LUMEN

integrated environmental management

Reducing N-loss to water: A summary of available and effective solutions

Version 3 (Final)

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Prepared by Lumen Environmental

1. Introduction

1.1. Intent and use of this report

Intention of this Report

This report has been prepared under the direction of Alastair Rutherford and Sarah Heddell of Environment Canterbury to generate a guide for auditors to use in assessing the probable relative change in nitrogen emissions to water from farming activities, if a range of mitigating tools or techniques are employed in accordance with the manufacturer, provider, or researchers' recommendations.

The initial brief given was:

> "Environment Canterbury wishes to provide tools to both help farmers, and their consultants, design credible N loss reduction strategies and equip FEP Auditors with the resources to help evaluate compliance with a farm's NLL where changes to, or within, the Baseline Farming System have been made or N loss reductions are required."

The mitigating tools or techniques reviewed are considered to be above good management and are collated in a tabular format to be used for:

- Internal Regional Council audiences for consenting and FEP Auditing purposes
- Providing guidance for consultants preparing consents or advising farmers or for farm managers in practical situations.

In this report, we summarise the probable range and magnitude of the nitrogen emission reductions that can be expected from an associated mitigation. We also outline the key physical or environmental (slope, soil type, weather) and management attributes that influence the range of expected nitrogen emission reductions.

To avoid unintended consequences of implementing the mitigation techniques or tools, we have included a broad indication of potential indirect consequences (both positive and negative) that could result from the use of a mitigation. The indirect consequences are primarily focused on Green House Gases (GHG's) and phosphorus runoff.

Report Basis

The report is based on a review of literature both published and un-published (but repeated) relating to existing mitigation techniques and tools. We have reviewed mitigations that are:

- currently available in the market
- are likely to be utilised by a large number of farmers in the community
- could reasonably be expected to be employed without significant change to farm systems.

The mitigation efficacies presented within this report represent a paddock-scale effect of the mitigation. In many instances, the paddock-scale efficacy of mitigations reviewed have been derived by extrapolation of results from plot or pot trials.

This report reviews only management practices that exceed the Good Management Practice (GMP) standards. The report does not consider farm system re-engineering (significant farm system change) as farm system re-engineering is property specific, extremely complex, often includes changing stock number or type and can require investment in infrastructure. GMP and farm system re-engineering are outside the scope of this project.

While there have been farm scale assessments of the effectiveness nitrogen emission reducing tools and techniques (including informing planning for Environment Canterbury's LWRP, Plan Change 2 and Horizons One Plan, Plan Change 2), these farm scale assessments relied heavily on OverseerFM (and its predecessors) to calculate the potential nitrogen emission reductions resulting from implemented mitigations. This report was commissioned to investigate mitigation impacts on nitrogen emissions without relying on OverseerFM.

Limited to Canterbury

This report has been prepared for Environment Canterbury and therefore consider only mitigations that are both suitable and effective in the Canterbury Region.

The mitigations listed are a summary of readily available tools that auditors could reasonably expect farmers in Canterbury to be using, which have a proven and detectable impact on nutrient losses by employing the technology or technique.

Disclaimer and Limitations of Use

This report has been prepared as a guide for auditors to assess probable relative change in nitrogen emissions from farms if the mitigation tool or techniques listed are or are not employed.

This noted probable savings in nutrient losses by employing the mitigations detailed by this report are to be used as a guide only and should not be considered as an absolute.

No assumption should be made that mitigations are additive. This report summarises the reported range of impacts of individual mitigations when employed in isolation, it does not assess whether impacts of mitigations that are "stacked" are additive or not. Further research or the use of a bio-physical modelling software should be used to assess the impacts of "stacked" mitigations.

While reasonable attempts have been made to ensure that the information summarised and reported in this document are true and accurate, Lumen Environmental and the collaborating parties accept no responsibility or liability for the costs or water quality changes resulting from the implementation of the mitigations within.

The information and commentary in this document are provided for general information purposes only. We recommend the individuals seek specific advice about their circumstances from their adviser before making any financial or investment decision or taking any action.

1.2. Contributing partners

Through the research phase of this project, we have reached out to and/or collaborated with industry partners to fast track the collaboration of resource. We thank those who have provided time and information to us and/or who collaborated with us to bring this resource together.

Collaborators:

- Pip Hedley (Dairy NZ)
- Ina Pinxterhuis (Dairy NZ)
- Katrina Macintosh (Dairy NZ)
- Virginia Serra (Dairy NZ)
- Keith Cameron (Lincoln University)
- Geoff Bates (Pastoral Robotics)
- Denis Collins (Pastoral Robotics)
- Paul Daly (EMNZ)
- Jon Jackson (Jackson Spreading Ashburton)
- Barenbrug
- Glenn Judson (Agricom)
- Alister Moorhead (Agricom)
- Sarah McKenzie (Agricom)
- Jeff Hurst (Nufarm)
- Hamish Brown (Plant and Food Research)
- Anton Nicholls (MRB)
- Ian McIndoe (Aqualinc Research Ltd)
- Ants Roberts (Ravensdown)
- Ballance Agri-Nutrients
- Hort NZ
- Potatoes NZ
- Pioneer
- Turi McFarlane (Foundation for Arable Research)

We would also like to acknowledge industry partners for their time reviewing and providing feedback on the draft versions of this report. Industry partners that have provided feedback include:

- Beef and Lamb NZ
- DairyNZ
- DeerNZ
- Environment Canterbury
- ECan Auditor Reference Group Members
- Foundation for Arable Research
- IrrigationNZ

1.3. Contributing authors

Reuben Edkins

Project Lead and Technical reference.

Bachelor of Commerce (agriculture), Master of Commerce (farm management) 17 years experience integrating resource management, compliance and environmental legislation, into viable farm businesses.

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Victoria Bishop

Technical reference.

Bachelor of Commerce (agriculture) Lincoln University (2015), 5 years' experience in nutrient management, and environmental legislation. Certified Nutrient Management advisor.

Mark Everest

Technical reference and editor.

Bachelor of Agricultural Science (Hons), 12 years independent farm systems advisory, research and extension integrating resource management efficiency. Project led several projects considering impacts and implementation nutrient loss mitigation strategies on farm management and financial performance. Contributed to Irrigo audit A+ framework.

2. Table of Contents

3. Summary

With the assistance of industry experts, a review of literature regarding nitrogen loss mitigation strategies available to farmers in Canterbury was carried out.

The goal of the project was to determine: the efficacy of the different mitigations identified; any limitations to implementing them; the probable cost to the farm of uptake; and any other effects resulting from implementation, in order to assist Environment Canterbury in measuring the progress of farms in meeting the nitrogen loss reduction targets under the LWRP.

The effects of the mitigations (unless otherwise noted) are specific only to the part of the farm to which they relate. For example: if 50% of a property is pasture and a mitigation was employed on the pasture with a 20% nitrogen loss reduction efficacy, the 20% efficacy only applies to the pasture block, not the whole farm.

The overall results from each mitigation strategy are listed in the table below and more information can be found in the corresponding sections. For some mitigations, there was no independently validated reduction in N loss established in the research. While these mitigations show promise, at this stage we have preferred to err on the side of caution and report a "no reduction" outcome for those mitigations. For some other mitigations, while found to be effective at reducing nitrogen emissions to water, the technology might not be available yet or may be costly to implement.

Please note that the cost per kg N conserved is calculated on market costs as at April 2022 and assumes a base pastoral leaching rate of 60kgN/ha/year.

The mitigations assessed have been assessed primarily in trial work that focus on one mitigation per trial. As a consequence, industry at this stage is unable to ascertain if mitigations "stack" or if some "offset" each other. The gap in this knowledge is something industry is aware of and research is yet to be completed to ascertain if any antagonistic/synergistic relationships exist between mitigations, or under which environmental conditions the efficacy of mitigation is influenced by antagonistic/synergistic relationships.

Overall mitigation strategy	Mitigation Tool	System N loss Reduction Significance	Limitations that impact effectiveness		Effective Range (% N loss/ha conserved	Cost ($/kgN conserved)	Indicative GHG impact
			Environmental	Management			
Cool season active grasses	Italian ryegrass based pasture	***	Less persistent in light soils. Less effective in very cold climates or saturated soils.	2-3 year life span, sensitive to treading damage.	24-54% lower N loss than other pasture swards	$8.85	None noted Possible reduction due to higher average digesibility of annual and italian ryegrasses.
	Late maturing Perennial ryegrass based pasture	-	less functional in heavier soils or cool climates. Likely only functional in coastal areas.	Persistent	0% lower N loss than other perennial pasture swards	$0	
	Annual ryegrass based pasture	*	Less persistent in light soils. Less effective in very cold climates or saturated soils.	One year life span, sensitive to treading damage.	53-58% lower N loss than other pasture swards	$8.85	
Plantain (approved varieties)	Plantain in sward up to 30%	****	less persistent in light soils. More persistent in heavier soils. Sensitive to treading damage and over grazing.	High grass seed rates can smother plantain at establishment. Regular re-seeding of plantain required to maintain >20% plantain in pasture.	10% - 40% reduction in N loss from feeding 10% - 30% plantain. (1% n loss reduction per 1% plantain in diet)	$3.80-$7.60 (15% plantain)	Has been found to reduce CH_4 emissions. More research required.

