelling can assist in estimate the value proposition of applying NIs to dairy pastures across a range of spatial and temporal scales.

Aims of study

Using DairyMod, quantify the impact of nitrification inhibitors applied in autumn or spring, on seasonal pasture production yield and reducing NO_3 leaching, N_2O emissions and ammonia (NH_3) volatilisation from N fertiliser application at Casino, northern New South Wales.

Methods

Farm system

DairyMod (version 4.9.6; Johnson, 2016) was used to examine N loss at Casino using a local patched point climate accessed from The Queensland Government 'The Long Paddock' website (https://legacy.longpaddock.qld.gov.au/silo/datadrill/location.php). Soil profile information was an adapted profile based on a black vertosol and field data (Isbell, 1996; Mumford *et al.* 2019; Harrison pers. comm. 2019). In addition, results from Mumford *et al.* (2019) were used to compare model outputs (annual pasture production and N_2O emissions) in parameterising DairyMod for this analysis. The soil water hydrology set-up is documented below. A single paddock was grazed by a herd of 200 lactating cows on the last day of each month. The cows were not fed any supplementary feed, so the N returned via their dung and urine was reflective of the N intake from the pasture. The feedbase was an annual kikuyu over-sown with annual ryegrass pasture with the two pasture species growing at separate times of the year. Emergence, anthesis and days from anthesis to maturity for kikuyu was 14 Sep, 1 Apr and 10, respectively. Emergence, anthesis and days from anthesis to maturity for annual ryegrass was 15 Apr, 1 Nov and 10. In addition, the high temperature effect was implemented for both species to restrict growth during days of high temperature. The onset, full and critical T-sum were 35°C, 40°C and 25 for kikuyu and 26°C, 32°C and 50 for annual ryegrass, although annual ryegrass was unlikely to be growing at times of the year when high temperature growth restriction would have been initiated.

N fertiliser and NI treatments

Urea fertiliser was applied at a rate of 15 and 25kg N/ha.month post-grazing. The rationale for the two rates was that the former rate may have months of N deficit to ascertain the benefit of the NI in retaining N in the soil for additional pasture production. The latter rate was selected based on the rationale that some months may have surplus soil N, thus ascertain the pathway(s) of this excess N. The fertiliser was applied in every second month during the active kikuyu growth phase (January and March) and then monthly during the active ryegrass growth phase (May through to November). This was a similar N fertiliser routine to that of Mumford *et al.* (2019), with the higher N fertiliser rate in this study similar to that of the field experimentation, at 26 kg N/ha post-harvest.

Model stabilisation and simulations

DairyMod was run for 40 years (1978 to 2017) with each N fertiliser rate, commencing/concluding either in autumn or in spring, to create a stable state for soil nutrient carbon and N. The soil nutrient conditions at the end of the long-term simulation became the new initial conditions for all data analysis simulations. Preliminary modelling of the effectiveness of a NI applied in spring in DairyMod at Allansford (south-western Victoria) indicated that to achieve reduction rates similar to those of the published papers (Kelly *et al. 2008)*, NI settings needed to be a minimum of 0.20 initial value (*i.e.* reduction of 80% at the commencement of the inhibitor) for 80 days and with a scale factor of 10. The parameter settings implemented for Allansford, and repeated for Casino, was a 0.05 initial value (95% reduction at the commencement of the inhibitor) for 100 days with a scale factor of 10.

Eighteen year continuous simulations were then undertaken, commencing 1st March 2000, with NI applied 1st April, for the autumn simulations or commencing 1st August 2000, with NI applied 1st September, for the spring simulations for both N fertiliser rates. The annual cumulative sum of N loss (N_2O, NO_3 and NH_3) and pasture production during the first 120 days (here-in referred to as short-term loss) and over the full 365 days (herein referred to as annual loss) was calculated for each N fertiliser rate for the control and NI. These were then averaged to estimate the long-term mean N loss and pasture production.

Results - spring

When the NI was applied in spring each year, the NI reduced short-term N_2O losses by a mean of 24 and 52% with the 15 kg and 25 kg N fertiliser rates, respectively, (Table 1), although this only equated to a saving of 0.1 and 0.8 kg N/ha, respectively. Annually, the NI reduced N_2O emissions by 10-11% (Table 1), equivalent to a saving of 0.2 and 0.5 kg N/ha.annum with the 15 and 25 kg N fertiliser rates, respectively.

The NI reduced short-term NO_3 losses by a mean of ~ 4.6% with both N fertiliser rates. Averaged over the 18 years, the NI reduced NO_3 leaching by ~ 7.5%, equivalent to a saving of 5 and 11 kg N/ha with the 15 and 25 kg N fertiliser rates, respectively (Table 1). When N_2O and NO_3 losses were summed together, the NI reduced N loss over the short-term by 4.9 and 3.5% for the 15 and 25 kg N fertiliser rate, respectively, and by 7.1 and 8.0% for the 15 and 25 kg N fertiliser rate, respectively (Table 1).

The application of the NI increased N volatilisation, although the increase was minimal, at 1 to 3 kg N/ha, depending on the N fertiliser rate and whether over the short term or annually (Table 1). When all three N loss pathways were summed together, the NI reduced N loss by between 1 and 5%, with little change over the short-term. Annually the NI reduced N loss by 4 kg N/ha.annum for the 15 kg N fertiliser rate and 11 kg N/ha.annum for the 25 kg N fertiliser rate.

The NI was effective in increasing pasture production, by 5-7% over the short-term and 3-4% on an annualised basis, equivalent to an additional 266 and 480 kg DM/ha over the short-term and 411 and 699 kg DM/ha over the 12 month period for the 15 and 25 kg N fertiliser rates, respectively (Table 1).

Table 1. Estimated 18-year mean short-term and annual N losses and pasture production during spring for two different N fertiliser rates at Casino.

Spring		**15 kg N**		**25 kg N**	
		Short term	**Annual**	**Short term**	**Annual**
N_2O	Control	0.4	1.8	1.4	4.3
(kg N/ha)	Inhibitor	0.3	1.6	0.6	3.8
	% reduction	24	9.8	52	11
NO_3	Control	26	74	46	139
(kg N/ha)	Inhibitor	25	69	44	128
	% reduction	4.6	7.0	4.7	7.9
NH_3	Control	10	27	14	37
(kg N/ha)	Inhibitor	11	29	16	40
	% reduction	-7.7	-4.5	-11	-6.5
$N_2O + NO_3$	Control	26	76	48	143
(kg N/ha)	Inhibitor	25	70	45	132
	% reduction	4.9	7.1	3.5	8.0
$N_2O + NO_3 + NH_3$	Control	36	103	62	181
	Inhibitor	36	99	61	172
(kg N/ha)	% reduction	1.4	4.0	2.0	5.0
Pasture Production	Control	5,571	15,179	6,752	17,655
	Inhibitor	5,837	15,590	7,232	18,324
(kg DM/ha)	% increase	4.8	2.7	6.7	3.8

For the first ~ 100 days post-application of the NI, there was similar N_2O losses between the 15kg N control and 25kg N with NI, indicating that the NI was able to reduce the N_2O losses associated with the additional 10kg N/ha.month (Figure 1). However, this was not the case with cumulative NO_3 losses (Figure 2) or pasture production (Figure 3). Within a fertiliser rate, the benefit of the NI was relatively immediate in reducing N_2O emissions, although there was no difference in NO_3 leaching during the activation period or during the first ~ 70 days with respect to pasture production.

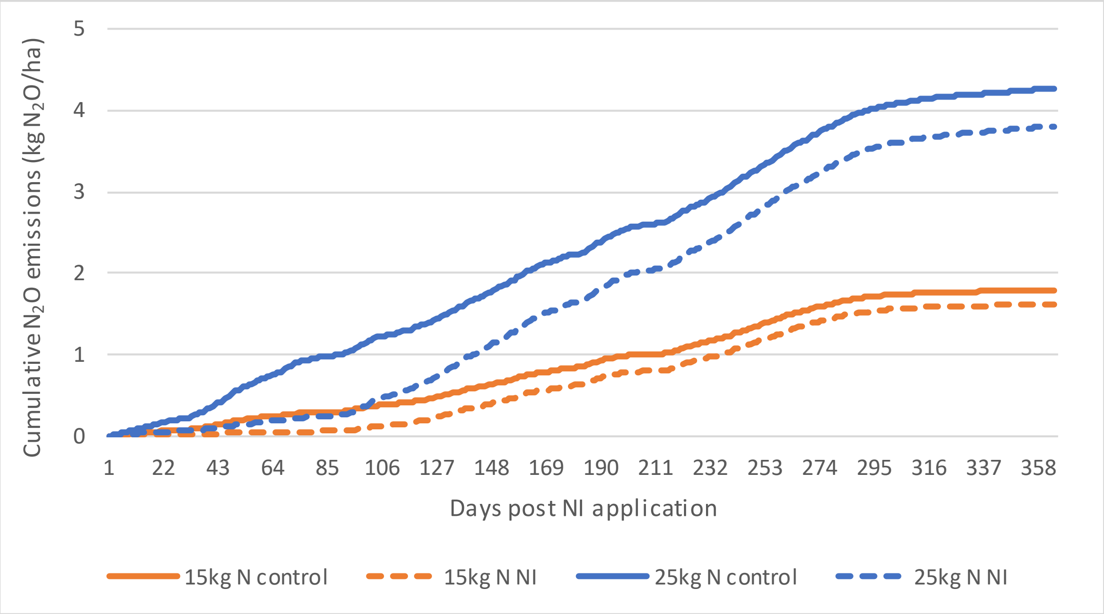

Figure 1. Estimated 18-year mean cumulative nitrous oxide emissions when applying either 15 or 25kg N/ha.month in spring without (solid lines) or with (dotted lines) a nitrification inhibitor at Casino.

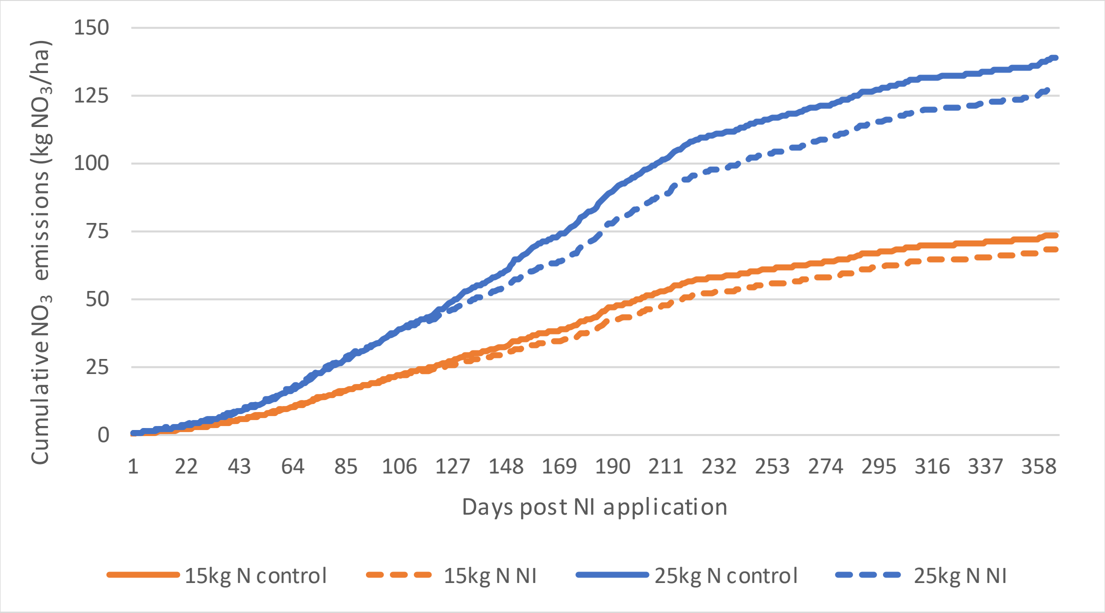

Figure 2. Estimated 18-year mean cumulative nitrate leaching when applying either 15 or 25kg N/ha.month in spring without (solid lines) or with (dotted lines) a nitrification inhibitor at Casino.