Overall mitigation strategy	Mitigation Tool	System N loss Reduction Significance	Limitations that impact effectiveness		Effective Range (% N loss/ha conserved	Cost ($/kgN conserved)	Indicative GHG impact
			Environmental	Management			
Low protein supplements	Feeding low protein supplementary feeds (ie maize silage or wheat/barley grain)	**	Less practical on heavy soils. Increased risk of soil damage resulting on heavy soils.	Cost and practicality of feeding supplement. Farm system preferences (low vs high supplement) Skill set of management to implement successfully. N loss from the ground used to grow the supplement needs to be lower than the farm it is getting fed out onto to have a nett positive impact.	8-21% reduction in N loss from feeding up to 30% diet as low protein supplements. (0.5% reduction per 1% diet as low protein)	\$2.60 (substituting pasture silage) \$146.70 (substituting pasture)	Reduction in N_2O emissions (depending on farm system)
High Sugar Grasses	High Sugar Grass based pastures	-	Not currently functional in Canterbury	Not currently functional in Canterbury	-	-	Not currently functional in Canterbury
Methanogen Inhibitors	Modifying rumen microflora by adding methanogen inhibitors to feed	-	No N loss reduction validation	No N loss reduction validation	-	-	Reduction in CH_4 emissions
Nitrification inhibitors	Gibberellic acid and Lignosulphonate (LS)	***	Gibberellic acid can increase clover content, leads to higher N loss if insufficient LS applied.	Most cost effective when targeted to urine patches. Must be applied within 48 hours of grazing for reliable results. Requires high macro-nutrient presence under urine patch to maintain efficacy across a season.	0-25% reduction N loss	\$6.36-\$24.49 (assumes 12.5% reduction in N loss)	Reduction in N_2O and CO^2 emissions
	3,4-dimethylpyrazole	-	More functional on lighter soils.	Most cost effective when targeted to urine patches. Increase in DM production.	29% reduction N loss	Not currently available	Reduction in N_2O emissions probable
	Calcium lignosulphonate (Ca-lig)	-	More functional on lighter soils.	Reductions given are % nitrification reductied	Pumice: 59% Pallic:32% Recent:39%	Not currently available	Reduction in N_2O emissions probable
	Co-poly acrylic-malic acid (PA-MA)	-	More functional on lighter soils.		Pumice: 56% Pallic:26% Recent:38%	Not currently available	Reduction in N_2O emissions probable
Urease Inhibitors	Coated urea products	-	No N loss reduction validation	No N loss reduction validation	-	-	Reduction in N_2O and CO^2 emissions
Catch crops	Catch crops	*****	Surplus N extracted from soil to reduce leaching risk. Most effective on light soils. Diffcult to establish in high rainfall/wet seasons/on heavy soils. Less effective in high rainfall seasons.	Timing of planting must be within one month of grazing for optimal results. Only effective on the part of paddock that is planted within one month of grazing - part paddock plantings needed for optimal results.	22-40% N removed	-\$4.32 (profit) - \$11.02	-
Supplement and Forage balancing	Feeding fodder beet in winter	*****	Potentially more damange to soil structure due to higher yields and therefore more time grazing paddock.	Careful management required to transition cows onto fodder beet	32% reduction in comparison to kale (29 kg N/ha)	-\$17.75 (profit)	Reduction in CH_4 emissions
	Feeding fodder beet in late lactation	**	Strategic used can avoid damage to pasture paddocks. Can result in winter fallow if catch crop is not sown.	Reduced production if not transitioned carefully. Minimum of 25% diet required to show effects, optimal results at 40% of diet.	7.1% reduction in urinary N in comparision to pasture only diet (Overseer suggests neutral after considering losses from crop paddock)	(nett cash positive)	Reduction in CH_4 emissions
Capture of rainfall in shoulders of irrigation season	Changing irrigation trigger points during season	****	Assumes 100% water reliability.	Operator must regularly view changes in soil moisture and adjust irrigation targets. Best results achieved when irrigation can be managed according individual crop and soil requirements. Most applicable to centre pivots, fixed grid, drip and sub surface drip systems.	Average reduction 27% (19 kgN/ha/yr) (range 4-58%)	-\$4.98 (profit)	None given, potential reduction N_2O emissions

Overall mitigation strategy	Mitigation Tool	System N loss Reduction Significance	Limitations that impact effectiveness		Effective Range (% N loss/ha conserved)	Cost ($/kgN conserved)	Indicative GHG impact
			Environmental	Management			
Nitrogen Type	Liquid Nitrogen and Fine Particle Application	-	No N loss reduction validation	No N loss reduction validation	-	-	Reduction in N_2O emissions
Non-Nitrogenous Growth Promotants	Gibb Acid	-	Best results achieved with soil temperature, moisture, soil nitrogen availability.	Replacing N fertiliser with Gibb Acid reduces pasture production in long term if underlying nutrient status is not maintained. Best results achieved when applied 0-5 days after grazing and remains ungrazed for 20 days from application. Works on plant and soil, once leaf is grazed off effect is reduced.	0% (refer to Nitrification Inhibitor section)	- (refer to Nitrification Inhibitor section)	Reduction in N_2O emissions
	N-Boost	***	Best results achieved with soil temperature, moisture.	Increases dry matter response per kg N applied. From 12:1 to 24:1. Inconsistent results.	15% reduction in N loss (modelled for Canterbury dairy farm)	$4.00	Expect reduction in N_2O emissions. (if N fertiliser volumes decrease)
	Effective Microbes	-	-	Must be sprayed on. Works on the soil and plant, once grazed, the plant function is reduced.	- (expect reduction as n ue efficiency increases)	-	-
Variable Rate Irrigation (VRI)	Variable rate irrigation alongside soil mapping (EM survey).	***	More advantageous on highly variable soils.	Irrigation to within 5% of available water holding capacity. More advantageous with localised weather station and evapotranspiration data. Multiple moisture probes needed (one per management zone).	80-85% reduction in N and P in drainage. 10% reduction in potato crop n loss. 16-33% less drainage volume.	$0.38 - $10.02	None given, potential reduction N_2O emissions
Crop N budgets and soil N testing	Soil nitrogen testing and crop nitrogen budgeting.	****	Mineralisable N influenced by soil moisture status and temperature. Soil N testing is difficult to complete on stony soils.	Test return timeframes can be more than one week. regular testing required to complete full picture. Timing of application to meet crop needs requires diligent manager with intimate crop knowledge.	0-40% (trial 4kg/ha from 9kg)	-$14.01 (profit)	Expected reduction in N_2O emissions
Horticulture Input Optimisation	Increased frequency of nitrogen assessment and application	**	High Rainfall, or low rainfall not suiting use.	The time to continually review N decisions. Accuracy of min N predictions	0-80% (suggested not measured)	(expect cost savings with efficiency gains requiring less inputs)	Expect reduction in N_2O emissions. (if N fertiliser volumes decrease)
	Optimum irrigation application	**	Wet seasons	Accurate soil moisture readings to avoid crop stress at key times	0-85% (based on VRI section)	-	N/A
	Types of tillage	-	Condition of soil. More burning is likely with less cultivation.	Appropriate for crop and residue management.	40% (compacted soils)	-	Tillage can increase N_2O emissions if compaction occurs
	Crop rotation	**	Effect of temperature and rainfall on N mineralisation	Efficiency of getting next crop in ground after harvest	-	-	Expect reduction in N_2O emissions. (if N fertiliser volumes decrease)

4. Method

4.1. Available Solution selection criteria

The N-loss mitigations selected in this analysis were considered for assessment as they are:

1. Readily available in the market
2. They are tools or techniques that Lumen consider to have been trialled sufficiently to give confidence that a mitigation will likely or will not likely result in a reduction of N loss to water if implemented.
3. The reduction in N loss to water resulting from the implementation of the described tool or technique, would be detectible or material.

An initial list of mitigation tools and techniques was compiled by Lumen, based on work already completed by Lumen for Irrigo. The list of proposed mitigations was submitted to Alistair and Sarah for consideration and refined to the final list presented and assessed in this report.

We acknowledge there are other mitigations available, however, they were not considered at this time because they did not sufficiently meet the criteria outlined in the first two paragraphs of this section.

4.2. Industry collaboration

In the interest of leveraging previous work of similar nature and ensuring greater resolution and detail of the potential impacts of mitigations, we elected to collaborate with the wider industry for their input. Due to the time and financial constraints of this project, it was not possible to consult with all members of industry, rather we have relied on key relationships already established that either have undertaken or invested in independent and scientific validation of technologies.

Mitigation subject matter experts were contacted with a brief explanation of the project and were asked to supply reference material to support the review of the topic or for any other contacts they had. The majority of experts we reached out to were able to respond with scientific papers or industry productions for us to review.

The key researchers and organisations within the industry that were identified in relation to the topics are listed in the table below. Some mitigations had more than one expert associated with them, and many researchers and collaborators were considered experts across multiple topics.

Mitigation	Expert or Organisation
Cool Season Active Grasses	Keith Cameron; Pip Hedley (DairyNZ); Ina Pinxterhuis (DairyNZ); Katrina Macintosh (DairyNZ); Virginia Serra (DairyNZ)
Plantain	Glenn Judson (Agricom); Alister Moorhead (Agricom) Sarah McKenzie (Agricom) Pip Hedley (DairyNZ); Ina Pinxterhuis (DairyNZ); Katrina Macintosh (DairyNZ); Virginia Serra (DairyNZ)
Low Protein Supplements	Pioneer
High Sugar Grasses	Keith Cameron; Glenn Judson (Agricom); Alister Moorhead (Agricom) Sarah McKenzie (Agricom); Barenbrug
Methanogen Inhibitors	
Nitrification Inhibitors	Geoff Bates (Pastoral Robotics); Denis Collins (Pastoral Robotics); Jon Jackson (Jackson Spreading)
Urease Inhibitors	Ballance Agri-Nutrients
Cover/Catch Crops	Pip Hedley (DairyNZ); Ina Pinxterhuis (DairyNZ); Katrina Macintosh (DairyNZ); Virginia Serra (DairyNZ)
Supplement and Forage Balancing	Keith Cameron
Capture of rainfall in shouders of irrigation season	Ian McIndoe (Aqualinc Research Ltd)
Nitrogen Type	Ants Roberts (Ravensdown); Anton Nicholls (MRB); Turi McFarlane (Foundation for Arable Research)
Non-Nitrogenous Growth Promotants	Paul Daly (EMNZ); Geoff Bates (Pastoral Robotics); Denis Collins (Pastoral Robotics); Jeff Hurst (Nufarm)
Variable Rate Irrigation	Ian McIndoe (Aqualinc Research Ltd)
Crop N budgets and soil N testing	Hamish Brown (Plant and Food Research); Anton Nicholls (MRB)
Horticulture Input Optimisation	Hamish Brown (Plant and Food Research); Potatoes NZ; Hort NZ; Turi McFarlane (Foundation for Arable Research)

Figure 1: Experts approached for each mitigation identified

4.3. Rigour of assessment

Due to the assistance provided by experts and industry bodies we were able to gain access to a number of useful resources in a time efficient manner. References in these resources were used to find additional material as were searches of scientific publications to ensure we covered as much material on the topic as possible. When phone conversations with experts yielded pertinent information to a mitigation in which they had considerable knowledge or expertise, the phone call was referenced and content used in the analysis.

Reference material was limited to scientific publications except where other printed material was recommended or provided by subject matter experts.

Papers identified for each topic were reviewed and key points regarding results and methodology were highlighted to ensure different environmental conditions and management decisions could be considered. Where there was no cost-benefit analysis in reported in the research papers, additional research or calculations were undertaken to determine the cost or benefit of using the mitigation.

The summary of findings in some fields has been submitted for review by subject matter experts where we considered a final third-party review necessary.

4.4. Assessment Table

Significance (System N loss Reduction Significance)

This column is an indication of the likely farm-scale impact to overall N loss reductions that implementing a mitigation could have. While some mitigations might be very effective at reducing N loss to water (for example annual ryegrasses), they might not be practical to implement over much of the property due to the environmental or managerial limitations, and therefore attract a lesser score.

A greater number of stars indicates greater probability of significant contribution to N loss reductions, a lesser number of, or no stars indicates a very low probability of contribution to N loss reductions at a farm-scale.

Financial Assessment (Cost ($/kgN conserved))

The column titled “Cost ($/kgN conserved)” represents a financial assessment of the costs or benefits to a farm of implementing the mitigation technique, based on a base pastoral leaching rate of 60kgN/ha/year.

The index is derived by calculating the costs of implementing a mitigation technique (for example planting a catch crop and associated nutrient replacement) and deducting from this any savings the farm is likely to experience (for example a catch crop yield that no longer needs to be purchased, or nitrogen fertiliser applications that can be reduced).

Any negative indexes indicate that the implementation of the mitigation technique may be financially beneficial to the business to implement.

Representing the effectiveness of a mitigation as a dollar value per kgN enables the reader to assess value for money when considering which mitigations to implement on their property.