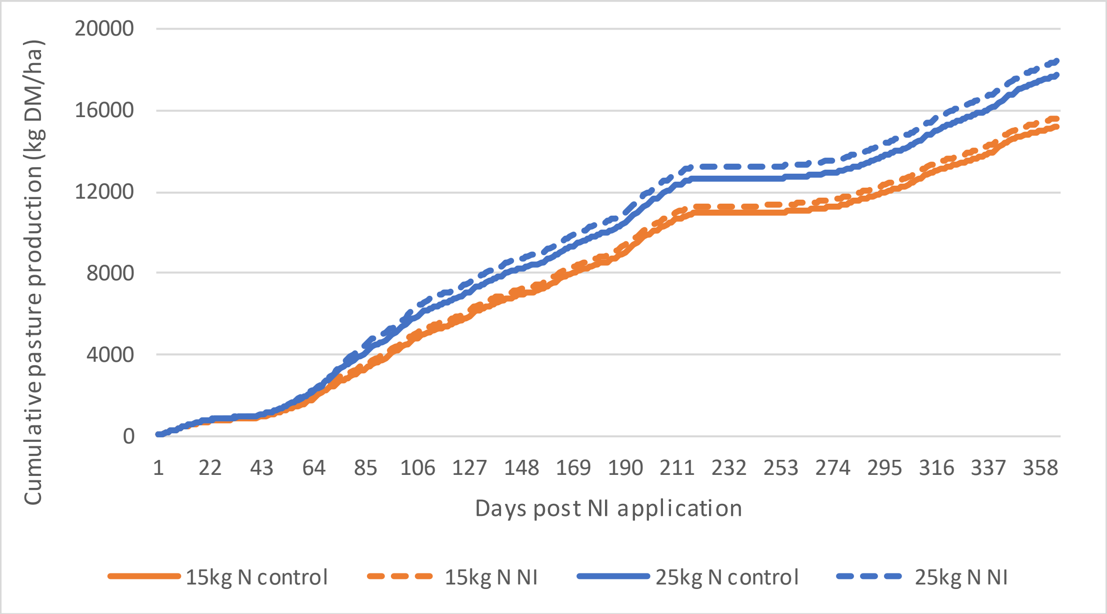

Figure 3. Estimated 18-year mean cumulative pasture production when applying either 15 or 25kg N/ha.month in spring without (solid lines) or with (dotted lines) a nitrification inhibitor at Casino

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Results - autumn

When the NI was applied 1st April every year, the NI reduced short-term N_2O losses by 65 and 61% with the 15 kg and 25 kg N fertiliser rates, respectively, equivalent to a reduction of 0.7 and 1.0 kg N/ha, respectively (Table 2). The NI reduced annual N_2O loss by 17 and 12% for the 15 and 25 kg N fertiliser rates, respectively, although this was only equivalent to a 0.5 kg N/ha reduction over the full 12 month period.

Implementation of the NI slightly increased short-term NO_3 loss, although by amounts of < 2 kg N/ha. The NI reduced annual NO_3 losses by 15% (12 kg N/ha.annum) with the 15 kg N fertiliser rate and by 10% (13 kg N/ha.annum) with the 25 kg N fertiliser rate.

The NI increased NH_3 volatilisation, both over the short-term and annually, and while the percentage increase was substantive, the increase in N loss was only 3 kg N/ha.annum, even less over the short-term (Table 2). The NI increased total N loss (sum of all three N loss sources) by 1 kg N/ha over the short-term for both N fertiliser rates, along long-term total N loss declined by 6 to 9 kg N/ha.annum.

The NI increased pasture production, over the short-term, by 10 to 13%, equivalent to an additional 400 to 450 kg DM/ha (Table 2). Over the full 12 months, the NI increased pasture production by 7 and 5% with the 15 and 25 kg N fertiliser rates, respectively, equivalent to an additional 1.1 t DM/ha.annum for the 15 kg N fertiliser rate and an additional 0.9 t DM/ha.annum for the 25 kg N fertiliser rate.

Table 2. Estimated 18-year mean short-term and annual N losses and pasture production during autumn for two different N fertiliser rates at Casino.

Autumn		15 kg N		25 kg N	
		Short term	**Annual**	**Short term**	**Annual**
N_2O (kg N/ha)	Control	1.1	2.7	1.6	4.2
	Inhibitor	0.4	2.2	0.6	3.7
	% reduction	65	17	61	12
NO_3 (kg N/ha)	Control	21	83	34	141
	Inhibitor	21	71	35	128
	% reduction	-2.2	15	-3.7	9.6
NH_3 (kg N/ha)	Control	4.1	27	6.3	37
	Inhibitor	5.2	30	7.5	40
	% reduction	-28	-11	-20	-8.1
$N_2O + NO_3$ (kg N/ha)	Control	22	86	35	146
	Inhibitor	21	73	36	132
	% reduction	1.3	15	-0.8	9.7
$N_2O + NO_3 + NH_3$ (kg N/ha)	Control	26	113	42	183
	Inhibitor	27	103	43	172
	% reduction	-3.3	9.1	-3.7	6.1
Pasture Production (kg DM/ha)	Control	2,969	15,295	3,505	17,641
	Inhibitor	3,403	16,397	3,910	18,540
	% increase	13	7.2	10	5.1

When the NI was applied in autumn, there was little difference in N_2O emissions between the two N fertilisers during the first ~ 100 days, with the NI dramatically reducing N_2O emissions for both N fertiliser rates (Figure 4). The NI, when applied in combination with 25 kg N fertiliser, was able to reduce N_2O losses for ~ 200 days to be below that of the 15 kg N fertiliser control treatment (Figure 4). The application of the NI did not result in any reduction in NO_3 leaching over the first ~ 190 post-application, although after 190 days, NO_3 leaching was reduced with the NI, relative to the control (Figure 5). There will little difference in cumulative pasture production between N fertiliser rates and with or without the NI over the first ~ 85 days, before a divergence between treatments began (Figure 6). In addition, cumulative pasture production was very similar between the 15 kg N fertiliser with NI and 25 kg N without NI for the first 200 days (Figure 6).

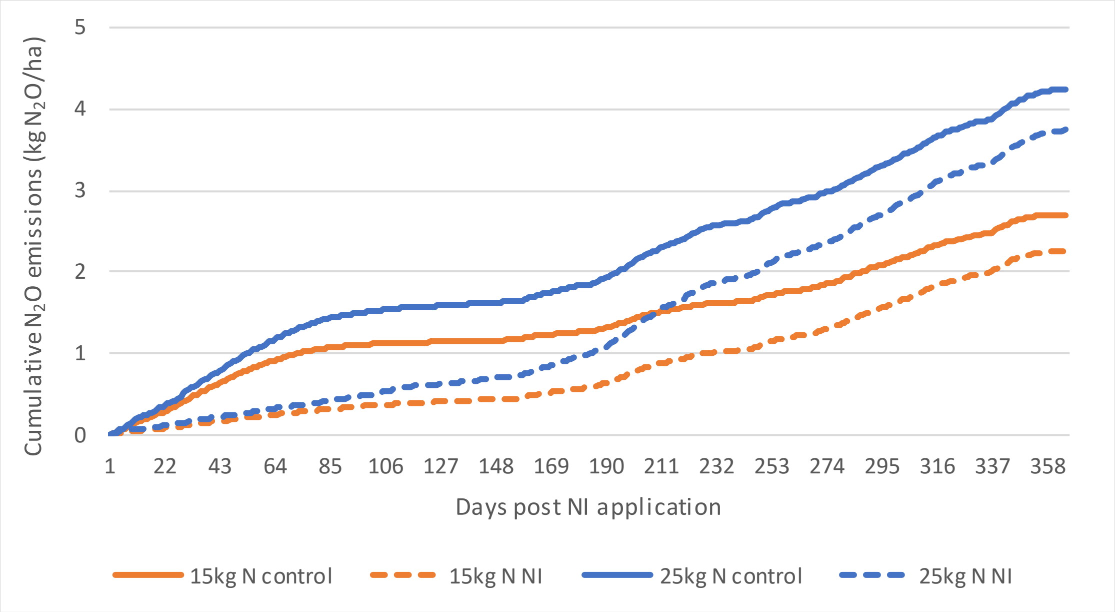

Figure 4. Estimated 18-year mean cumulative nitrous oxide emissions when applying either 15 or 25kg N/ha.month in autumn without (solid lines) or with(dotted lines) a nitrification inhibitor at Casino.

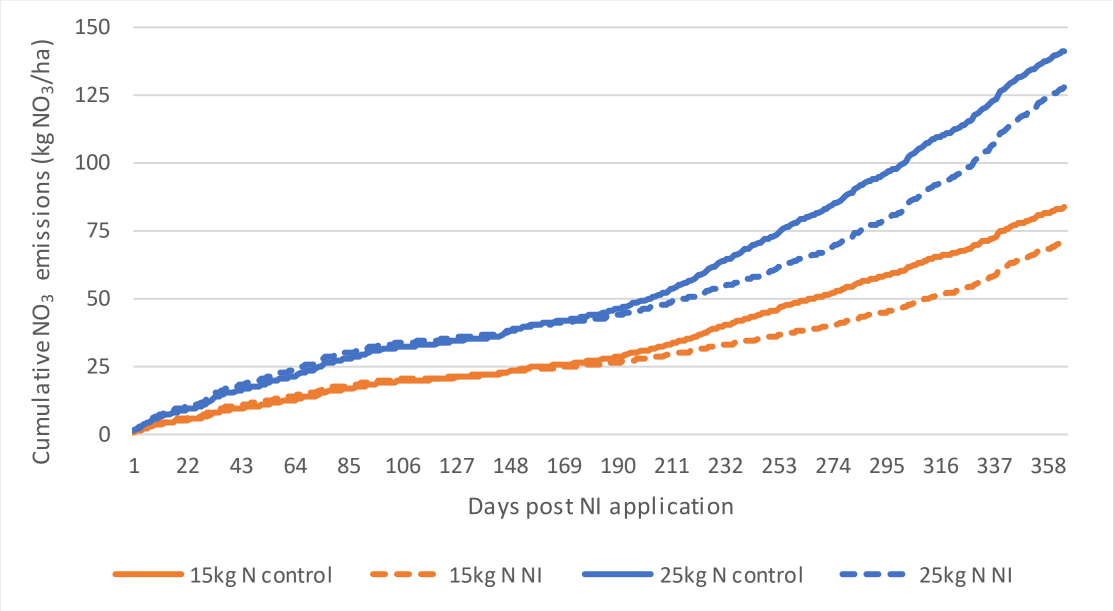

Figure 5. Estimated 18-year mean cumulative nitrate leaching when applying either 15 or 25kg N/ha.month in autumn without (solid lines) or with(dotted lines) a nitrification inhibitor at Casino.