Efficacy (Effective Range (% N loss/ha conserved))

The column “Effective Range (% N loss/ha conserved)” represents the expected level and range of reductions in n emissions to water that could be expected of the mitigation if implemented in accordance with the product suppliers specifications or the scientific recommendations.

5. Discussion

5.1. Cool Season Active Grasses

5.1.1. Background

Cool season active grasses such as annual ryegrasses, Italian ryegrasses and some late maturing perennial ryegrasses can reduce N leached. These grasses have been found to yield higher and therefore take up more nitrogen than other earlier maturing perennial ryegrasses and mixed swards.

The higher growth rates are particularly noticeable in the autumn and winter months when the risk of N leaching is high. The increased autumn and winter growth results in the plant taking up more N and reducing drainage and soil mineral N levels (Dairy NZ, 2020).

The species included in this assessment are:

- Italian Ryegrasses (*L. multiforum*)
- Annual Ryegrasses (*L. multiforum)*
- Perennial Ryegrass (*L. Perenne*)

5.1.2. Summary

Mitigation Tool	Limitations that impact effectiveness		Effective Range (% N loss/ha conserved)	Cost ($/kgN conserved)	Indicative GHG impact
	Environmental	Management			
Italian ryegrass based pasture	Less persistent in light soils. Less effective in very cold climates or saturated soils.	2-3 year life span, sensitive to treading damage.	24-54% lower N loss than other pasture swards	$7.42	None noted Possible reduction due to higher average digesibility of annual and italian ryegrasses.
Late maturing Perennial ryegrass based pasture	less functional in heavier soils or cool climates. Likely only functional in coastal areas.	Persistent	0% lower N loss than other perennial pasture swards	$0	
Annual ryegrass based pasture	Less persistent in light soils. Less effective in very cold climates or saturated soils.	One year life span, sensitive to treading damage.	53-58% lower N loss than other pasture swards	$9.17	

5.1.3. Efficacy

Italian ryegrasses were found to have 35% less N leaching (133 kg N/ha) compared to a late heading perennial ryegrass and white clover mix (205 kg N/ha) (Woods, Cameron, Edwards, Di, & Clough, 2016). An Italian ryegrass and white clover mix was found to leach 24% less than a perennial ryegrass-white clover-tall fescue mix and found to leach 54% less than a diverse pasture mix containing Italian and perennial ryegrasses white and red clover, chicory and plantain.

Another study found pure sward Italian ryegrasses to have 33-46% less N leaching (143 kg N/ha/yr) than early and mid-season maturing pure sward perennial ryegrasses (267 kg N/ha/yr) (Maxwell, McLenaghen, Edwards, Di, & Cameron, 2018). The same study found that the late maturing perennial ryegrass was not significantly different in N loss (178 kg N/ha/yr) than the pure Italian sward indicating that winter active perennial ryegrasses, also reduced N loss. While this study indicated late maturing perennial ryegrass cultivars may result in lower leaching losses of up to 30% in their first years of establishment, the findings were not mirrored in other research. We have therefore elected to consider all perennial ryegrasses as having no impact on reducing N loss to water.

Annual ryegrass pure swards have been shown to leach 53% (134 kg N/ha) and 58% (130 kg N/ha) less respectively than two pure swards of perennial ryegrasses (280 kg N/ha) and (310 kg N/ha) (Moir, Edwards, & Berry, 2013).

5.1.4. Limitations and interactions

When sowing an Italian in conjunction with a perennial ryegrass, the persistency of the Italian will need to be encouraged through cautious grazing management, otherwise the Italian can senesce out of the pasture and leave the sward open for damage from weeds and pugging.

Italian persistency is typically 18 months to 3 years and depends on soil type (it is less persistent on light soils) and management. If Italians are not grazed correctly (at the 3 leaf stage) or are taken for silage when the plant is going to seed then the persistency can be greatly reduced as the plant does not tiller as well and more weeds are able to enter the sward.

Because Italian's persistency ranges they can be difficult, especially on bigger farms with more paddocks, to keep track of and renovate in time when they start to die off. As soon as the growth of an Italian drops off so will its nitrogen uptake therefore it might be easier to use an annual where it must be replaced after a year or a late maturing perennial which will give longer term growth (Findlay, 2022).

While annual ryegrasses are equally as functional as Italian with respect to reducing N loss to water, they have only a functional life span of 12 months. Annual pastures are therefore not a suitable substitute for traditional perennial pastures. Annuals (and Italians) however, can be suitable oversowing options to extend the persistence of a perennial ryegrass pasture a further one to three years and add some N loss mitigation qualities to a pasture.

5.1.5. Cost

Italians

Italians require replanting every two to three years, therefore regular oversowing or reinstatement is necessary. The cost of additional regrassing with Italian based pastures rather than perennial ryegrass based pastures is estimated to average $107/ha/year nett of urea savings.

Annuals

Annuals require regrassing every 12 months, therefore, as is discussed earlier they are not a suitable long term pasture solution if looking for a feed with low N loss to water. Instead we will consider Annual ryegrass a 12 month option to extend the life of an Italian or perennial pasture.

The cost of annual oversowing with annual based pastures rather than perennial ryegrass based pastures is estimated to average $303/ha/year nett of urea savings.

5.1.6. Possible Indirect Consequences

Overland Flow and P loss

None currently reported however for annual and Italian swards which are less persistent and need to be replaced more often this could result in both an increase in sediment loss if cultivation occurs or increased compaction from machinery from drilling, increasing overland flow.

Carbon

Soils: Short term pasture swards do not accumulate soil carbon as well as perennial swards because there is time between pasture renewals were the inputs of carbon into the soil will be lower than in the perennial sward and in some cases soil carbon may be released during the renewal stage.

Atmosphere: Additional re-pasturing requires additional machinery time resulting in greater fuel burning and machinery wear. The burning of fossil fuels and production of new wear parts on machinery, cultivation gear and drills all result in increased heavy industry emissions of CO_2 to the atmosphere.

Methane

Possible reductions in methane could be expected. Italian and Annual ryegrass pastures have an average digestibility greater than that of perennial ryegrass. In some instances, more highly digestible feeds have resulted in lower methane emissions from ruminants, although this is yet to be proven for Italian and Annual based pastures.

5.2. Plantain

5.2.1. Background

Incorporating efficacy-approved varieties/cultivars of plantain into the pasture sward as a way to reduce nitrate leaching has undergone extensive research primarily on dairy farms. There are four ways in which efficacy-approved plantain has been found to reduce N leaching:

- Reducing the rate of ammonia released in the rumen meaning more is excreted in dung instead of in urine (Nguyen, Navarrete, Horne, Donaghy, & Kemp, 2022).
- Reducing the concentration of N in the urine through its diuretic effects so the volume of urine increases and the nitrogen content of it is effectively diluted (Box, Edwards, & Bryant, 2017).
- Improving cool-season growth and N uptake, resulting in increased urine N uptake by plants in autumn and winter (Martin, et al., 2017).
- Biological Nitrification Inhibition (BNI) – reduced conversion to nitrate in the soil (Carlton, Cameron, Di, Edwards, & Clough, 2018).

It is important to consider that while there are a number of plantain cultivars/varieties commercially available, the efficacy of each cultivar to reduce nitrate leaching varies greatly. Only cultivars that have provided evidence meeting the standards of partitioning and dilution set by the Evaluation System should be considered efficacy-approved with respect to having potential to reduce nitrate leaching.

5.2.2. Summary

Mitigation Tool	**Limitations that impact effectiveness**		**Effective Range (% N loss/ha conserved)**	**Cost ($/kgN conserved)**	**Indicative GHG impact**
	Environmental	**Management**			
Plantain in sward up to 30%	less persistent in light soils. More persistent in heavier soils. Sensitive to treading damage and over grazing.	High grass seed rates can smother plantain at establishment. Regular re-seeding of plantain required to maintain >20% plantain in pasture.	10% - 40% reduction in N loss from feeding 10% - 30% plantain. (1% n loss reduction per 1% plantain in diet)	$3.80-7.60 (15% plantain)	Has been found to reduce CH_4 emissions. More research required.

5.2.3. Efficacy

A lysimeter study found that N leaching decreased by 88.9% when efficacy-approved plantain comprised 42% of the sward in comparison to a ryegrass/white clover only sward. These results were attributed to the lower concentration of urinary N in the efficacy-approved plantain treatment, the increased cool season activity of the plantain and the ability to take up N during the cooler shoulder seasons (Woods, Cameron, Edwards, Di, & Clough, 2018).

A model designed to scale up small scale studies found that for two whole farm scenarios where 20% and 50% of the farm was sown in diverse pastures (including efficacy-approved plantain), N leaching was reduced by 11% and 19% respectively. The leaching reduction was attributed to less urinary nitrogen being deposited on pastures and a dilution of this urinary nitrogen due to larger urine volumes (Beukes, et al., 2014).

5.2.4. Limitations

More than 20% of efficacy-approved plantain is needed in the sward to achieve fullest reductions in N loss, although reductions in N loss are still observed with lower proportions of efficacy-approved plantain in the diet.

Plantain content declines with age of a pasture and requires maintenance after to ensure efficacy-approved plantain content remains at 30% or above (Dodd, Moss, & Pinxterhuis, 2019).

When plantain is initially established it is recommended that around 4 kg/ha plantain is included in the seed mix to achieve the desired content (around 30% of sward), followed up by direct drilling in another 6-8 kg/ha (Agricom webinar, 2021) into the sward.

5.2.5. Cost

Introducing plantain into the pasture will most likely occur over time (in conjunction with regrassing), although some operators are broadcasting or oversowing plantain into established pastures to accelerate the introduction of plantain.

Introducing plantain into a new pasture with a target composition of 30% plantain requires substituting 4kg of grass seed for 4kg of plantain seed. A reduction in herbicide use over plantain based pasture results in no additional cost to establish plantain based pasture compared to a grass based pasture.

Maintaining 20-30% plantain across a property can be achieved a number of ways, the two examples given are:

1. Oversowing with 6kg/ha plantain every three years to maintain 20-30% plantain in a pasture incurs an annual cost nett of urea savings of $68/ha/year.
2. Broadcasting plantain on with fertiliser annually at a rate of 2.5kg/ha every year to maintain 20-30% plantain in a pasture incurs an annual cost nett of urea savings of $34/ha/year.

5.2.6. Possible Indirect Consequences

GHG

Reductions in methane emissions from plantain-based pastures have been recorded, however no scientific trials have been successfully completed at the time of writing. The study which recorded methane emission reductions from plantain-based pastures noted that CO_2 equivalent emissions from die-back of the previous sward as part of the plantain establishment process would need to be taken into account (Wall, et al., 2021).

Decreases in N_2O emissions were seen from including plantain in the sward possibly due to the release of aucubin into the soil via leaf litter, reductions were variable and require more research (Gelos, 2020).

5.3. Low Protein Supplements

5.3.1. Background

The crude protein concentration of standard ryegrass-white clover pasture diets in NZ is typically in excess of 200 g of crude protein/kg DM. As a result, the daily nitrogen (protein) intake of livestock is typically exceeds demand by 60-70. In dairy cows, the excess nitrogen intake from pasture is equivalent to 262 g N/head/day or 751 kg N/ha/day urinary nitrogen, which can result in losses through drainage and nitrous oxide emissions.