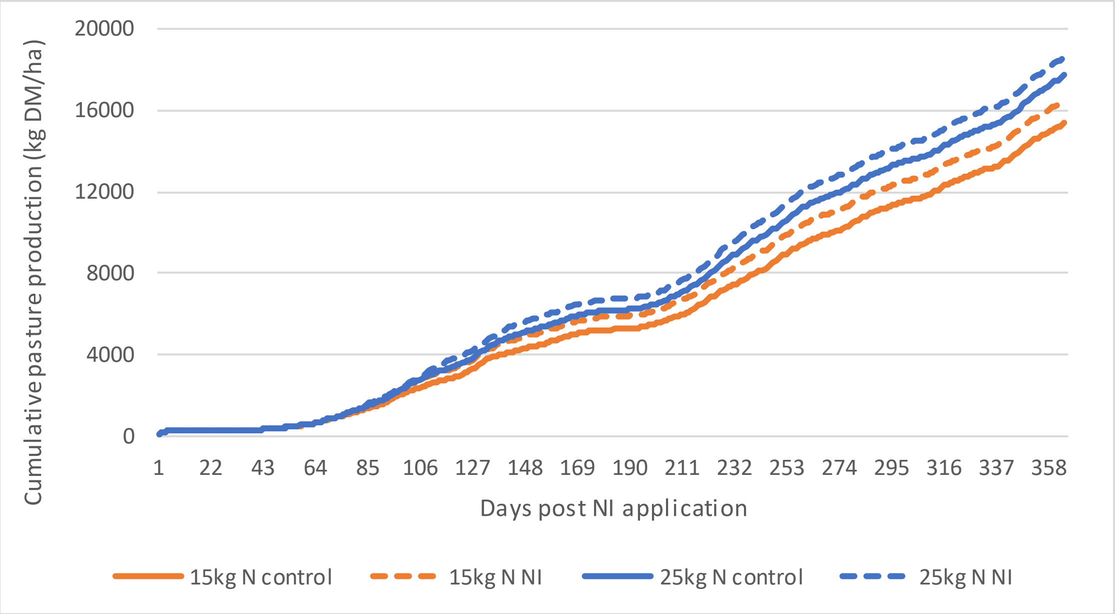

Figure 6. Estimated 18-year mean cumulative pasture production when applying either 15 or 25kg N/ha.month in autumn without (solid lines) or with(dotted lines) a nitrification inhibitor at Casino.

Discussion

Applying the NI, either in spring or in autumn as a one-off application, was beneficial in reducing N_2O loss, relative to the control, irrespective of N fertiliser rate or if comparing short-term or annually. The short-term reductions in N_2O emissions associated with incorporating an NI (autumn > 60% and spring > 50%) were higher than to those found by Kelly *et al.* (2008) where the NI reduced N_2O loss during spring by 43% over the first 120 days post-application of the NI. That said, it must be noted that the NI settings in DairyMod in this analysis were at the upper limit in terms of reduction in N_2O denitrification. The northern Victoria field site of Kelly *et al.* (2008) had cooler soil conditions than at Casino. In addition most of the rainfall at Casino was during the summer/early autumn months, so not corresponding to the increased risk period for N_2O loss between late autumn through to spring.

Field experimentation for the Casino region by Mumford *et al.* (2019), examining the effect of a range of irrigation regimes, found that N_2O loss varied between 3.8 and 5.9 kg N/ha.annum when applying 381 kg N/ha.annum. This was comparative to the control in this study, emitting ~ 4.2 kg N_2O/ha.annum with the comparative 25 kg N fertilise rate treatment. It must be noted that the field experiment was a cutting study, thus no recycling of N through the animal, although the site was previously grazed by up to 6 cows/ha, supported with N fertiliser rates of up to 340 kg N/ha.annum for decades prior to be excluded from grazed animals 3 months prior to the commencement of the experiment. Thus, there was most likely N available for mineralisation to contribute to N loss.

There was also a clear benefit in reducing N_2O emissions by including the NI with the higher N fertiliser rate during spring, with divergence between this and the 15 kg N control treatment not occurring until the efficacy of the NI would have substantially declined by around 100 days post application (comparison of blue dotted line with the solid orange line in Figure 1). The additional N fertiliser with the NI treatment was able to produce an additional tonne of DM production/ha over the first 100 days. Similar results occurred in autumn, when the NI applied in combination with the higher N fertiliser rate, was able to reduce N_2O losses below that of the lower N fertiliser rate without NI (comparison of blue dotted line with the solid orange line in Figure 4) for around 200 days, thus until spring, resulting in an additional 1.5 t DM/ha.

Overall, the NI was effective in reducing total N loss, with the reduction in N_2O and NO_3 offsetting the small increase in NH_3 volatilisation. However, over the full 12 month period, the reduction was only 10 to 11 kg N/ha.annum during autumn. This reduction in N loss, thus retaining the N in the soil for pasture production, was not sufficient to deliver the increase in DM production of ~ 1.0 t DM/ha.annum. There was essentially no difference in pasture production between the control and NI for the first ~ 75 and 90 days when the NI was applied in spring and autumn respectively. Thus, retaining the N in the NH_4 form in the soil was not the driver for additional pasture production during the NI activation period. The difference in soil N (inorganic and organic to full depth of soil profile) at the conclusion of the 18-year simulation was minimal between the control and NI. For example, the difference between the two treatments was only 27 kg N/ha with the autumn 25kg N fertiliser rate simulations. Soil water balance was consistent between the two treatments; therefore this alone did not promote additional pasture production. Thus, further exploration of the data is required as it is unclear what contributed to this increase in pasture production when the NI was applied.

Conclusion

The modelling results here indicate merit in applying a NI at the subtropical Casino region. Overall N loss was reduced, irrespective of whether the NI was applied in autumn or spring. While NH_3 loss was increased with the NI, this was offset by the reduction in N_2O and NO_3. The inclusion of the NI clearly promoted additional pasture production, especially in autumn, although the source of additional N to promote this increased pasture production can't be explained just by the reduction in N loss with the NI. In addition, if the focus for dairy farmers is to increase pasture production, without increasing N_2O emissions, there was a clear merit of applying 25 kg N fertiliser with the NI. However, NO_3 leaching was greater, and by a rate greater than the reduction in N_2O emissions, highlighting the importance of considering all aspects of the farm system and risk pathways for N loss.

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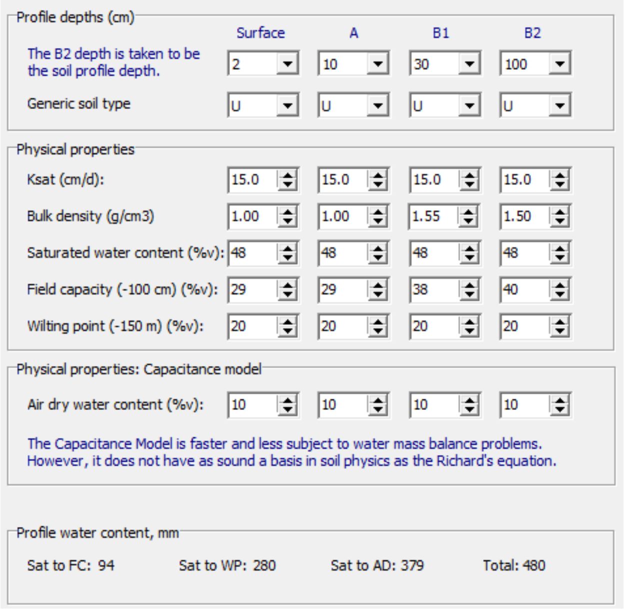
Appendix A



Profile depths (cm)

	Surface	A	B1	B2
The B2 depth is taken to be the soil profile depth.	2	10	30	100
Generic soil type	U	U	U	U

Physical properties

	Surface	A	B1	B2
Ksat (cm/d):	15.0	15.0	15.0	15.0
Bulk density (g/cm3)	1.00	1.00	1.55	1.50
Saturated water content (%v):	48	48	48	48
Field capacity (-100 cm) (%v):	29	29	38	40
Wilting point (-150 m) (%v):	20	20	20	20

Physical properties: Capacitance model

	Surface	A	B1	B2
Air dry water content (%v):	10	10	10	10

The Capacitance Model is faster and less subject to water mass balance problems. However, it does not have as sound a basis in soil physics as the Richard's equation.

Profile water content, mm

Sat to FC: 94   Sat to WP: 280   Sat to AD: 379   Total: 480

8.2.11 Summary of use of a nitrification inhibitor with 2 rates of N fertiliser in spring and autumn at Allansford and Casino

Reference

Not published as yet. Research led by Karen Christie.

Introduction

Nitrification inhibitors (NIs) are compound that delay the nitrification process in soils that converts soil ammonium into nitrite and then nitrate by depressing the activity of Nitrosomonas bacteria, thus reduce N loss through nitrous oxide (N_2O) denitrification and nitrate (NO_3) leaching. Two commonly used NIs are 3,4-dimethylpyrazole phosphate (DMPP) and dicyandiamide (DCD). A review of studies from New Zealand found that NIs could be reduce NO_3 leaching and N_2O denitrification from under dairy cattle urine patches by the order of 50 and 57%, respectively (Di and Cameron, 2016). In some of these studies, pasture production was reported to also increased by 20 to 25%. Some studies in Australia have resulted in no significant reduction in N loss coupled with no increase in pasture production (Dougherty *et al.*, 2016). Where the NI has significantly reduced N_2O loss, the amount of retained N has not necessarily translate into additional pasture production (Kelly *et al.*, 2008; Suter *et al.*, 2016). Given the efficacy of NIs are temperature and soil moisture dependant (Chen *et al.* 2010; Di and Cameron, 2016), modelling can assist in estimate the value proposition of applying NIs to dairy pastures across a range of spatial and temporal scales.

Aims of study

Using DairyMod, quantify the impact of nitrification inhibitors applied in autumn or spring, on seasonal pasture production yield and reducing NO_3 leaching, N_2O emissions and ammonia (NH_3) volatilisation from N fertiliser application at Allansford, south western Victoria and Casino, northern New South Wales.

Methods

DairyMod (version 4.9.6; Johnson, 2016) was used to examine N loss at Allansford and Casino. A single paddock was grazed by a herd of 200 lactating cows on the last day of each month. The cows were not fed any supplementary feed, so the N returned via their dung and urine was reflective of the N intake from the pasture. The feedbase was either perennial ryegrass at Allansford, or annual kikuyu over-sown with annual ryegrass pasture with the two pasture species growing at separate times of the year at Casino. Additional soil and pasture information for each site can be seen either in the previous Milestone report (May 2019), in the case for Allansford, or the current Milestone report (Nov 2019) for Casino.

N fertiliser and NI treatments

DairyMod was run for 40 years (1978 to 2017), with urea applied at a rate of 15 or 25 kg N/ha.month, commencing/concluding either in autumn or spring, to create a stable state for soil nutrient carbon and N. The soil nutrient conditions at the end of the long-term simulation became the new initial conditions for all data analysis simulations. Preliminary modelling of the effectiveness of a NI applied in spring in DairyMod at Allansford (south-western Victoria) indicated that to achieve reduction rates similar to those of the published papers, NI settings needed to be a minimum of 0.20 initial value (i.e. reduction of 80% at the commencement of the inhibitor) for 80 days and with a scale factor of 10. For both sites, the control treatment (no NI) was compared to an NI with 95% reduction for 100 days, representing the upper limit in terms of efficacy of the NI.

Eighteen year continuous simulations were then undertaken for two N fertiliser rates, 15 and 25 kg N/ha.month, commencing 1st March 2000, with NI applied 1st April, for the autumn simulations and 1st August 2000, with NI applied 1st September, for the spring simulations.