By combining low protein supplements with the standard pasture diet, nitrogen concentration in faeces and urine can be reduced and therefore so can nitrate leaching losses (Wilkinson & Waldron, 2017). For example, during early lactation a dairy cow requires 18% crude protein but ryegrass-white clover pasture can provide more than 30% crude protein. Provided that the whole farm system is considered supplementing or substituting pasture with a low crude protein feed such as maize silage or grain can decrease nitrogen in the urine.

It is important to consider that there are consequences of introducing an additional supplement to a farm system. The substituted feed (pasture) must be allocated to another animal (possibly requiring additional animals, or cutting silage), and the low protein supplement needs to be of sufficient quality to maintain the production of the animals it is fed to.

5.3.2. Summary

Mitigation Tool	Limitations that impact effectiveness		Effective Range (% N loss/ha conserved	Cost ($/kgN conserved)	Indicative GHG impact
	Environmental	Management			
Feeding low protein supplementary feeds (ie maize silage or wheat/barley grain)	Less practical on heavy soils. Increased risk of soil damage resulting on heavy soils.	Cost and practicality of feeding supplement. Farm system preferences (low vs high supplement) Skill set of management to implement successfully. N loss from the ground used to grow the supplement needs to be lower than the farm it is getting fed out onto to have a nett positive impact.	8-21% reduction in N loss from feeding up to 30% diet as low protein supplements. (0.5% reduction per 1% diet as low protein)	$2.60 (substituting pasture silage) $146.70 (substituting pasture)	Reduction in N_2O emissions (depending on farm system)

Note that the cost $/kgN conserved does not consider some feed conversion efficiencies that may be obtained through having a more protein balanced diet.

5.3.3. Efficacy

Reducing total crude protein in the diet from 200 g crude protein/ kg DM consumed to 150 g/kg DM reduced N in faeces by 21% and N in urine by 66% (Castillo, Kebreab, Beever, & France, 2000).

Another study found that urinary N excretion ranged between 30-58% of N intake and decreased by 30-40% when grass was partially replaced. In some instances, nitrogen partitioning between urine and faeces can be influenced by introducing low protein supplements. An example of this effect was demonstrated when nitrogen deposition did not change, but the proportion portioned to faeces was increased when low protein supplement was added to an existing pasture diet at a rate of 25-30% (Van Vuuren, Van Der Loelen, Valk, & De Visser, 1993).

Feeding maize silage (7.5% crude protein) instead of pasture silage can reduce the absolute N content of urine by 70% (Ledgard, 2006). At a farm scale the reduction in N loss from feeding maize supplements was 21-32% when feeding 5.5-13.3 TDM/ha/year maize compared with the grass only control. It is, however, important to consider the whole farm system N loss when introducing a crop such as maize silage into a farm system. When the N loss from the area used to produce the maize was included in the whole farm N loss comparison, the N loss over the whole farm exceeded that of the grass control by 7 to 15%. If best practices were employed when growing the maize crop such as minimising cultivation, establishing another crop immediately afterward and minimising fertiliser inputs to maximise mineralised N then N loss reductions of 8-10% overall would be seen compared with the grass control (Williams, Ledgard, Edmeades, & Densley, 2007).

5.3.4. Limitations

Even though nitrate leaching may decrease due to a decrease in dietary nitrogen from feeding low protein supplements, it is important to consider the N leaching from the land which grew the low protein supplement and ensure an overall reduction to the whole system in total N losses (Wilkinson & Waldron, 2017).

The cost of feeding low protein supplements will change with demand and input costs and this will determine how viable it is for farmers to purchase and include them in their system. Maize silage is a suitable supplement for both dairy and non-dairy cattle farms, whereas grain is a suitable supplement for some dairy farms, breeding ewes, and deer.

Feeding maize silage on some farms is impractical. To functionally implement maize silage feeding into a farm system, a farm must have:

- a suitable site for locating a maize silage stack,
- local climate that suits growing Maize silage,
- a silage wagon,
- land contour and farm access that safely and practically permits the towing of a silage wagon and efficient feeding of the maize silage.

If the key criteria are not met, then it may not be practical for a farm to implement maize silage or low protein supplement feeding.

Similarly, not all properties have the ability to feed grain as not all dairy sheds are fitted with grain feeders, and not all farms have suitable aspect to tow grain feeders to paddocks.

It is critically important to consider that the aim of feeding low protein supplements is to optimise the use of protein in an animal’s diet which is provided by the pasture.

It will not be practical to implement low protein supplement feeding in all farm businesses in Canterbury. For some farms it will be financially unviable, for some it will be impractical, for some they will not have the necessary machinery or infrastructure, for some the supplement might not be readily available and not all available low protein supplements will be compatible with the stock classes or quality assurance programmes.

5.3.5. Cost

The primary driving factor of the cost of switching to a low protein supplement is the cost of the feed that the supplement replaces. If the feed substituted is a pasture silage/baleage, then the cost of substitution is approximately neutral, however, if the substituted feed is nitrogen-boosted pasture, then the cost of the low protein feed is approximately \$320/tDM.

Summary substituted feed costs:

1000kgDM(equivalent) nitrogen boosted pasture for maize silage:	\$344/tDM
1000kgDM(equivalent) nitrogen boosted pasture for grain:	\$293/tDM
1000kgDM(equivalent) pasture silage/baleage for maize silage:	\$42/tDM
1000kgDM(equivalent) pasture silage/baleage for grain:	-\$8/tDM

5.3.6. Possible Indirect Consequences

GHG

Reductions in N_2O emissions of 22% per kg MS have been reported when feeding 5.56 TDM/ha/year maize silage compared to a pasture only control (this included the whole area of the farm including area to grow maize). N_2O emissions could be further reduced if maize silage was fed on a feed pad/ stand off area to avoid pugging of soil in wet weather as these conditions increase N_2O emissions (Williams, Ledgard, Edmeades, & Densley, 2007).

5.4. High Sugar Grasses

5.4.1. Background

Ruminants excrete most of the nitrogen they consume from feed as it is surplus to their requirements. For example, the N utilisation of cows fed a pasture only diet was found to be only 22%.

In some instances, N loading in urine can reduce as the soluble sugar intake of a cow increases resulting in improved nitrogen conversion efficiency through increased microbial protein synthesis. Otherwise increasing soluble sugar in the diet does not reduce urinary N in NZ (Dairy NZ, 2020).

5.4.2. Summary

Research to date does not support any production benefit or decrease in urinary nitrogen deposition as a result of feeding “high sugar” grasses in comparison with good quality ryegrass (Dairy NZ, 2020). This could be because the sugar content of “high sugar” grasses is not different enough to a “normal” ryegrass to have an effect on urinary nitrogen. Research is being carried out on the impact of high fat pastures on urinary N to ascertain if they deliver any benefits, however, at the time of writing, no research regarding high fat pastures impact on nitrogen leaching have been published (Findlay, High sugar grasses, 2022)

5.4.3. Efficacy

There is currently no research showing that high sugar grasses have a high enough soluble sugar content when grown in Canterbury to result in a reduction of N loading in urine and therefore induce a reduction in N loss.

5.4.4. Limitations

Work done in Northland suggests that “high sugar” grasses when grown in this climate do result in high levels of soluble sugars than normal ryegrasses. However currently there is no research to support this being the case in Canterbury.

5.4.5. Cost

If a high sugar grass is proven to be effective in Canterbury then the cost of this would likely be negligible as it would replace current seed costs and be incorporated onto the farm as regrassing was required.

5.4.6. Possible Indirect Consequences

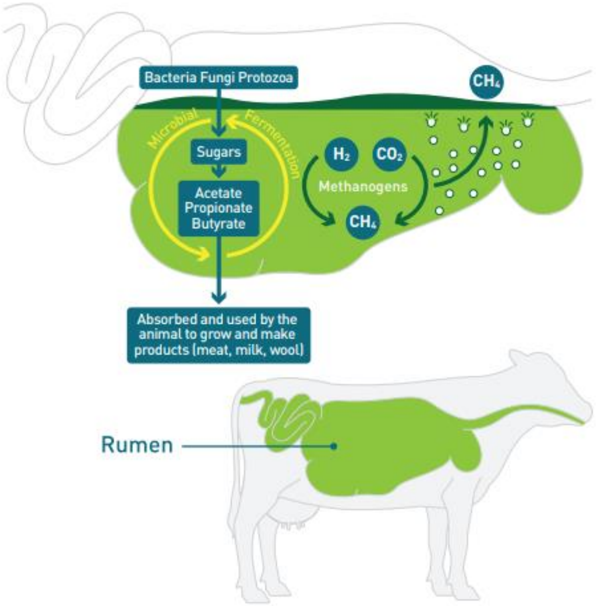
GHG

If high sugar grasses in Canterbury could reduce urinary N then less urinary N has been shown to reduce N_2O emissions (Dijkstra, et al., 2013).

5.5. Methanogen Inhibitors

5.5.1. Background

A methanogen inhibitor is a chemical compound that blocks critical enzymatic pathways in rumen-dwelling bacteria to restrict their growth and ability to produce methane (NZAGRC, 2022). Anaerobic fermentation occurs as ruminants break down fibrous food (such as pasture) to provide energy through the symbiotic relationship with bacteria in the rumen. A small portion of this plant energy is lost as methane, as shown by the diagram below (PGGRC & NZAGRC, 2017).



There have been a number of inhibitors on trial in NZ over the recent years. A compound called Bovaer® (3-nitrooxypropano or 3-NOP) has been successfully developed and trialled by the Dutch company DSM, but is not yet commercially available in New Zealand.

5.5.2. Summary

There is currently no data describing the effect of methanogen inhibitors on nitrogen movement through the animal. However, one study notes that body weight gain for lactating Holstein cows was 80% greater than for cows not receiving 3-NOP (Hirstov, et al., 2015). Another study found that, compared with the control group, cows fed 3-NOP increased milk fat concentrations and milk fat yield (Melgar, et al., 2021). This suggests that if feed conversion efficiency can be improved, then more of the nitrogen from feed will be converted to product and less will be excreted, reducing N losses.

5.5.3. Cost

Pricing for Bovaer® has yet to be released.

5.5.4. Possible Indirect Consequences

GHG

Reductions in methane emissions from cattle are reported to be approximately 30% for dairy cows and up to 90% for beef cows. There has been a range in the reductions of methane seen due to differences in diet and animals across the countries tested (DSM, 2021). Trials are currently underway in New Zealand in conjunction with Fonterra, no results have been released at this stage.

5.6. Nitrification Inhibitors

5.6.1. Background

Research is ongoing regarding substances that can be used to reduce the rate of nitrification. Nitrification is the breakdown of ammonium (NH_4^+) into nitrate nitrogen (NO_2^-).

Positively charged ammonium ions are held tightly by the net negative charges in the soil however the negatively charged nitrate ions are prone to leaching due to their negative charge. To reduce the risks of leaching, holding nitrogen as ammonium during times of the year when crop or pasture uptake of nitrogen is low has been found to reduce leaching losses of nitrogen. A product which was (but not currently) commercially available and successfully reduced nitrate leaching by prolonging the degradation phase from ammonium to nitrate was DCD.

Substances included in this assessment are:

- Gibberellic acid and Lignosulphonate (LS), (Bishop & Jeyakumar, 2021)
- 3,4-dimethylpyrazole phosphate (DMPP), (Bishop & Jeyakumar, 2021)
- Calcium lignosulphonate (Ca-lig), (Themba Matse, Jeyakumar, Bishop, & Anderson, 2021)
- Co-poly acrylic-malic acid (PA-MA), (Themba Matse, Jeyakumar, Bishop, & Anderson, 2021)

5.6.2. Summary

Mitigation Tool	**Limitations that impact effectiveness**		**Effective Range (% N loss/ha conserved**	**Cost ($/kgN conserved)**	**Indicative GHG impact**
	Environmental	**Management**			
Gibberellic acid and Lignosulphonate (LS)	Gibberellic acid can increase clover content, leads to higher N loss if insufficient LS applied.	Most cost effective when targeted to urine patches. Must be applied within 48 hours of grazing for reliable results. Requires high macro-nutrient presence under urine patch to maintain efficacy across a season.	0-25% reduction N loss	$6.36-$24.49 (assumes 12.5% reduction in N loss)	Reduction in N_2O and CO^2 emissions
3,4-dimethylpyrazole	More functional on lighter soils.	Most cost effective when targeted to urine patches. Increase in DM production.	29% reduction N loss	Not currently available	Reduction in N_2O emissions probable
Calcium lignosulphonate (Ca-lig)	More functional on lighter soils.	Reductions given are % nitrification reductied	Pumice: 59% Pallic:32% Recent:39%	Not currently available	Reduction in N_2O emissions probable
Co-poly acrylic-malic acid (PA-MA)	More functional on lighter soils.		Pumice: 56% Pallic:26% Recent:38%	Not currently available	Reduction in N_2O emissions probable

5.6.3. Efficacy

The combination of GA at 0.032 kg/ha and LS at 120 kg/ha reduced N losses by 25%.

DMPP at 6 kg/ha reduced N losses by 29%.

Ca-lig and PA-MA were found to cause reductions in nitrification not N loss itself. Copper increases nitrification, and the addition of a copper complexing compound to reduce bioavailable copper (such as Ca-lig and PA-MA) were found to reduce nitrification across different soil types.

5.6.4. Limitations

None of these options are on the market currently. GA alone is, however there are no published reductions in nitrification from it or reductions in N loss when GA alone is applied to urine patches (Woods, Cameron, Edwards, Di, & Clough, 2016).

For LS to be functional it must be applied at a rate as high as 120 kg/ha to reduce N loss. It is proposed that the GA+LS and the DMPP treatments be applied only to urine patches through the Spikey® machine (Pastoral Robotics, 2022). Targeted applications (through the likes of Spikey) reduce the rate of total product and therefore the effective cost per hectare, and also target the primary cause of leaching.

Reductions in N loss were significant for the DMPP treatments however reductions in N loss for the GA+LS were only significant when the rate of LS was also high (around 120 kg/ha LS) when a low rate of LS was applied it increased N loss (Bishop & Jeyakumar, 2021).

5.6.5. Cost

Currently Spikey® is the only targeted application method available, which applies only GA at a cost of $50/ha (including the GA) (Jackson, 2022).

5.6.6. Possible Indirect Consequences

GHG

Reduction in N_2O and CO_2 emissions have been reported from Lignosulphonate (LS) application (Yang, Lui, & Ju, 2019).

By holding nitrogen in the less vulnerable ammonium form for longer, the risk of volatilisation is reduced and we could therefore expect that there is a probability that the N_2O emissions would reduce if any of the above tools were implemented (although this is not yet proven).

5.7. Urease Inhibitors

5.7.1. Background

Urease inhibitors reduce the conversion of surface applied urea to ammonium until adequate rain or irrigation can wash the urea into the soil. When urea is applied to the soil, urease enzymes on the surface break down the urea and convert it to ammonia decreasing the amount available to be converted to ammonium and nitrate for the plant to uptake, this is called volatilisation.

Urease inhibitors are used to temporarily reduce the activity of the enzyme and slow the rate at which the urea is converted to ammonia (hydrolysed).

Most widely used urease inhibitors: (International Plant Nutrition Institute, n.d.)

- N-(n-butyl) thiophosphoric triamide (nBTPT), such as Agrotain (used in SustaiN).
- Phenylphosphorodiamidate (PPD/PPDA).
- Hydroquinone.

5.7.2. Summary

Mitigation Tool	**Limitations that impact effectiveness**		**Effective Range (Kg N/ha conserved**	**Cost ($/kgN conserved)**	**Indicative GHG impact**
	Environmental	**Management**			
Coated urea products	No N loss reduction validation	No N loss reduction validation	-	-	Reduction in N_2O and CO^2 emissions

When no urease inhibitor is used 10-20% of the nitrogen fertiliser applied may be lost through volatilisation.

Conditions that increase volatilisation:

- Moist/ heavy dew with no follow up rain within 8 hours.
- Hot dry conditions.
- High soil temperatures.
- Application rate – higher application rates lead to higher rates of volatilisation.
- Surface application.

Urease inhibitors have not been found to impact nitrogen leaching losses.

5.7.3. Efficacy

The use of a urease inhibitor halves the amount of volatilisation of nitrogen to the atmosphere (ammonia).

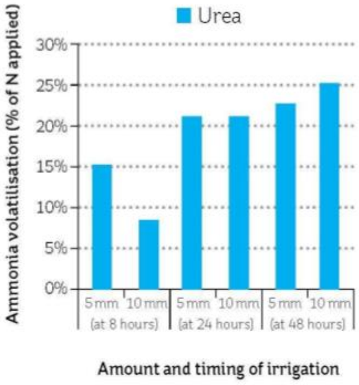


FIGURE 2
The effect of rainfall amount and timing on ammonia volatilisation losses from urea applied at 30 kg N/ha.

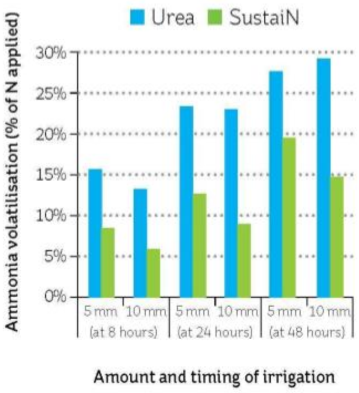


FIGURE 3
The effect of rainfall amount and timing on ammonia volatilisation losses from urea and SustaiN applied at 60 kg N/ha.

The figures above demonstrate the change in volatilisation depending on how much rainfall/ irrigation was receiving at different times after application of urea on pasture (Ballance Agri Nutrients, n.d.).

5.7.4. Limitations

See above figures.

5.7.5. Cost

The most common urease inhibitor and urea fertiliser combinations in NZ are SustaiN and N-protect supplied by Ballance Agri-nutrients and Ravensdown respectively. The urease inhibitor coated products are typically $50/tonne more expensive than straight urea, however, the savings in nitrogen losses to volatilisation enjoyed through using coated products offset the additional cost of the urease inhibitor as less product is required to get the same pasture response.

Example:

If 50kg/ha of urea was to be applied (23 kg N/ha) with a volatilisation risk coefficient of 15%, 3.5kg N/ha is at risk of volatilising. With the addition of urease inhibitor, half of the nitrogen potentially lost (1.7kg N/ha) would be retained, saving $3.70/ha in N, offset by the increase in cost of $2.50/ha for urease inhibitors.

5.7.6. Possible Indirect Consequences

GHG

If all nitrogen fertiliser used in New Zealand was coated with urease inhibitor the reduction of CO_2 equivalent would be 0.2%. (Agmatters, 2022).

Overland Flow and P loss

No impact on overland flow or P loss.

5.8. Cover/Catch Crops

5.8.1. Background

The primary objective of a catch crop is to take up excess nitrogen in soils that would otherwise be lost through leaching. Catch crops are typically a short rotation crop that is used following an autumn or winter grazed crop and have rapid and deep establishing root systems.

Plant species utilised are required to be winter active, cold tolerant and have a fibrous deep rooting system that is able to extract nitrogen from throughout the soil profile.

Catch cropping benefits vary depending on weather and soil conditions, cultivation methods used for drilling and establishment.

It is practical to sow catch crops after winter grazing in most circumstances in Canterbury, however, this generalisation does not extend to poorly drained soils in every instance. Catch cropping has the potential to offer high quality feed as well as reduce the risk of N leaching during a period when the paddock would otherwise be left fallow.

5.8.2. Summary

Mitigation Tool	Limitations that impact effectiveness		Effective Range (Kg N/ha conserved)	Cost ($/kgN conserved)	Indicative GHG impact
	Environmental	Management			
Catch crops	Surplus N extracted from soil to reduce leaching risk. Most effective on light soils. Diffcult to establish in high rainfall/wet seasons/on heavy soils. Less effective in high rainfall seasons.	Timing of planting must be within one month of grazing for optimal results. Only effective on the part of paddock that is planted within one month of grazing - part paddock plantings needed for optimal results.	22-40% N removed	-$4.32 (profit) - $11.02	-

5.8.3. Efficacy

The earlier the crop is planted the greater potential to reduce N leaching. The reduction in leaching loss largely depends on how quickly after grazing the crop is planted and established. The table below summarises the impact sowing date of catch crops post winter forage had on leaching rate in Canterbury.

Sowing Date	Canterbury
June	41%
July	33%
August	26%
September	14%

It is important to recognise that N leaching is strongly dependent on crop management as well as the timing and amount of rainfall. Therefore, the reduction in N leaching resulting from planting a catch crop will vary dependant on sowing date (both seasonally and with regard to how soon after grazing) and seasonal climate variation. Weather, particularly rainfall and temperature, influence how much, and how quickly nitrogen moves through the soil profile and therefore how much N is able to be taken up by the roots of the catch crop. (Brendon Malcolm, 2017)

5.8.4. Limitations

Unsuitable conditions for crop establishment, such as an extremely wet winter can delay or even prevent a catch crop being planted in some seasons.

5.8.5. Cost

It is important to consider that there is additional feed grown with the catch crops. After deducting the opportunity cost of feed produced that no longer would have to be bought in catch cropping can be financially beneficial. A low yielding catch crop may be a nett cost to a business of $114/ha or a high yielding catch crop may yield a cash benefit of $291/ha.

With favourable growing conditions Oats can reach maturity (ready for whole crop silage) in as little as 8 weeks.

5.8.6. Possible Indirect Consequences

GHG

Neutral effect on methane emissions from livestock. Potential increase in CO_2 and N_2O emissions from extra machinery passes required and if crops are harvested.

If additional N fertiliser is applied in the spring, both CO_2 emissions from application and N_2O emissions from volatilisation could increase.

Overland Flow and P loss

Growing catch crops will have a positive benefit on risk of P loss and overland flow. With having vegetative ground cover will slow the flow of water across the soil surface in comparison to leaving the soil bare during this period.