Results and discussion

Nitrous oxide emissions

Estimated cumulative N_2O emissions was greater at Allansford than Casino, irrespective of the season (Figure 1). The NI was effective in reducing 18-year mean annual cumulative N_2O emissions at Allansford in spring and both seasons at Casino. However, while the NI was effective during the first six months at Allansford when applied in autumn, cumulative N_2O at the end of the 12 months was greater with the NI compared to the control (Figure 1b). During spring at Allansford (Figure 1a) and autumn at Casino (Figure 1d), cumulative N_2O emissions were lower with the 25kg N with NI treatment, compared to the 15 kg N control treatment for approx. 280 and 210 days, respectively. However, by the end of the 12 months, N_2O loss was greater with the 25 kg N with NI treatment, compared to the 15kg N control treatment, although only just at Allansford in spring (Figure 1a).

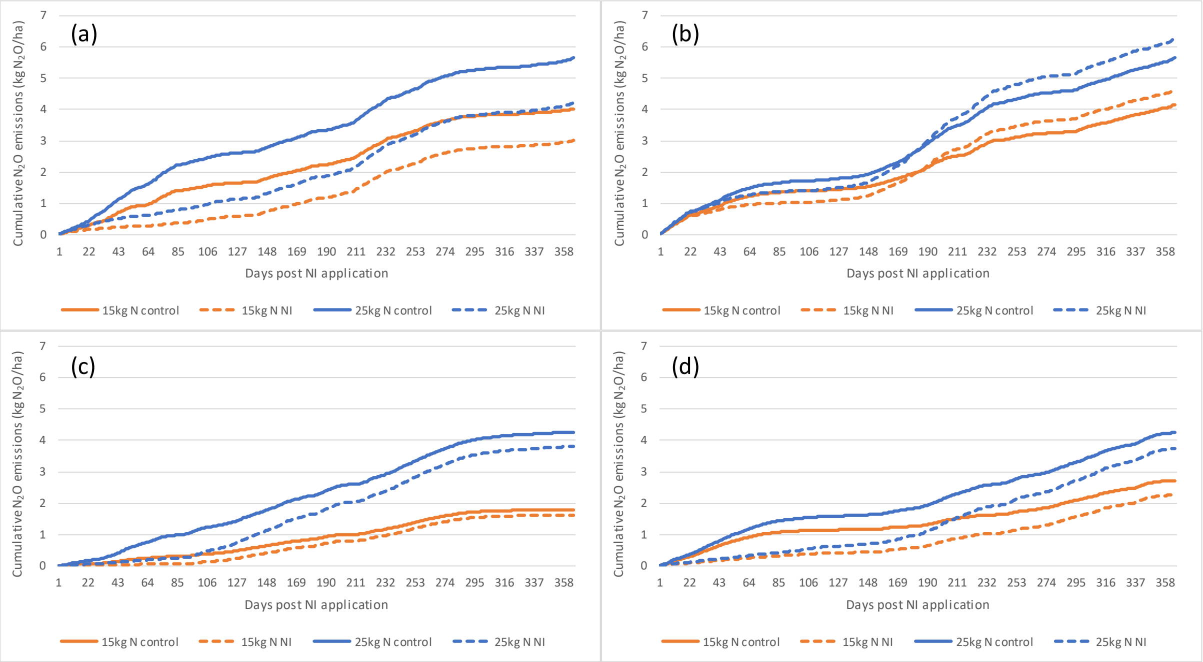


Figure 1. Estimated 18-year mean cumulative nitrous oxide emissions when applying either 15 or 25kg N/ha.month in spring at Allansford (a), autumn at Allansford (b), spring at Casino (c) and autumn at Casino (d) without (solid lines) or with (dotted lines) a nitrification inhibitor.

Nitrate leaching

Estimated cumulative NO_3 leaching was greater at Allansford than Casino, irrespective of the season (Figure 2). The NI had little to no effect in reducing NO_3 leaching when applied at Allansford during spring (Figure 2a), with only a small divergence between the control and NI at around 150 days at Allansford during autumn (Figure 2b), 130 days at Casino during spring (Figure 2c) and 200 days at Casino during autumn (Figure 2d). While the scaling of graphs in Figures 1 and 2 are different, there is clearly a greater benefit of the NI in reducing NO_3 leaching than N_2O emissions.

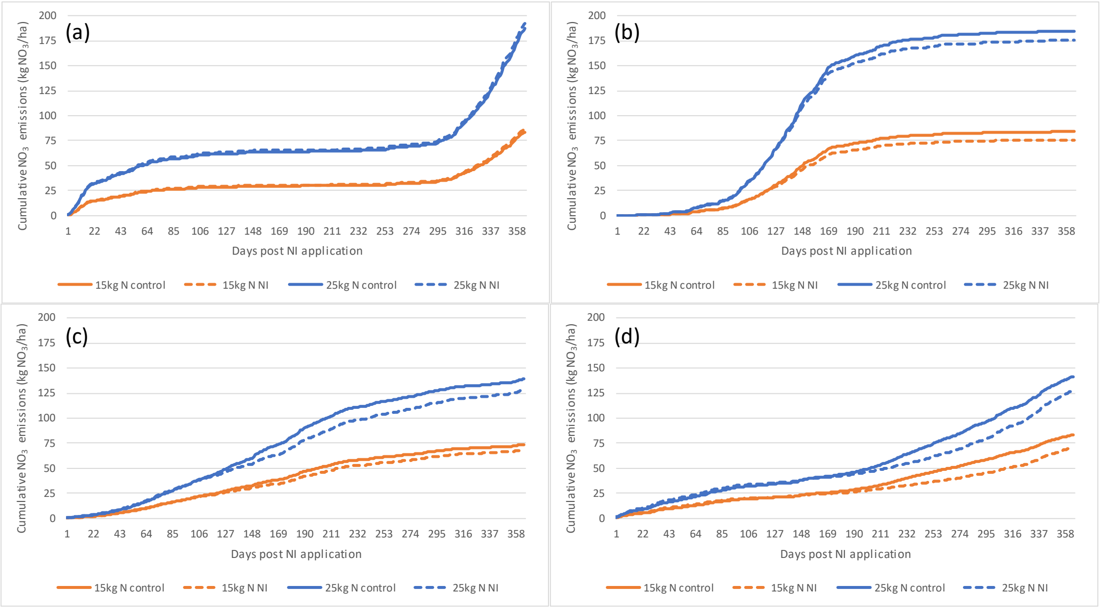


Figure 2. Estimated 18-year mean cumulative nitrate leaching when applying either 15 or 25kg N/ha.month in spring at Allansford (a), autumn at Allansford (b), spring at Casino (c) and autumn at Casino (d) without (solid lines) or with (dotted lines) a nitrification inhibitor.

Pasture production

Estimated annual pasture production was greater at Casino than Allansford, at around 16 t DM/ha.annum compared to 12 t DM/ha.annum (Figure 3). There was no benefit of applying an additional 10 kg N fertiliser per month or the NI at Allansford in terms of increasing pasture production (Figures 3a and 3b). In contrast, at Casino there was a benefit of increasing the N fertiliser rate from 15 to 25 kg N/ha.month (Figure 3c and 3d). The inclusion of the NI also resulted in additional pasture production, irrespective of N fertiliser rate at Casino (Figures 3c and 3d).

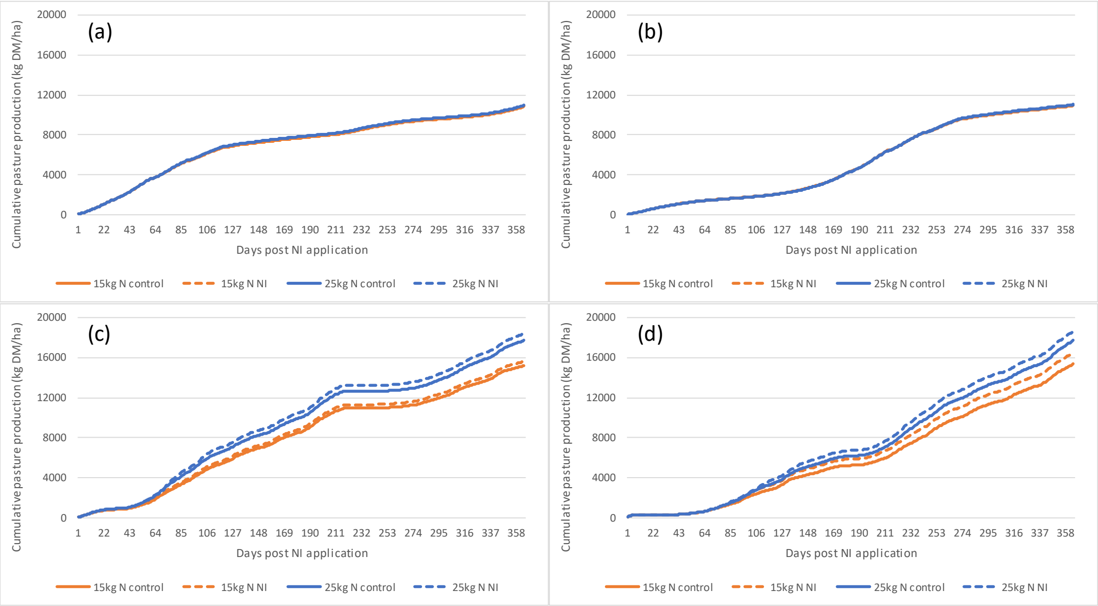


Figure 3. Estimated 18-year mean cumulative pasture production when applying either 15 or 25kg N/ha.month in spring at Allansford (a), autumn at Allansford (b), spring at Casino (c) and autumn at Casino (d) without (solid lines) or with (dotted lines) a nitrification inhibitor.

Conclusions

The inclusion of an NI was beneficial in increasing pasture production, reducing N_2O emissions and NO_3 leaching at Casino, irrespective of whether it was applied in spring or autumn. The question remains whether the cost of the NI remains lower than the cost of having to purchase additional supplement to overcome the difference in pasture production when comparing the control with the NI.

However, at Allansford, there was no benefit of the NI in terms of increasing pasture production, sufficient to cover the cost of the NI. In addition, while there was a small benefit of applying the NI in spring, in terms of reducing N_2O emissions, it did not reduce NO_3 leaching the following autumn/winter. There was also no benefit of applying the NI in autumn, to reduce N_2O emissions, as once the efficacy of the inhibitor had ceased by springtime, the N remaining in the soil became available for N_2O loss, although the amount of N lost via N_2O was lower than the reduction in NO_3 leaching. Thus, it is critical to evaluate which N loss pathway is more critical to reduce; N_2O, contributing to greenhouse gas emissions or NO_3, contributing to pollution of waterways.

There are notions within the industry that for an NI to be most effective and more likely to be taken up by farmers, there is a need to identify how much less N fertiliser, combined with an NI, a farmer can apply to produce a similar amount of pasture production. It is clear from this analysis, that applying 180 kg N/ha.annum in combination with an NI was not able to match annual pasture production compared to applying 300 kg N/ha.annum. However, could a farmer reduce N fertiliser to around 250 kg N/ha.annum in combination with an NI, and match pasture production to that grown when applying 300 kg N/ha.annum without the NI. Future analysis is needed to ascertain how much less N fertiliser can be applied, when combined with an NI, and whether the reduced cost of the N fertiliser can offset the increased cost of the NI.

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8.2.12 Managing nitrogen fertiliser on Tasmanian dairy farms

Reference

Not published as yet. Research led by Karen Christie.