5.9. Supplement and Forage Balancing

5.9.1. Background

This section builds on section 5.3 by looking at balancing the diet of an animal during the late autumn, early winter (shoulder seasons) and winter to reduce protein (nitrogen) consumption which can be in excess of animal requirements.

Cow protein requirements range from 18% protein in early lactation, 16% in mid lactation, 14% in late lactation and as low as 12% when cows are not lactating. By feeding crops low in protein such as fodder beet, dietary protein can be more closely aligned to animal crude protein requirements meaning less N in the urine and less potential for N leaching (Dairy NZ, 2020).

The amount of dietary N in a feed can be determined from the crude protein (CP) content of a feed multiplied by 6.25. When N is consumed by an animal in excess of its requirements, the surplus is excreted in urine at a rate of 0.65-085 g N/g N in diet (Dairy NZ, 2020).

As an example, If a feed is 18% CP but only 12% CP is required, the difference in N required and supplied when feeding 15 kg DM/day over the cow's dry period would be 165 g N which would equate to 124 kg/ha additional urinary nitrogen deposition.

5.9.2. Summary

Mitigation Tool	Limitations that impact effectiveness		Effective Range (Kg N/ha conserved)	Cost ($/kgN conserved)	Indicative GHG impact
	Environmental	Management			
Feeding fodder beet in winter	Potentially more damange to soil structure due to higher yields and therefore more time grazing paddock.	Careful management required to transition cows onto fodder beet	32% reduction in comparison to kale (29 kg N/ha)	-$17.75 (profit)	Reduction in CH_4 emissions
Feeding fodder beet in late lactation	Strategic used can avoid damage to pasture paddocks. Can result in winter fallow if catch crop is not sown.	Reduced production if not transitioned carefully. Minimum of 25% diet required to show effects, optimal results at 40% of diet.	7.1% reduction in urinary N in comparision to pasture only diet (Overseer suggests neutral after considering losses from crop paddock)	(nett cash positive)	Reduction in CH_4 emissions

5.9.3. Efficacy

Feeds most likely to result in less urinary nitrogen excretion, and thus less N leaching, will have a CP content of less than 12% and a soluble sugars and starch (SSS) content of greater than 50%. Feed types meeting the CP and SSS thresholds include fodder beet, potato, swedes, turnips, barley and wheat grain. The high SSS content of these diets can also support high levels of animal production but may increase the risk of nutritional disorders if fed as a high proportion of the diet (Dalley, Malcolm, Chakwizira, & de Ruiter, 2017).

Winter grazed fodder beet was found to have a N loss rate 32% lower (41 kg N/ha) than from winter grazing of kale (70 kg N/ha). These results were found in Southland however similar results would be expected for Canterbury (Smith & Monaghan, 2020).

Feeding fodder beet at 45% of DM intake during late lactation reduced the amount of urinary N by 7.1% relative to a pasture only diet (Waghorn, Law, Bryant, Pacheco, & Dalley, 2018). However, Dalley et al., (2019) found that while fodder beet fed in late lactation at 40% of the diet (6 kg DM/cow/day) resulted in less urinary N excreted there was an associated reduction in Milk Solids. This was due to several cows showing signs of sub-clinical acidosis which would have reduced milk production. Cows fed fodder beet at 25% of DM had urinary N concentrations of 3.28 and 3.10 g/L in the morning and afternoon respectively whereas those with fodder beet at 40% of DM had urinary N concentrations of 2.53 and 2.71 g/L respectively.

5.9.4. Limitations

While fodder beet in a low CP feed option, inclusion in animal's diets needs to be carefully considered and monitored to reduce risk to animal health.

The impacts of introducing fodder beet as a low protein, grazing supplement in Autumn needs to be evaluated at the whole farm level. While the modelling undertaken in this assessment indicates an indifferent environmental benefit, the indifferent effect is obtained by ensuring that there is pasture sown immediately after grazing in late May. If a pasture (or a catch crop) is not sown immediately after grazing and the paddock is left fallow until September, there is significant risk of the autumn deposited urinary nitrogen being leached if the soil becomes saturated in late winter or early spring. This late winter leaching from the fallow paddock could result in a nett increase in nitrogen leached from the property, effectively nullifying the environmental advantages of using the crop.

Autumn grazing of fodder beet as a supplement should only be considered indifferent if it is used in conjunction with catch cropping or immediate re-pasturing.

5.9.5. Cost

The cost of using fodder beet as an autumn supplement during lactation or late production season is a nett cash positive tool as it substitutes a higher cost bought in feed such as baleage for a relatively lower cost fodder beet crop, grown and grazed in situ. The nett benefit is estimated at $2,922/ha of fodder beet planted.

As is with using fodder beet as an autumn feed for production stock, it is also a cost effective solution for winter or grazing stock as the area in winter feed is able to be cut by 30%, creating scope for additional grain crops or pasture grown on the area not sown in winter feed crops. The effect of switching to fodder beet from a brassica is a 40% nett reduction in N losses compared to a brassica crop.

5.9.6. Possible Indirect Consequences

GHG

Dry cows fed 10 kg DM/cow/day fodder beet and 6 kg DM/day grass silage produced 18% less CH_4 (g/day) than dry cows fed 14 kg DM/cow/day kale and 3 kg DM/day barley straw.

Lactating cows fed 3 kg DM/cow/day of fodder beet with the rest of their diet being pasture, also produced 18% less CH_4 (g/day) than cows fed pasture alone (Jonker, et al., 2017).

Overland Flow and P loss

Growing and feeding winter feed crops in situ can result in overland flow if not carefully managed. Winter grazing plans and farm environment plans are aimed at identifying specific paddocks and practices on farm associated with winter grazing, any issues which may arise and practices which can be used to mitigate these.

5.10. Capture of rainfall in shoulders of irrigation season

5.10.1. Background

Soil moisture sensors allow farmers to compare the water held in their soil with the maximum amount of water the soil can usefully store and therefore assist farmers to determine the capacity of the soil to store more water. This information is then used to guide when to start and stop irrigating as well as how much irrigation should be applied.

In the shoulders of the irrigation season (Spring and autumn), the probability of rainfall events that would induce drainage is greater than during summer. Therefore, when irrigating in this shoulder period, it is recommended that irrigation is delayed so that there is a larger deficit available to capture rainfall when it occurs, this rainfall capture is intended to reduce the risks of drainage.

Suggested deficit levels are presented in Bright, McIndoe and Birendra (2018). This paper outlines recommended target levels (the soil moisture level after irrigation) and trigger levels (the soil moisture level before irrigation). In these shoulder months, the trigger level is set so that more depletion occurs before irrigation is applied and the target level is reduced so that the soil has more available storage capacity after the irrigation has occurred.

5.10.2. Summary

Mitigation Tool	Limitations that impact effectiveness		Effective Range (Kg N/ha conserved	Cost ($/kgN conserved)	Indicative GHG impact
	Environmental	Management			
Changing irrigation trigger points during season	Assumes 100% water reliability.	Operator must regularly view changes in soil moisture and adjust irrigation targets. Best results achieved when irrigation can be managed according individual crop and soil requirements. Most applicable to centre pivots, fixed grid, drip and sub surface drip systems.	Average reduction 27% (19 kgN/ha/yr) (range 4-58%)	-$4.98 (profit)	None given, potential reduction N_2O emissions

5.10.3. Efficacy

Reductions in N loss rates achieved by these strategies ranged from 4% to 58% with an average of 27%. Modelled pasture production was not reduced.

Most farmers use a depletion trigger of 50% of plant available water (the readily available portion), while this study suggests less than 50% trigger in higher risk months is required to enable efficient capture of the likely drainage-inducing rainfall and reduce the risk of drainage occurring.

Target soil water content was also reduced in comparison to typical practices, to 80% to ensure there is always a soil water deficit to have some capacity to store rainfall after irrigating.

The irrigation practices described are more practically implemented on centre pivot, fixed grid and dripline/sub surface drip irrigation systems.

5.10.4. Limitations

To achieve these reductions the following irrigation target and trigger values were used (Bright, McIndoe, & Birendra, 2018).

Month	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**
Irrigation Trigger (% of plant available water)	20%	40%	50%	50%	50%	40%	30%	20%
Irrigation Target (% of plant available water)	80%	80%	80%	80%	80%	80%	80%	80%

5.10.5. Cost

It is difficult to put a cost on managing a lower soil moisture deficit in the shoulders, it will vary per farm based on the soil moisture sensors and potential weather forecasting they have available and level of staff understanding. This mitigation relies on an irrigation system that can be varied to apply the desired amount of water at the right time.

However, assuming an average irrigation system (well managed centre pivot), an operator could expect to save $35/ha/year on imported nitrogen and $45/ha/year on electricity associated with pumping. As this is all resource saving, there is no cost, the gain is both cash positive and less nitrogen leaching.

5.10.6. Possible Indirect Consequences

GHG

N_2O emissions increase as soil saturation increases when NO_3^- is susceptible to denitrification under anaerobic soil conditions (Skiba, 2008). Anaerobic soil conditions are most commonly found in soils of low drainage potential, those with a high clay content and in areas with high water tables.

Overland flow

Increasing soil deficit would theoretically reduce the potential of overland flow occurring due to saturated soils. Although deficits during the irrigation season are unlikely to significantly influence saturation during the winter months.

5.11. Nitrogen Type

5.11.1. Background

Liquid nitrogen is made by dissolving granular N fertiliser (typically urea) in water through agitation or heating of the water to aid dissolution. Fine particle application (FPA) is the application of ground down fertiliser (typically between 100-200 µm) for aerial boom spraying or ground application.

A review of research carried out on pasture and wheat showed there were no statistically significant benefits in applying liquid nitrogen over granular. The same review suggested there was not enough information available to recommend the use of FPA of fertiliser over granular fertilisers (Morton, Tillman, & Morton, 2018). The two studies where FPA significantly outperformed granular occurred at a small scale using mini-plots and glasshouse plots (Dawar K. , Zaman, Rowarth, Blennerhassett, & Turnbull, 2011).

5.11.2. Summary

No significant benefits to be noted for liquid nitrogen.

5.11.1. Efficacy

The two trials demonstrated pasture dry matter production increases through FPA of fertiliser require explaining to ensure the results are not misrepresented. One trial was a mini plot trial using field lysimeters and high rates of urea applied at (100 kg N/ha). The pasture production was found to increase under FPA by 27% compared to granular urea (Dawar K. , Zaman, Rowarth, Blennerhassett, & Turnbull, 2011).

Another trial was glasshouse based where urea was applied at 25 kg N/ha found that FPA fertiliser resulted in higher dry matter production and higher growth rate responses to nitrogen than the granular fertilisers (Dawar K. , Zaman, Rowarth, & Turnbull, 2012). It is important to recognise that these trials were both carried out at small scales and may not fairly represent the influences of in-field fluxes.

Of eight statistically significant trials that were reviewed by Morton, Tillman & Morton (2018), only the two studies noted above found that there was a significant response from FPA. Furthermore, no significant responses were found in the 22 trails reviewed comparing liquid and granular fertilisers (Morton, Tillman, & Morton, 2018).

There is likely greater potential for nitrogen use efficiency gains of liquid/fine particle application when the product is applied using a precision application technology. Currently, only spray boom applicators are able to maintain a high level of uniformity in a range of conditions. Granular and deflector nozzle applicators' uniformity degrades rapidly as wind increases or as product viscosity/density changes, requiring the applicator to be re-calibrated more regularly than is required by regulation. Application as a dilute liquid through an irrigation system also shows potential, however, with the majority of irrigators having in-field application coefficient of variation of less than 15%, reductions in input nitrogen while maintaining production (inferring possible reductions in nitrogen leaching) are unlikely. Without highly repeatable application uniformity, significant improvements in nitrogen use efficiency and therefore reductions in risks of nitrate leaching, are unlikely to result from the application of liquid or FPA nitrogen.

There is a significant opportunity in Canterbury to apply nitrogen in liquid form with irrigation water. Application with irrigation water ensures a more dilute application, a more regular, low dose application and ensures nitrogen is washed into the soil and not lost to volatilisation. This is a functional tool that is developing, but will require irrigator uniformity to meet the 15% CV that granular spreaders must meet before any improvements in nitrogen use efficiencies (and therefore reductions in N loss to water) are recognised.

5.11.2. Limitations

While there is plenty of research published comparing FPA, liquid and granular fertiliser, there are a number with potential biases, resulting in mis-representation of the effectiveness of liquid/FPA in reducing N loss. The research discussed in this review are peer-reviewed journal studies and only those peer-reviewed papers which showed statistically significant results are included.

After review of the research, it is inconclusive as to whether there is a more efficient application method between granular, liquid or FPA.

We would however expect that on light soils where there are more direct drainage pathways, there may be a benefit in applying N as liquid or FPA. This gain on lighter soils is expected because there is a higher concentration of N in one spot with granular application than with liquids, the higher concentration could result in an increase in N loss at this location.

5.11.3. Cost

If reductions in N loss of 1.2 kg/ha are seen for every 100 kg N/ha applied then a cropping farm applying 300 kg N/ha/yr could see savings of 3.6 kg N/ha in a season or $7.80/ha/year.

5.11.4. Possible Indirect Consequences

GHG

FPA resulted in a 5% decrease in N_2O emissions in comparison to the granular urea application (Dawar K. , Zaman, Rowarth, Blennerhassett, & Turnbull, 2011).

5.12. Non-Nitrogenous Growth Promotants

5.12.1. Background

Non-nitrogenous growth promotants is a grouping given to products or tools that are not necessarily aimed at reducing n loss in the same manner as nitrification inhibitors are, rather they are products that have the potential to improve nitrogen use efficiency and therefore may also induce a reduction in n loss. In this review we have used three common products to represent a wider group.

Gibberellic Acid

(GA_3) is a naturally occurring hormone that is involved in regulating plant growth. When applied to pasture, GA_3 stimulates growth through mobilisation of plant energy reserves, resulting in leaf and stem elongation. The application of GA_3 can be used as a tool to manipulate pasture growth and assist in matching feed supply and animal demand in the shoulders of the season when anticipated pasture growth is low (Dairy NZ, 2020).

Effective Microbes

Effective Microbes (EM) are formulations of microbes, nutrients and additives that can enhance the natural processes in the soil that provide nutrients in available forms to plants. They act as a bio-stimulant increasing the nitrogen fixation capacity directly through the stimulation of N fixing bacteria, and indirectly by increasing clover growth, increasing mycorrhizal activity, and reducing the need for fertiliser inputs, whilst maintaining levels of production.

Lactic acid is a major ingredient in EM that suppresses pathogenic microbes both directly, and indirectly, through the production of actinomycetes. EM also induces an antioxidant effect which enhances the immune system of plants and animals.

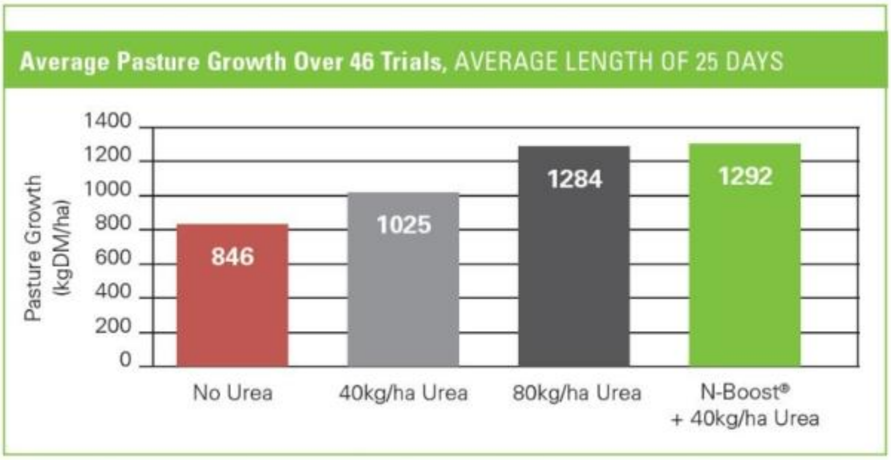
Different types of EM can be used in different parts of the farm system:

- In effluent ponds
- As an animal supplement
- Applied to pastures, crops and soils

N-boost

Donaghys N-Boost® is a patented nitrogen booster technology for pasture and selected crops. Scientific studies at Lincoln University found that N-Boost® stimulates mitochondria and chloroplasts which are the key cell components of the plant responsible for energy storage and biomass production.

Pasture production responses, shown in the graph below, demonstrate that 3l/ha N-boost and 40kg/ha Urea (dissolved in water) can give the same result as 80kg/ha of urea. When comparing 3l/ha N-boost and 40kg/ha urea with 40kg/ha urea, the pasture growth response rate increases from 9.7 to 24 kg DM/ kg of N applied per hectare.



5.12.2. Summary

Mitigation Tool	Limitations that impact effectiveness		Effective Range (% N loss/ha conserved	Cost ($/kgN conserved)	Indicative GHG impact
	Environmental	Management			
Gibb Acid	Best results achieved with soil temperature, moisture, soil nitrogen availability.	Replacing N fertiliser with Gibb Acid reduces pasture production in long term if underlying nutrient status is not maintained. Best results achieved when applied 0-5 days after grazing and remains ungrazed for 20 days from application. Works on plant and soil, once leaf is grazed off effect is reduced.	0% (refer to Nitrification Inhibitor section)	- (refer to Nitrification Inhibitor section)	Reduction in N_2O emissions
N-Boost	Best results achieved with soil temperature, moisture.	Increases dry matter response per kg N applied. From 12:1 to 24:1. Inconsistent results.	15% reduction in N loss (modelled for Canterbury dairy farm)	$4.00	Expect reduction in N_2O emissions. (if N fertiliser volumes decrease)
Effective Microbes	-	Must be sprayed on. Works on the soil and plant, once grazed, the plant function is reduced.	- (expect reduction as n ue efficiency increases)	-	-

5.12.3. Efficacy

Gibb Acid: (Dairy NZ, 2020)

Replacing a small amount of N with GA_3 in early spring and/or autumn may be an option for some to reduce N use while still influencing the timing of pasture supply. However, there is a limit to the quantity of N that can be replaced without negatively affecting pasture production. GA_3 may be a tool in the toolbox, however it is unlikely to be a ‘silver bullet’ to reducing N use.

Both N fertiliser and GA_3 are used to influence the pattern of pasture production in the shoulders of the season. As they are used for similar purposes, it seems intuitive that GA_3 could be used to complement at lower rates of N used within our farm systems.

Effective Microbes:

A review of the research carried out on fodder beet and maize crops shows that there is a benefit to crop yields when using EM products alongside nitrogen fertilisers. In some cases, less nitrogen fertiliser can be applied for the same or better response. There is currently no evidence to suggest this leads to a reduction in nitrogen losses from drainage. However, it does indicate that these products enable inputs to be utilised more efficiently and assumptions could be made that this would reduce N losses and improve environmental outcomes.

N-Boost:

Modelling of a typical 160 ha Canterbury dairy farm, using the Overseer® nutrient budget software, indicated up to a 15% reduction in nitrogen leaching from using the N-Boost® System and 40 kg/ha of urea, in comparison to an application of 80 kg/ha of urea only.

5.12.4. Limitations

Gibb Acid:

- When moisture and nitrogen are not limiting dry matter responses typically range from 200-500 kg DM/ha over a four week period following application.
- Apply in late winter/early spring, to pull feed forward ahead of balance date; or in autumn to increase feed supply.
- Apply within 5 days following grazing, when there is adequate green leaf present for uptake.
- Graze treated pastures within 3-4 weeks after application
- Be aware of the potential for reduced growth (lag) in future rounds and factor this into feed planning if Gibb Acid is used as a nitrogen replacement rather than a nitrogen complement.

N-Boost:

- Increases dry matter response per kg N applied. Responses range from 12:1 to 24:1.
- In liquid form, required to spray it on, requires equipment to dissolve and mix the urea.

5.12.5. Cost

Gibb Acid:

Climatic conditions, and soil moisture impact the response of GA_3 therefore benefit and cost per kg/DM is variable.

If the net yield response is only 150 kg DM/ha, the cost of additional feed generated increases to 20 – 33 c/kg DM (Dairy NZ, 2020). This is approximately the same as nitrogen boosted pasture with urea priced at $1000/t.

N-Boost:

The cost of spraying N-boost and urea four times per year, nett of urea saved by through improved nitrogen use efficiency that N boost promotes is calculated to be $35.97/ha/year.

5.12.6. Possible Indirect Consequences

GHG

- **Gibb Acid** has been shown to have a positive impact on nitrous oxide emissions. Application within a few days of grazing can decrease nitrous oxide emissions from a single urination event by 14%. Continuous use of gibberellins may lead to reduced herbage production as growth rates will become limited by nitrogen supply. More research is still needed (Whitehead & Edwards, 2015).
- **N-Boost** use should reduce nitrous oxide from the farm system due to less nitrogen applied.

5.13. VRI – block level

5.13.1. Background

Variable rate irrigation (VRI) is the process of applying different amounts of irrigation to different areas of the farm matching water supply to water holding capacity of the soil and crop demand.

In comparison, uniform rate irrigation (URI) results in the same amount of irrigation applied uniformly across the property without giving consideration to crop needs or soil type variation.

For VRI to be implemented successfully, detailed soil mapping is carried out to determine the water holding capacity of the soil types throughout the irrigated block (Hedley, Bradbury, Ekanayake, Yule, & Carrick, 2010). Soil water holding capacities and crop types must then be matched closely with suitable soil moisture monitoring.

Once all information is collected and all tools are implemented, more water can then be applied to soils which have a higher water holding capacity and less to those with a larger water holding capacity to maintain an appropriate soil moisture deficit and reduce drainage (McDowell & Nicholson, 2017). Water can also be applied at different rates to different arable crops depending on specific water demands (Hedley, Yule, Tuohy, & Vogeler, 2009).