Introduction

The N nutrition of dairy pasture systems in southern Australia has changed from an almost total dependence on legumes in the early 1990s (Eckard and Franks 1998), through to an almost complete reliance on N fertiliser today (Gourley *et al.* 2012). On-going intensification of the dairy industry has led to fewer and larger farms, with increased inputs of fertiliser and supplementary feed to maintain higher stocking rates. In 1990, the average Australian dairy farm imported 91 kg N/ha.annum, comprising of N coming onto the farm in supplementary feed (forages and concentrates), fertiliser and the estimated contribution of legumes. Farms exported 36 kg N/ha.annum in milk and meat (cull cows and non-replacement young stock), resulting in a 54 kg N/ha surplus. By 2012, the N surplus had increased to 158 kg N/ha.annum, due to a doubling of N imports to 214 kg N/ha while N exports only increasing to 57 kg N/ha (Stott and Gourley, 2016).

According to national farm benchmarking data (www.dairybase.com.au), the average Tasmanian dairy farm is stocked at 2.9 cows/ha, consuming 10.7 t dry matter (DM)/ha with annual N fertiliser inputs of 232 kg N/ha.annum. This highlights an emerging issue for dairy systems targeting high levels of pasture production, where an average of 22 kg N fertiliser/ha is applied for each tonne of pasture DM consumed. For fully irrigated temperate dairy systems, potential yields of 20 t DM/ha.annum have been reported (Rawnsley *et al.* 2007), thus N inputs of > 400 kg N/ha may be required to achieve these yields.

Using a modelling approach, the aims of this study were to: (i) examine a range of N fertiliser rates required to achieve 20 t DM/ha pasture consumption from five Tasmanian dairy regions, (ii) estimate the timeframe for comparative DM production between an initial low and high soil organic matter (OM) status, (iii) determine the effect of reducing N fertiliser inputs after stabilisation of DM production, and (iv) review the effect of reducing N fertiliser inputs after stabilisation on environmental N loss and N mineralisation.

Methods

This study used DairyMod (version 5.6.7; Johnson 2016), a herd of 400 milking cows grazed a single 1ha paddock, comprising of perennial ryegrass (*Lolium perenne)*, on the last day of each month across a range of Tasmanian dairy regions. Simulations were implemented used daily weather data, obtained as a patched point dataset from the Australian Bureau of Meteorology SILO dataset (Jeffrey *et al.* 2001). The cows were not fed any supplementary feed, so that all biomass above residual height (1.4 t DM/ha) was removed each grazing event. The N returned via their dung and urine was reflective of the N intake from the pasture. Irrigation was applied (25mm/application) when the cumulative rainfall deficit (rainfall minus potential evapotranspiration) was ≥ 25mm. Nitrogen fertiliser, as urea, was applied post-grazing and at rates of 10, 20, 30, 40 and 50 kg N/ha.month. While this report refers to N fertiliser inputs, given no other input source of N (except minimal atmospheric N in rainfall), the N fertiliser rate is indicative of all N inputs (fertiliser, supplementary feed and N fixation with legumes).

Two contrasting initial soil OM regimes were examined, a low OM starting status and a high OM starting status (Table 1). These two soil types were modelled across five dairy regions of Tasmania to ascertain the N fertiliser required to achieve 20 t DM/ha.annum. These were Currie (-39.93, 143.85), Togari (-40.91, 144.87), Sheffield (-41.38, 146.33), Scottsdale (-41.16, 147.52) and Ouse (-42.48, 146.71) (Figure 1). A two loops simulation was run from 1st Jan 1979 to 31st Dec 2018, with the data from the first loop discarded from data analysis.

Table 1. Contrasting initial soil conditions for the low and high organic matter regimes

	Low OM	**High OM**
Labile pool surface C%	0.5	1.0
Slow pool surface C%	1.5	3.0
Depth for 50% decline in C%, cm	15	20
C:N ratio labile pool	18	12
C:N ratio slow pool	18	12

Figure 1. Location of the five sites examined to ascertain the N fertiliser rate required to achieve 20 t DM/ha.annum.

The Togari site was then examined in more detail to ascertain the timeframe required to achieve comparative DM production between the two OM regimes. A new climate file was generated with the daily climate from 1st July 1999 to 30th June 2019, repeated seven times to create a 150-year 'current' climate file (longest simulation possible with DairyMod). This was undertaken to reduce the interdecadal change in climate over time, while allowing the model to stabilise in terms of DM production and soil N dynamics. A 100-year simulation was run with each N fertiliser rate by OM regime. In addition to DM production differences between the N fertiliser rate by OM regime, other aspects of the farm system were also explored. These included pasture biomass N concentration, N mineralisation and environmental N loss (nitrate (NO_3) leaching, nitrous oxide (N_2O) denitrification and ammonia (NH_3) volatilisation).

In addition, the low OM 50 kg N fertiliser regime simulation was run for 150 years, to allow stabilisation of the N system, with a step-change in N fertiliser implemented at the end of the 60th year. The N fertiliser was reduced to either 40, 30, 20 or 10 kg N/ha.month to ascertain the effect of a step-down in N fertiliser inputs on DM production, N mineralisation and environmental N loss.

Results

Comparison of sites to achieve 20 t DM/ha.annum

At the lower N fertiliser rates, there was a clear distinction in the long-term average annual DM production between the low and high OM status soils at all five sites (Figure 2). When applying only 10 kg N/ha.month, the high OM regime produced an additional 32 to 65% more pasture production relative to the low OM regime (variation due to site selection). The difference in pasture production between the two OM regimes was reduced to <10% with the 20 kg N/ha fertiliser rate, with minimal difference in DM production between OM regimes with the 40 kg N/ha fertiliser rate (Figure 2).

The target of 20 t DM/ha.annum was achieved at Ouse (Figure 2b), Scottsdale (Figure 2c) and Sheffield (Figure 2d), with Currie achieving 18.4 t DM/ha.annum (Figure 2a) and Togari achieving 19.3 t DM/ha.annum (Figure 2e) with the 50 kg N/ha fertiliser rates. The irrigation applied did not vary between N fertiliser rates, as the schedule was based on rainfall deficit, and was 4.0, 5.6, 4.8, 4.4 and 3.2 ML/ha.annum at Currie, Ouse, Scottsdale, Sheffield and Togari, respectively.

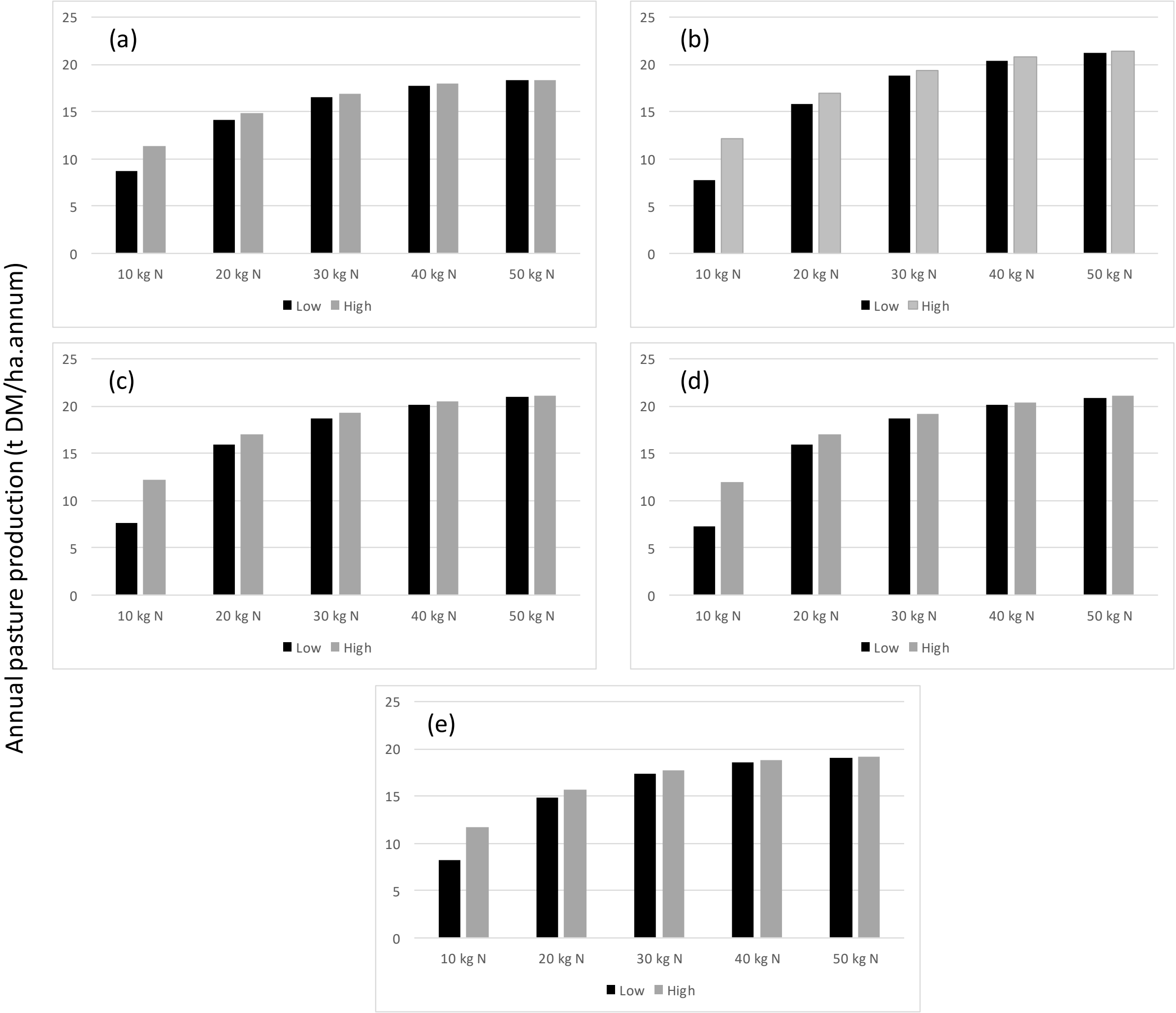

Figure 2. Estimated mean annual pasture production (t DM/ha.annum) under a range of N fertiliser rates, and either a low (■) or high (▨) organic matter starting point regime at (a) Currie, (b) Ouse, (c) Scottsdale, (d) Sheffield and (e) Togari.

Effect of starting soil organic matter status on pasture production and N dynamics

The timeframe required for the low OM regime simulation to achieve similar annual DM production to the high OM regime at Togari varied between N fertiliser rates (Figure 3). There remained a 9% difference in DM production between the low and high OM regimes after 100 years of applying 10 kg N fertiliser/ha.month (Figure 3a). In contrast, when applying 50 kg N fertiliser/ha.month, the low OM regime required ~ 15 years to produce a similar DM production (< 5% difference) to the high OM regime (Figure 3e). The low OM regimes required ~ 50, 30 and 17 years to produce within 5% of the high OM regime with the 20, 30 and 40 kg N fertiliser rates, respectively (Figures 3b, 3c and 3d).

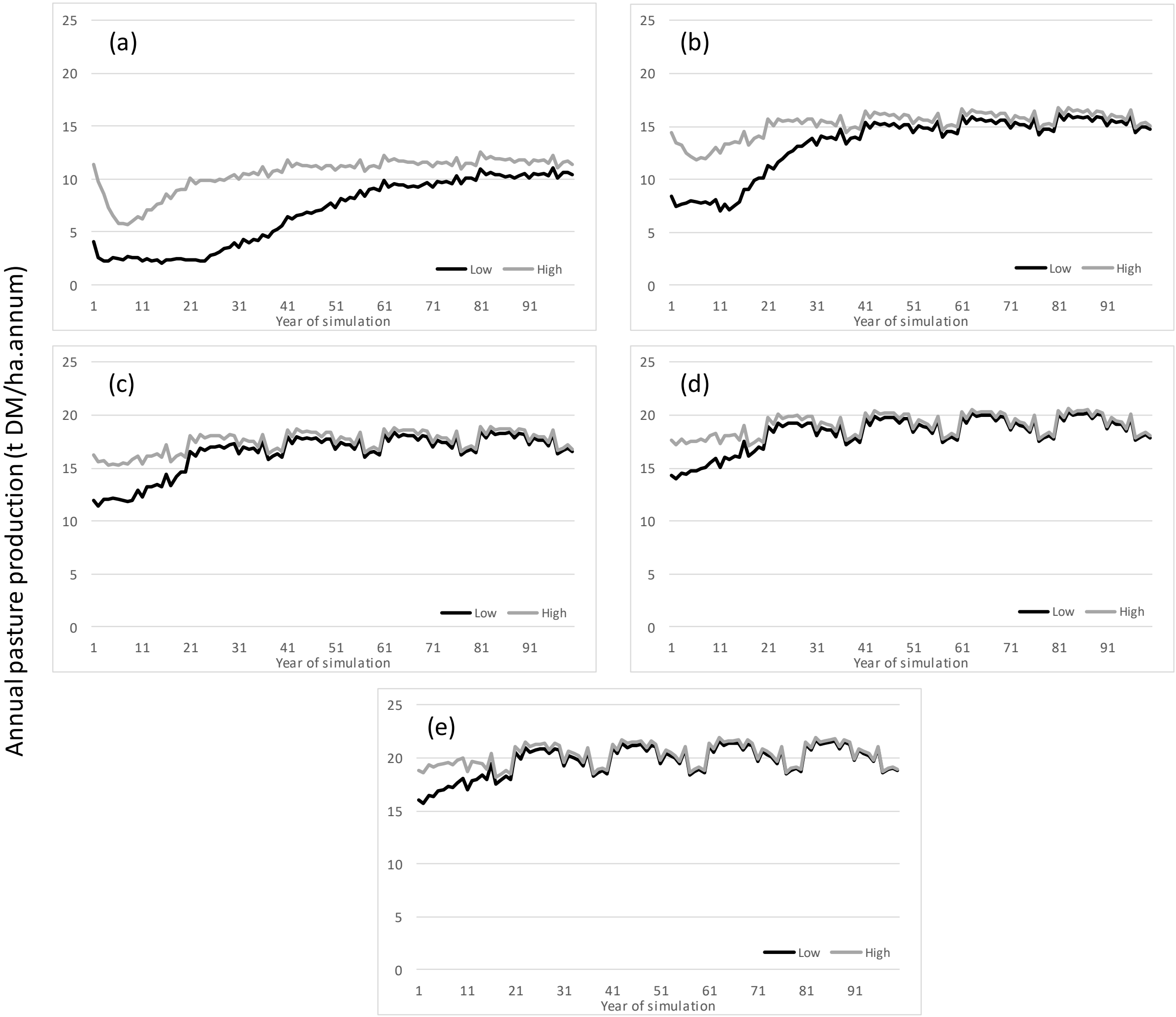

Figure 3. Estimated annual pasture production at Togari with the low (■) or high (▨) organic matter starting point when applying (a) 10 kg N fertiliser/ha.month, (b) 20 kg N fertiliser/ha.month, (c) 30 kg N fertiliser/ha.month, (d) 40 kg N fertiliser/ha.month, and (e) 50 kg N fertiliser/ha.month.

By the end of the 100 year simulation, there remained differences (> 5%) in soil N mineralisation for all five N fertiliser rates (Figure 4a). Only the 50 kg N rate results are shown here but a difference in N mineralisation remained for all five N fertiliser rates. For example, N mineralisation in the 100th year was 496 kg N/ha for the low OM regime compared to 523 kg N/ha with the high OM regime (Figure 4a). Similarly, with the 10 kg N fertiliser rate, in the last year of the simulation N mineralisation was 223 kg N/ha.annum with the low OM compared to 267 kg N/ha.annum with the high OM regime (data not shown).

When applying 50 kg N/ha.month, there was minimal difference in other N dynamics between the two OM regimes (Figure 4b to 4f). This minimal difference was consistent with the 20, 30 and 40 kg N fertiliser rates, with the exception of differences in the amount of leached N with the lower N rates. For example, when applying 20 kg N/ha.month, during the last 20 years of the 100-year simulation, the low OM regime was leaching 51 kg N/ha.annum compared to 67 kg N/ha.annum with the high OM regime (data not shown).

When applying 10 kg N fertiliser, there were differences in all N dynamics between the two OM regimes. For example, leached N at the end of the 100-year simulation with the low OM regime was 34% of the high OM regime leached N (data not shown). Likewise, urinary N with the low OM regime was 87% of the high OM regime.

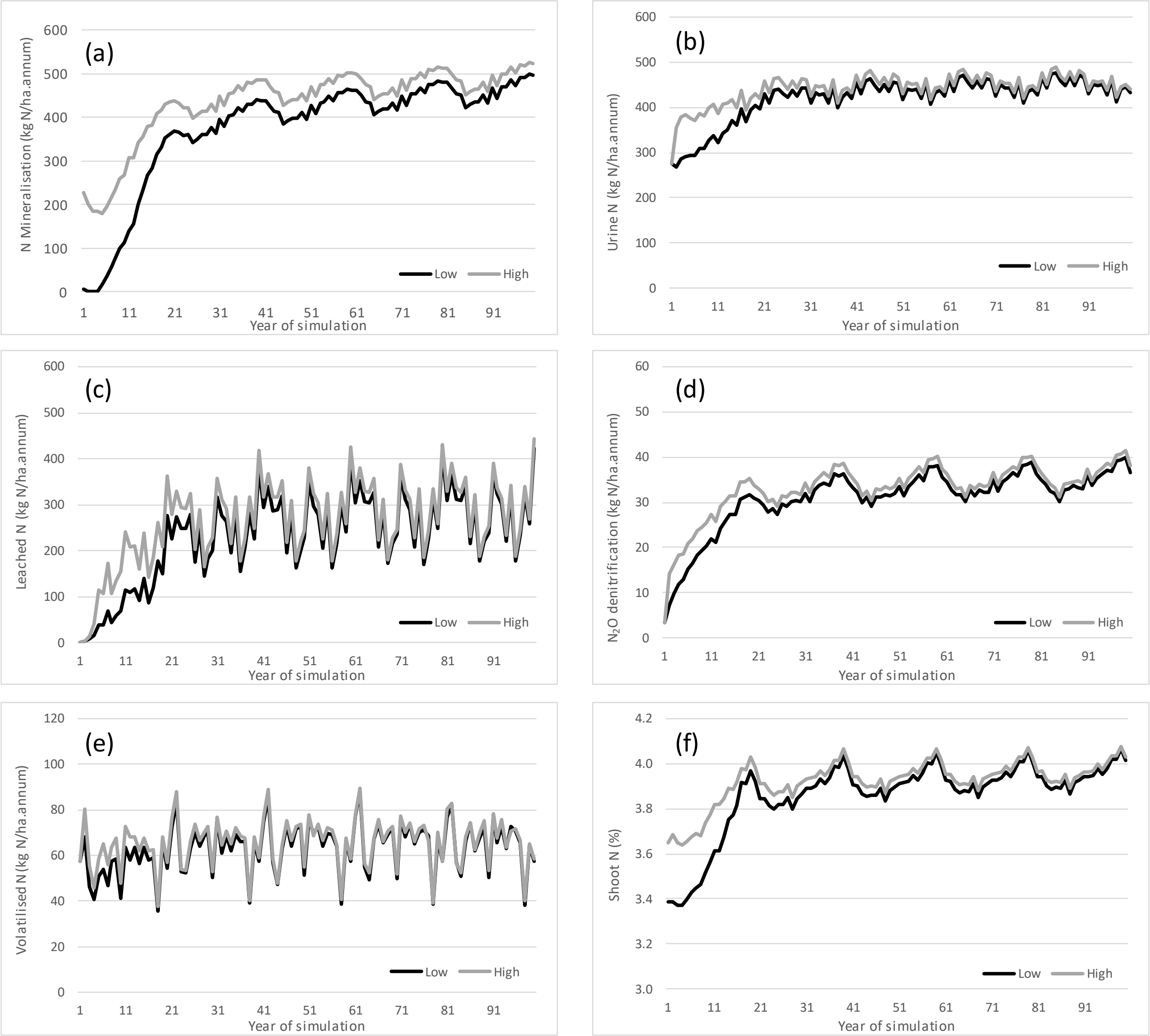

Figure 4. Estimated annual (a) N mineralisation, (b) urinary N, (c) leached N, (d) nitrous oxide denitrification, (e) ammonia volatilisation, and (f) shoot N concentration at Togari when applying 50 kg N fertiliser/ha.month in combination with the two OM regimes. Note the change in scale of the y-axis for some of the graphs.

Effect of reducing N fertiliser inputs after stabilisation of DM production

Reducing N fertiliser inputs from 50 kg N/ha.month to either 40, 30, 20 or 10 kg N/ha.month reduced DM production, with the rate of decline varying between N fertiliser rates (Figure 5). Annual pasture production declined the first year post application, by between 0.5 t DM/ha.annum with the 40 kg N fertiliser rate and 3.0 t DM/ha.annum with the 10 kg N fertiliser rate. At the end of the 150-year simulation, relative to applying 50 kg N/ha.month, annual pasture production declined by 5, 13, 22 and 39%, with the 40, 30, 20 and 10 kg N fertiliser rates, respectively (Table 2).

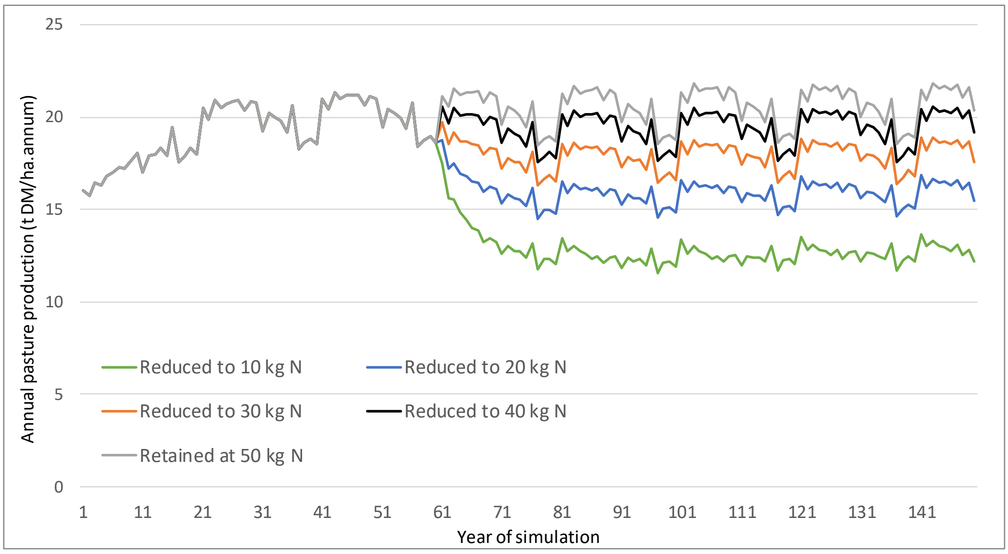

Figure 5. Estimated annual pasture production at Togari when reducing monthly N fertiliser input from 50 kg N/ha to either 40, 30, 20 or 10 kg N/ha at the 60th year of the 150-year simulation.