5.13.2. Summary

Mitigation Tool	Limitations that impact effectiveness		Effective Range (% N loss/ha conserved)	Cost ($/kgN conserved)	Indicative GHG impact
	Environmental	Management			
Variable rate irrigation alongside soil mapping (EM survey).	More advantageous on highly variable soils.	More advantageous with localised weather station and evapotranspiration data. Multiple moisture probes needed (one per management zone).	80-85% reduction in N and P in drainage. 10% reduction in potato crop n loss. 16-33% less drainage volume.	$0.38 - $10.02	None given, potential reduction N_2O emissions

5.13.3. Efficacy

One study collecting water samples from an irrigated dairy pasture found reductions of 80-85% in N and P concentration in drainage water under VRI irrigated land compared to uniform rate irrigation (URI), see table above for key variables (McDowell & Nicholson, 2017).

The reduction in N loss from VRI in comparison to URI under pasture was modelled using Overseer by Hedley et al. (2009). While N loss reductions were variable, water use reductions were between 9-19% and drainage reductions between 25-45%.

Another study cites reduction in water use from 4-7% and reduction in drainage from 16-33%, nitrogen loss was not investigated in this study however some reduction would be expected (Hedley, Bradbury, Ekanayake, Yule, & Carrick, 2010).

5.13.4. Limitations

There are many variables which could affect the amount of nitrogen leaching under variable rate irrigation systems. The reduction in drainage will depend on the specific soil types, climates and crops and likewise the nitrogen in the drainage water will be dependent on soil mineral N and potentially mineralisable N, crop type or N loading from stock and N fertiliser applications.

The biggest driver to making VRI effective in reducing N losses to water is the effective management of the irrigation system, ensuring that the irrigator is uniform to begin with and that operators have sufficient soil moisture probes installed to enable them to have confidence in variable watering.

Consider that VRI enables operators to exclude water from non-productive but potentially fertile areas of land. This is particularly advantageous for livestock farmers where irrigation water can be kept off tracks, away from gateways and away from water troughs, reducing the risk of inducing drainage that carries urinary N through the profile to groundwater.

VRI could present some material N loss saving opportunities if it is used to accurately match soil moisture, crop demands and rainfall capture, without this integration, VRI will not deliver N loss reductions as described.

5.13.5. Cost

Cost savings can be due to both reductions in water use and nutrient loss.

Depending on the length of irrigator and water use efficiencies or nitrogen use efficiencies made, before considering maintenance savings, VRI could have a cost of between 15.04/ha/year and $180.36/ha/year.

The capital cost to establish the system includes the cost of the VRI onto an existing pivot (or bought new), soil moisture sensors and EM mapping of the area to determine zones for irrigation.

Cost comparison:

- 400m centre pivot irrigator $1,195/ha
- 600m centre pivot irrigator $750/ha

5.13.6. Possible Indirect Consequences

Use of other precision technology

Potential reductions in N_2O emissions may be plausible due to improved management of soil water deficit meaning less potential anaerobic conditions which result in denitrification and an increase in N_2O (Skiba, 2008).

Overland Flow and P loss

Potential reductions in P loss due to more targeted watering and reduced risks of overland flow from micro-over watering.

5.14. Crop nitrogen budgets and soil nitrogen testing

5.14.1. Background

To increase N use efficiency and reduce N losses, the supply of N needs to closely match crop N demand. To achieve this, it is important to predict the amount of N supplied to the crop during the growing season from the mineralisation of soil organic matter and structure fertiliser applications accordingly.

Plant available nitrogen in the soil can be broken down into two main groups: mineral N (ammonium and nitrate available for plant uptake) and potentially mineralisable N (in organic form needing to be broken down by bacteria for the plant to take it up).

To carry out a soil nitrogen budget the amount of mineral N (readily available) and mineralisable N (potentially available) in the soil must be known. The use of both a mineral and mineralisable test together allows a thorough crop nitrogen budget to be carried out (MPI, 2019).

Mineral N

The Nitrate Quick Test is relatively simple and provides an estimate of nitrate in the top 30 cm of soil, which on average accounts for 88% of total mineral N (Beare, et al., 2020). Another method of determining mineral N is through a KCl extraction method in a lab.

Mineralisable N

The Hot Water Extractable Organic Nitrogen method (HWEON) and Anaerobically Mineralisable Nitrogen (AMN) tests can be used to measure the potentially mineralisable N in the soil, indicating what might be available later in the season.

5.14.2. Summary

The desktop study summarised below shows that using a crop N budget alongside soil test results reduced the uncertainty and resulted in a lower N leaching loss predicted by Overseer (Mathers, 2016).

There are a number of crop calculators available to help growers determine crop N requirements such as:

- AMaizeN.
- The wheat calculator.
- The potato calculator.

Due to the number of variables required to run these model and the fact they do not include a water balance model, it is not possible to predict N loss reductions likely to result from improved nitrogen budgeting using these calculators.

Mitigation Tool	Limitations that impact effectiveness		Effective Range (Kg N/ha conserved	Cost ($/kgN conserved)	Indicative GHG impact
	Environmental	Management			
Soil nitrogen testing and crop nitrogen budgeting.	Mineralisable N influenced by soil moisture status and temperature. Soil N testing is difficult to complete on stony soils.	Test return timeframes can be more than one week. regular testing required to complete full picture. Timing of application to meet crop needs requires diligent manager with intimate crop knowledge.	0-40% (trial 4kg/ha from 9kg)	-$14.01 (profit)	Expected reduction in N_2O emissions

5.14.3. Efficacy

Soil temperature and moisture are extremely important in determining the rate at which mineralisable N is broken down and becomes plant available.

More regular testing will give operators higher accuracy and repeatability of testing across seasons will improve operational knowledge over time.

5.14.4. Limitations

The Nitrate Quick Test only measures nitrate in the soil however it has been found to account for 88% of the total mineral N in the soil when ammonium levels are low (this occurs when total soil mineral N was above 3 mg N/kg soil). When total soil mineral N was below this level, ammonium accounted for a larger portion of total available N.

The top 30 cm of the soil, on average accounted for 60-83% of the mineral N in the top 90 cm.

More work is needed across a wider range of soils and crops to verify these results.

Due to the number of variables, it may be difficult to determine the N loss reduction that would result from the implementation of these practices on farm and they should instead be taken as demonstrating system efficiency.

5.14.5. Cost

Nitrate Quick Test tool kit is $189 (incl GST and delivery) and includes 20 tests for farmers to carry out themselves in field (MPI, 2019).

HWEON test (Hills laboratories) $49 (excl GST but incl delivery to Hills), turnaround time around a week from the lab (Hills Labs, 2022).

5.14.6. Possible Indirect Consequences

GHG

Nitrous oxide emissions would be expected to reduce if N fertiliser applications reduced because of carrying out soil N testing and crop N budgets.

5.15. Horticulture Input Optimisation

5.15.1. Background

For arable and horticultural growers, the amount of N lost by different crops can vary immensely. When crops are grown repeatedly and/or successively, the N leaching for the same crop can vary immensely. A study found that the factor most correlated to N and P leached per crop was drainage. The lowest N losses occurred when fertiliser applications were much lower than crop uptake, allowing mineral contributions and mineral N to meet crop demand.

Mineralisable N contributed a sizeable amount to the N balance in all systems but was difficult to predict accurately. A conservative allowance for N supply through mineralisation when calculating fertiliser requirements reduces fertiliser N and therefore reduce N susceptible to leaching (Trolove, et al., 2021). There is ongoing research into options and more will continue to become available.

5.15.2. Summary

Mitigation Tool	Limitations that impact effectiveness		Effective Range (% N loss/ha conserved)	Cost ($/kgN conserved)	Indicative GHG impact
	Environmental	Management			
Increased frequency of nitrogen assessment and application	High Rainfall, or low rainfall not suiting use.	The time to continually review N decisions. Accuracy of min N predictions	0-80% (suggested not measured)	- (expect cost savings with efficiency gains requiring less inputs)	Expect reduction in N_2O emissions. (if N fertiliser volumes decrease)
Optimum irrigation application	Wet seasons	Accurate soil moisture readings to avoid crop stress at key times	0-85% (based on VRI section)	- (refer to VRI and rainfall capture sections)	N/A
Types of tillage	Condition of soil. More burning is likely with less cultivation.	Appropriate for crop and residue management.	40% (compacted soils)	-	Tillage can increase N_2O emissions if compaction occurs
Crop rotation	Effect of temperature and rainfall on N mineralisation	Efficiency of getting next crop in ground after harvest	-	-	Expect reduction in N_2O emissions. (if N fertiliser volumes decrease)

5.15.3. Efficacy

Optimum irrigation application drives horticultural crop nitrogen use efficiency. If enough water is not supplied then crop roots can be stunted and crops will not meet their yield potential which could result the crop not taking up all the N supplied therefore increasing the chances on N leaching (FAR, 2021).

Making nitrogen decisions with increased frequency was found to improve the alignment between N supply and demand without limiting yield. Information required for the decision making included predicted soil N supply and crop demand. When N decisions were made weekly rather than once per season the nitrate nitrogen concentration in the soil was consistently lower (around 50 kg NO_3/ha) in comparison to being well above 50 kg/ha 90% of the time when N decisions were only made once in the season. Daily soil NO_3 content was accumulated and used as an indicator of N leaching risk. The cumulative soil NO_3 content was four times lower when decisions were made weekly rather than once per season suggesting that leaching losses would be four times lower when N decisions were managed in this way (Hunt, Sharp, Johnstone, & Searle, 2019).

Tillage was found to have relatively little influence on N leaching with the exception of the use of minimum tillage in autumn for cultivation which resulted in significantly less nitrate than either intensive or no tillage (Fraser, et al., 2013). Another study found that while the type of tillage itself did not directly affect leaching losses, there was a strong correlation between cultivation and treading damage. Tilled soils were more susceptible to compaction by treading than direct drilled soils. The result of compacted soils was that there was reduced N leaching losses (up to 40%) but increased N_2O emissions due to the anaerobic conditions present (Trolove, et al., 2019).

The effect of ploughing in crop residues after harvest on N leaching losses between harvest and the start of winter was studied and it was found that the highest rate of leaching occurred after ploughing in of leguminous crop residues (124 kg N/ha) in comparison to non-leguminous (80 kg N/ha). When N leached was assessed as a percentage of the total mineral N content of the soil the losses for both treatments were similar at 54-61% (Francis, Haynes, & Williams, 1994).

5.15.4. Limitations

Due to the number of variables surrounding each of these practices it is very difficult to assess a representative reduction in N loss that might result if the techniques are employed. We suggest that these practices be used as proxies or as examples of system efficiency. Remembering that not all discussed techniques will be applicable on each farm and that some may in fact have negative impacts in some climates, soils and management regimes.

While there has been some research completed regarding management and mitigation impacts on N loss, much of the research infers loss reductions based on mathematical calculation, modelling, or expectation based on changes in soil mineral N pools.

5.15.5. Cost

Will vary dependent on practice implemented

5.15.6. Possible Indirect Consequences

GHG

Many possible effects including changes to N_2O emissions and potential increase/ decrease in overland flow depending on the mitigation practice employed. When choosing which practices to implement it is important the growers evaluate secondary impacts.

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