Reducing N fertiliser inputs from 50 kg N/ha.month to a lower rate of the N, reduced other N dynamics and by varying percentages, depending on the dynamic examined. For example, when averaged over the last 40 years of the 150-year simulation, reducing N fertiliser from 50 to 30 kg N reduced shoot N by 8% while reducing leached N by 53% (Table 2). Summing all three environmental N losses (leached, denitrification and volatilisation) together, reducing N fertiliser inputs to 40 kg N/ha.month reduced environmental N loss by 24%, and by up to 91% when reducing N inputs to 10 kg N/ha.month (Table 2).

Table 2. Effect of reducing from 50 kg N fertiliser to a lower N fertiliser rate on estimated annual pasture production (t DM/ha.annum) and a range of N dynamics (kg N/ha.annum), averaged over the last 40-years of the 150-year simulation.

	50 kg N fertiliser rate	**% reduction when reduced to 40 kg N rate**	**% reduction when reduced to 30 kg N rate**	**% reduction when reduced to 20 kg N rate**	**% reduction when reduced to 10 kg N rate**
DM production	20.6	5	13	23	39
N mineralisation	485	11	22	32	47
Dung N	165	9	19	31	41
Urine N	455	11	24	39	58
Leached N	295	27	53	79	98
N denitrification	36	17	33	49	76
Volatilised N	70	19	37	55	74
Total environmental N	418	24	48	70	91
Shoot N	4.0	3	8	14	22

Discussion

Under irrigated conditions, achieving ~ 20 t DM/ha.annum is possible throughout Tasmania when applying between 40 and 50 kg N/ha.month through N fertiliser, N fixation from legumes and supplementary feeding. Togari was explored in greater detail, and achieved 19.1 and 19.3 t DM/ha.annum with the low and high OM regimes, respectively, when averaged over the 40-year period from 1979 to 2018 inclusive. However, when modelling a more recent climate, by repeating the 1999 to 2019 climate several times over to generate a 100-year simulation, DM production over the last 20 years, averaged 20.5 and 20.7 t DM/ha.annum with the low and high OM regimes, respectively when applying 50 kg N/ha.month. Thus, the warmer climate of the last 20 years was able to increase DM production by around 1.4 t DM/ha.annum.

When modelling a repeat of the most recent 20 years of climate over 100 years, the low OM regime was able to produce similar DM production to the high OM regime after 15 to 18 years when applying high rates of N fertiliser (600 and 480 kg N/ha.annum, respectively). However, when starting with a low OM soil status, the 20 and 30 kg N fertiliser rates required 48 and 27 years, respectively, to be comparative (~ 0.5 t DM/ha.annum difference) to the high OM regime.

A low OM soil, when only applying 10 kg N/ha.month, was only able to produce ~ 90% of that produced with the high OM regime, even after 100 years.

The difference in DM production between the two OM regimes was most likely a result of the differentiation in N mineralisation between the two regimes, at ~ 50 and 30 kg N/ha.annum with the 10 and 50 kg N fertiliser rates, respectively (data not shown), when averaged over the last 20 years of the 100-year simulation. The lower N mineralisation with the low OM regime also contributed to lower N losses to the environment. The high OM regime lost an additional 17-20 kg N/ha.annum compared to the low OM regime, when averaged over the last 20 years of the 100-year simulation.

Currently, there are no pressures, financial or market-driven, for Australian dairy farmers to manage their N inputs to reduce N surpluses being potentially lost to the environment. Urea prices are relatively inexpensive, and there is no restriction to the amount of N inputs (fertiliser or manure slurry) that can be applied to pastures, unlike in other regions, such as New Zealand and Europe (DairyNZ 2013; Van Grinsven *et al.* 2016). However, this is unlikely to remain the case indefinitely, with an expectation that Australia will join most of the developed world in limiting N use (Rawnsley *et al.* 2019).

By modelling for an extended period of 150 years, with the same climate repeated every 20 years, reflecting the most recent climate, there was stabilisation of annual pasture production and N dynamics after ~ 60 years. Thus, from this point forward, we were able to reduce N inputs to ascertain the effect of this reduction in N inputs on pasture production and N dynamics.

Reducing N fertiliser by 20% reduced annual pasture production by only 5%, while reducing total environmental N loss by 24%, much of this as reduced leached N. Similar results have been found in other modelling experiments, where nominal reductions in N fertiliser, although resulting in a small reduction in pasture production, can deliver substantive reductions in N loss (Christie *et al.* 2019; Smith *et al.* 2019).

Conclusion

With scheduled and targeted irrigation, modelling suggests that it is possible to grow 20 t DM/ha.annum at all five sites across Tasmania examined in this study, although total N inputs to achieve this was between 480 and 600 kg N/ha.annum. Some farms could be importing this level of N, through high N fertiliser rates, supplementary feeding and N fixation via legumes. Applying N rates of this magnitude were able to overcome the lower OM status soils, to produce similar annual DM production within 15 to 17 years, although some N dynamics, such as N mineralisation remained lower with the low OM status soils, even after 100 years of simulations. Modelling a long-term high N input system and then implementing a 20% reduction in N inputs, while reducing DM production by a modest 5%, resulted in a substantially larger 24% reduction in environmental N loss, predominantly leached N. This N management approach requires further research in the final phase of this project.

References

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8.2.13 Investigating the microbial ecology of N_2O emission hot-spots in dairy pastures

Reference

Not published as yet. Study led by Karina Marsden.

Summary of the context and overall objectives of the project

Areas of dairy farm pastures with high stocking densities have been identified as hot-spots of emissions of the powerful greenhouse gas, nitrous oxide (N_2O). This is due to enhanced excretal deposition and pugging/poaching of the soil leading to edaphic conditions which can stimulate soil N_2O emissions. As such, mitigation strategies which target such farm areas have been suggested (e.g. application of nitrification inhibitors), but there is limited information on the efficacy of such technologies directly applied to these hot spot areas. The Target-N_2O project aims to determine the agronomic and environmental cost-benefits of a targeted nitrification inhibitor (DMPP) mitigation strategy in both northern and southern hemisphere intensive dairy farms. Specific objectives are to 1) establish factors influencing N_2O emissions and DMPP performance in soils with a history of high livestock impact; (2) determine if the microbial N-cycling community is functionally distinct in areas of soil with a history of high livestock impact compared to standard areas of pasture; (3) determine spatially appropriate N turnover rate constants and urine patch N_2O emission factors, with and without DMPP, in hot-spot feature soils, and (4) model paddock and farm-scale implications and conduct cost-benefit analysis of a targeted DMPP mitigation strategy.

Work performed from the beginning of the project to the end of the period covered by the report and main results achieved so far

Through conducting spatial sampling campaigns, we characterised the soil and vegetation characteristics as a function of distance from a farm-scale feature with high cattle occupancy. We established a gradient of impact by livestock from low (standard pasture), medium (gateway soil) and high (sacrifice paddock) impact by livestock. This resulted in soils increasing in bulk density, dissolved organic C and decreasing in degree of vegetative cover. We conducted an incubation experiment with intact soil cores taken from across this transect and monitored N_2O, CO_2 and CH_4 emissions and soil properties following cattle urine application. Cumulative N_2O emissions increased alongside the gradient of impact by livestock, and the temporal dynamics of N_2O emission and mineral N were affected by degree of impact by livestock. Soils from this study are currently being analysed for N cycling gene abundance and amplicon sequencing to determine the microbial community composition in these areas, towards Obj. 2.

A field trial was conducted on an intensive dairy farm in sub-tropical NSW, Australia (Fig. 1), to determine whether the nitrification inhibitor, DMPP, would be effective in reducing nitrification and subsequent N_2O emissions from an area of the farm receiving greater stocking densities (a gateway). The gateway area had a greater bulk density and labile C contents than standard pasture, indicating impact through livestock via poaching and pugging and excretal deposits. Under the conditions of our study DMPP (1.5 kg ha^{-1}) was ineffective in reducing nitrification rates or N_2O emissions. We tested increasing rates of DMPP application in the laboratory but found no effect on DMPP performance when increasing from 1 to 10 % of the urine-N applied. A similar field trial will be conducted in the return year (2021) on a temperate dairy farm to complete Obj.

3. Additional work for Obj. 1 in the return year will determine the efficacy of DMPP in reducing nitrification rates and DMPP degradation rates within a range of soil types, soil temperatures, soil moisture contents, degree of compaction and combinations of the above. This will help elucidate a mechanistic understanding of the variable efficacy of DMPP observed in the field.

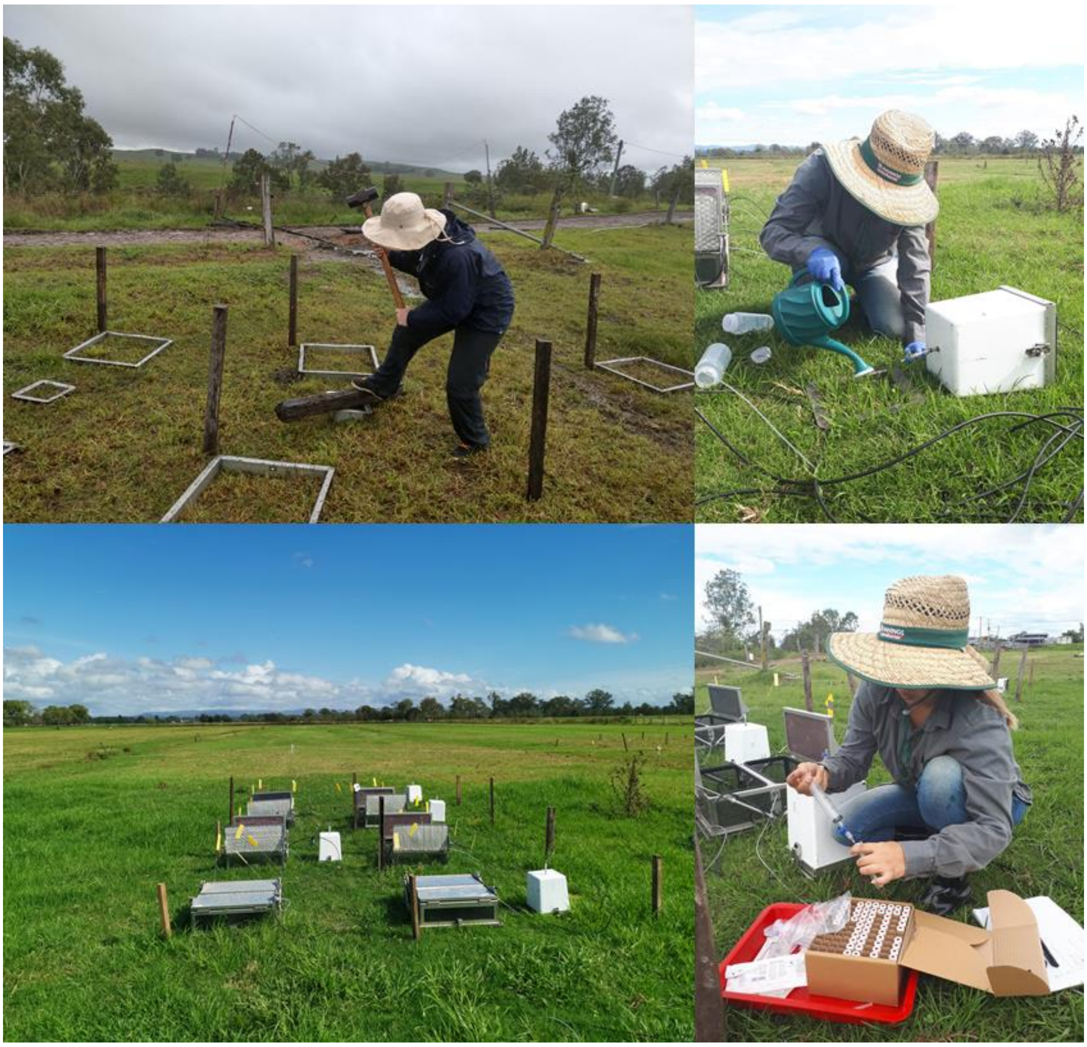

Figure 1 Establishment of field trial in an intensive dairy farm in Casino, NSW. Top left: installing greenhouse gas chamber bases in the field; top right: applying ^{15}N labelled urine to micro-chambers for N_2 flux determination; bottom left: automated greenhouse gas chambers in the field; bottom right: gas sampling using the ^{15}N-gas flux technique.

Using DairyMod we modelled the effects of nitrification inhibitor application on N gains and losses in temperate and sub-tropical intensive dairy farms. We specifically simulated standard areas of pasture and emission hotspot areas (through modifying bulk density, saturated hydraulic conductivity and degree of plant cover), running the model over a 20 year period. We simulated no urine deposition, single urine deposition and overlapping urine patches applied within each season at each site. Using a spreadsheet approach we calculated a partial N budget accounting for the environmental N loses and gains due to inhibitor application. In all our simulations, the nitrification inhibitor delayed rather than reduced N_2O emissions from urine patches. Nitrification inhibitor application was, however, effective in reducing NO_3^- leaching by up to almost 50%; therefore, it has the potential to reduce indirect N_2O emissions. A blanket nitrification inhibition strategy was more effective at reducing N losses compared to when the inhibitor was applied only to emission hotspot areas. Work is currently underway to assess the economic implications of each nitrification inhibitor application strategy.

Progress beyond the state of the art, expected results until the end of the project and potential impacts (including the socio-economic impacts and the wider societal impacts of the project so far)

At the end of the project we expect to deliver a decision-support tool which will inform farm managers on the best practice in terms of nitrification inhibitor application and use on dairy farms. This will cover a range of soil types and temperatures representing contrasting climatic zones, nitrification inhibitor application rates and expected duration of efficacy. Our results have demonstrated contrasting nitrogen cycling dynamics in soils with a history of livestock impact, suggesting these areas of dairy farms should be modelled as spatially explicit zones when assessing N losses. We expect this was due to contrasting microbial community composition and functioning between the areas, with analysis underway to confirm this. Results from our field trial in a sub-tropical dairy farm, we showed N_2O emission factors were not significantly greater from urine deposition to soil near a gateway. This does not provide evidence that these areas should be disaggregated within national greenhouse gas inventories. Whether the same phenomenon holds true in a temperate dairy farm will be explored in the return phase. The nitrification inhibitor, DMPP, did not reduce N_2O emissions from gateway soils in the field trial, adding to a growing body of evidence of a variable effect of DMPP in the field. We expect this may have been linked to warm temperatures resulting in rapid DMPP degradation. From our modelling study and economic analysis we aim to assess contrasting nitrification inhibitor application methodologies to see whether they are a financially viable mitigation strategies for dairy farmers. Results from the project will provide a better understanding of N cycling and N_2O emissions from emission hotspots of intensive dairy farms, leading to improvements in national greenhouse gas inventories and in quantification of the contribution of livestock to climate change. Practical advice will also be generated for the use of inhibitors on farm, relevant to farmers interested in reducing their carbon footprint, the dairy industry for developing sustainability roadmaps and policy makers assessing livestock greenhouse gas mitigation strategies within agri-environment schemes. The results are also expected to be of interest to the wider community interested in sustainable food production.

8.2.14 Modelling the efficacy of nitrification inhibition on two commercial dairy farms under temperate and sub-tropical conditions

Introduction

Study led by Karina Marsden. The protocol for this modelling study was included in Milestone 8. Two peer review papers are being prepared from this study with one conference abstract published.

Reference #1

Marsden K.A., Ward G., Martin B., Jones D.L., Gleeson D., Suter H.C., He J., Eckard R.J., Chadwick D.R. (2020) Nitrous oxide emissions and N cycling functional gene abundance in dairy pasture soils with contrasting degrees of impact by livestock. *Paper in preparation*.

Reference #2

Marsden K.A., Ward G., Jones D.L., Suter H.C., He J., Eckard R.J., Chadwick D.R. (2020) Targeting farm scale features for nitrification inhibitor application: an effective N_2O mitigation strategy? *Paper in preparation*.

Reference #3

Marsden K.A., dos Santos C.A, Friedl J., Rowlings D., Suter H.C., Eckard R.J., Chadwick D.R. (2019). Targeting farm scale features for nitrification inhibitor application: an effective N_2O mitigation strategy? Proceedings of the 2019 Greenhouse Gas and Animal Agriculture conference, August 2019, Igazu, Brazil.

Abstract

The movement and behaviour of grazing livestock can influence the fate of N at the farm scale. Features such as gateways, shaded areas, laneways and soil areas around drinking troughs are potential hotspots of emissions of the powerful greenhouse gas, nitrous oxide (N_2O). Here, elevated excretal loads can supply substrates (N-rich urine and C-rich dung) which fuel N_2O production processes, with elevated compaction also creating favourable conditions for denitrification. Nitrification inhibitors are a potential technology to reduce N losses from dairy pastures. Their effectiveness in reducing both N_2O and N_2 emissions from features where livestock congregate have not been widely studied. Utilising an automated greenhouse gas monitoring system, the current study assessed whether urinary-N emissions were higher when deposited to soil near a gateway in comparison to standard areas of pasture. The performance of the nitrification inhibitor DMPP was then assessed as a N_2O mitigation strategy from urine deposited to this gateway. The effect of DMPP on N_2 emissions was also measured using 15N-labelled urine, which although environmentally benign can amount to substantial agronomic losses of N from the system, plus allows calculation of total N loss through denitrification. The information will be used to assess whether targeted nitrification inhibitor application to features highly frequented by livestock can be used as an effective N loss reduction strategy in intensive dairy systems.

9 Table of Extension Activities

Activity name	Date	Location	Activity type	Participants
Nitrogen Use Efficiency field day - Bemboka	27/07/2016	NSW - South	Field day/ Walk	51
Nitrogen Efficiency Field day - Taree	28/07/2016	NSW Mid-Coast	Field day/ Walk	26
Gippsdairy field day - Maffra	26/04/2017	Victoria - Gippsland	Discussion group	18
Dairy farmer visit to Elliott Research Station	14/02/2018	Tasmania	Discussion group	29
Allansford Field day: Latest developments in nitrogen fertiliser use from local trials	23/02/2018	Victoria - SW	Field day/ Walk	38
Irrigation workshop - Field day	27/02/2018	Tasmania	Field day/ Walk	40
Nitrogen Field Day, West Gippsland	1/02/2019	Victoria - Gippsland	Field day/ Walk	27
N Field day Jamberoo	4/02/2019	NSW - South	Field day/ Walk	22
Evening N presentation - Nowra	4/02/2019	NSW - South	Evening presentation	23
N field day Bodalla	5/02/2019	NSW - South	Field day/ Walk	28
Naringal N Field day	22/05/2019	Victoria - SW	Field day/ Walk	67
Service Provider update - Warrnambool	23/05/2019	Victoria - SW	Industry Training	36
Australian Fertiliser Industry Conference Field Day: Quantifying the whole farm systems impact of nitrogen best practice on dairy farms	6/09/2019	NSW - North	Industry Workshop	103
What, Where and When? The use of nitrogen in pastures - Part 1	19/09/2019	Victoria	Webinar	86
What, Where and When? The use of nitrogen in pastures - Part 2	25/09/2019	Victoria	Webinar	72
Gippsland Dairy EAST & MID DISCUSSION GROUP Zoom Workshop	30/04/2020	Victoria - Gippsland	Discussion group	26
Making the Most from Nitrogen 2020 Webinar Series	28/09/2020	NSW Mid-Coast	Webinar	21
Strategic N applications give best responses MPfN Webinar	29/09/2020	Victoria - SW	Webinar	60
Strategic N applications - and the fate of N MPfN Service Provider Webinar	13/10/2020	Victoria - SW	Webinar	58
MPfN Webinar Nitrogen budgeting & rye-kikuyu carry-over	23/11/2020	Victoria - SW	Webinar	20

Workshops	**Date**	**Location**	**Activity type**	**Participants**
N modelling workshop #1.1	4/05/2017	Victoria	Research Training	26
N modelling workshop #1.2	5/05/2017	Victoria	Industry Training	25
N modelling workshop #2	27/02 /2018 28/02 /2018	Christchurch, NZ	Research Training	15

Conferences	**Date**	**Activity type**	**Participants**
MODSIM conference	5/12/2017	Conference	200
Presentation at Australasian Grassland Association conference	12/02/2019	Conference	55
19th Australian Agronomy Conference: Soil Nitrogen: can pasture yields be increased by capitalising on seasonal trends in mineralisation and immobilisation?	19/08/2019	Conference	200
6th Farming Systems Design Conference (FSD6) - Smith	29/11/2018	Other	600
ADSS 2018 Conference - Matt Harrison	25/06/2018	Communication to industry	250
ADSS 2018 Conference - Karen Christie	21/11/2018	Communication to industry	300
Harrison Agronomy Conference Abstract	29/11/2018	Research activity achievements	400

10 Table of Media and Communication

Media and articles	Date	Distribution
How now Gippy Cow article	1/11/2017	750
Australian Dairy Farmer - NBMPs	22/05/2018	4,000
Australia Dairy Farmer - Do nitrogen BMPs stack up?	1/08/2018	1,000
Marginal response to nitrogen fact sheet	1/02/2019	35
The Milk Flow - Dairy NSW newsletter	15/04/2019	500
BMPs for nitrogen (N) fertiliser use on dairy pastures	22/05/2019	1,000
ABC Radio Interview (Western Victoria): Richard Eckard on N BMP for Dairy	23/05/2019	5,000

Videos and podcasts	Date	Link	Views
Efficiency of nitrogen	18/07/2018	https://youtu.be/JsgjRCHXwxI	136
Timing of nitrogen application	18/07/2018	https://youtu.be/rjeS5BS22mg	295
Using Nitrogen to maximise your feed - Feed Shortage 2018	16/08/2018	https://youtu.be/8FuZFIeJ9GE	785
Maximising autumn with nitrogen	13/05/2019	https://youtu.be/MERql2I5DdE	354
DairyPod- Podcast for GippsDairy: NUE Strategies for 2019 Spring	26/09/2019	https://podcasts.apple.com/ca/podcast/podcast-9-prof-richard-eckard-on-maximising-spring/id1462706322?i=1000451017564	500
Nitrogen-grown pasture versus purchased feed	17/07/2018	https://youtu.be/-ZQlHIIU698	194
YouTube video: What, Where And When? The Use Of Nitrogen In Pastures (Part 1 of 2)	3/11/2019	https://youtu.be/oFmKvbqbGrs	316
YouTube video: How? The Use Of Nitrogen In Pastures (Part 2 of 2)	3/11/2019	https://youtu.be/5alVdxwhHtY	191
GippsDairy You Tube Video: Autumn Nitrogen May 2020	15/05/2020	https://youtu.be/T505-TVcMC4	38
Making the Most from Nitrogen Webinar “Denitrification Losses” #1	26/09/2020	https://youtu.be/Hqf1F1JehWc	53
MMON Webinar “Seasonal Nitrogen Demand” #2	26/10/2020	https://youtu.be/MwniTcwXvUA	25
MMON Webinar “Seasonal Nitrogen Demand” #3	26/10/2020	https://youtu.be/eOuxzrCqfMg	16