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REVIEW OF NITROGEN MITIGATION STRATEGIES FOR DAIRY FARMS - IS THE METHOD OF ANALYSIS AND RESULTS CONSISTENT ACROSS STUDIES?

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Abstract

Nitrogen leaching is fast becoming a major issue for New Zealand farms, Regional Councils are developing legislation to control nitrogen losses from the farm. This will impact farm management and economic viability.

Nitrogen losses are impractical to measure for each farm so most councils are adopting a modelling approach using OVERSEER to quantify losses.

There are a number of studies commissioned by industry and Regional Councils assessing nitrogen leaching mitigations and the economic impacts.

This analysis considered twelve studies, with two methods of analysis identified:

- Single mitigation approach, defining the effectiveness and economics of each strategy in isolation.
- Combined mitigation approach, reaching a predefined reduction to assess the economic impact of meeting the legislation.

Single mitigation strategies showed large variation between studies for the same mitigation strategy, e.g., changing to low protein feeds reduced nitrogen leaching by 3-42%. Differences were due to:

- Soil type and climate
- Current farm system
- Current leaching loss
- Secondary changes (e.g., reduced nitrogen fertiliser impacts on production unless feed is sourced elsewhere)
- Magnitude of change (e.g., quantity of nitrogen fertiliser removed)
- Definition of profit and consideration of capital

Combined mitigation strategies were well aligned (R^2 = 0.66). Studies showed leaching reductions of 0-20% resulted in no significant impact on profit; beyond this profit was exponentially negatively impacted.

Overall there is a large number of mitigation strategies available (20 considered in this study) and there is no one size that fits all. All farms are different and the effectiveness of the strategy will depend on the individual farm situation.
Clear guidelines on each strategy and the impact it will have on nitrate leaching and profit would provide clarity for farmers. However this is required at a granular level to capture soil type and climatic differences, considering each farm system separately.

Secondly a clear procedure on how to model and quantify each strategy is required as differing methods and assumptions were apparent. If consistent and realistic council policy and messaging to farmers is to be delivered, studies need to be consistent.

Purpose

The Fertiliser Association of New Zealand has commissioned this study to summarise research analysing nitrogen mitigation strategies, their impact on nitrogen leaching losses and subsequent financial performance for dairy farms in New Zealand.

The purpose of this report is to draw the work together and provide some general conclusions and recommendations, identifying key similarities and explaining differences.

Background

Regional Councils are in the process of setting and implementing policies for managing freshwater quality. This is driven by requirements under the Resource Management Act and the National Policy Statement for Freshwater Management. The approach taken by councils varies from setting broad limits across catchments and designated sensitive areas, through to use of Land Use Classification soil maps.

In comparison to other countries the approach is somewhat unique, with the legislation focusing on outputs from the farm as opposed to the inputs. This provides the farmer with freedom to select how the farm will operate as long as the outputs from the farm are within the legislation.

The outputs councils are basing legislation on are those that will impact on water quality, namely nitrogen and phosphorus, and in some cases *E.coli* and sediment.

These outputs however are diffuse in nature and are difficult to measure. For this reason most Regional Councils are using OVERSEER for this purpose to model the likely nutrient outputs from the farm boundary.

Often, once limits are set and legislation is implemented, farms are required to complete an assessment of their current farm system, providing an estimate of losses from the farm boundary. The intent is that they would have a consent to farm provided they can demonstrate that they can meet the discharge limits within a set timeframe.

There are a number of studies analysing nitrogen mitigation strategies and it is perceived that the studies provide differing results on the effectiveness of similar strategies to reduce leaching losses and the cost to the farming business.

Farmers are prepared to do their part when it comes to environmental restoration and are already adopting mitigation strategies (Perrin *et al*. 2012). However there is a perception that the costs of each strategy differ between studies, and this needs to be addressed to provide clear, consistent messages to farmers.

A number of studies have been reviewed for this paper, with the approaches broken down into two strategies:

- Single mitigation approach - the study has sought to investigate each strategy to compare it against alternatives so that the effectiveness of each strategy to reduce nitrate losses, and the cost of doing so, could be identified.
- Combined mitigation approach – the report seeks to identify the cost to a farm to reduce nitrate leaching, commonly to a target specified by a Regional Council.

The studies are summarised based on a percentage change in nitrate leaching losses and change in farm profit. As there was a large variation in base nitrate leaching, farm profit and version of OVERSEER used between the studies, the use of percentage change minimises the impact of these items on the comparison. Also some of the studies did not express absolute values, so they could not be presented here.

Single Mitigation Approach

A selection of single mitigation strategies are summarised in this section to contrast and compare the studies, and to identify common elements where studies differ.

Supplementary Feeding

Manipulating the type of supplements fed will alter the amount of nitrogen consumed and hence excreted by the animal. Reducing the nitrogen concentration of supplementary feed bought onto the farm presents an opportunity to reduce nitrogen excreted by the animal which in turn will lower nitrogen leached. The studies summarised in Table 1 demonstrate that a reduction in nitrate leaching is feasible across all studies although the magnitude of reduction is variable.

Monaghan *et al*. 2008 considered the impact in four catchments across New Zealand, showing variable responses. The N losses in the Bog Burn catchment are significantly lower than other catchments, possibly due to the lower base N leaching. The N loss reduction for the Waikakahi catchment is significantly higher due mainly to significantly more supplement being used at 2.5T/ha compared to the other farms at 0.2 – 0.9T/ha.

Perrin *et al*. 2012 used an average of 1.3T/ha of supplement, with supplements switching from PKE to Maize silage. Allen *et al*. 2009 moved from a high to low protein feed, and although the quantity used was not stated, a reduction of 0-5% was indicated. The Perrin *et al*. (2012) and Allen *et al*. (2009) studies align well, but the reason for the difference against Monaghan *et al*. (2008) is not apparent.

Table 1. Impact of manipulating supplementary feeding on nitrate leaching losses
[1] Approximate values only

Report	Catchment	Mitigation strategy	% change in N leaching	% change in profit
Monaghan *et al*. 2008	Toenepi	Low N Feed	-24%[1]	-5%[1]
Monaghan *et al*. 2008	Waiokura	Low N Feed	-29%[1]	-7%[1]
Monaghan *et al*. 2008	Waikakahi	Low N Feed	-42%[1]	-0%[1]
Monaghan *et al*. 2008	Bog Burn	Low N Feed	-8%[1]	-6%[1]
Perrin *et al*. 2012	Lake Rotorua	Swap PKE for Maize Silage	-7%	
Allen *et al*. 2009	Upper Waikato	Move from high to low protein feeds	-3%	

Nitrogen Fertiliser

Reducing the amount of nitrogen fertiliser applied will reduce pasture production, in-turn reducing the amount of pasture consumed by animals and the amount of urine excreted. This will lead to reduced nitrogen losses.

Perrin *et al*. 2012 used a range of strategies ranging from reducing nitrogen fertiliser use and replacing with supplementary feed, through to removing nitrogen fertiliser use completely and presumably accepting a loss in production. Eliminating nitrogen fertiliser use without replacing the lost feed with supplement was most effective in reducing N losses, but also resulted in the largest cost to the farm, of three to four times greater than replacing nitrogen with supplement, presumably through lowered production.

The differences in the four strategies analysed by Perrin *et al*. 2012 highlight an important point that it is not just the manipulation of an input that will affect the result. It is also the impact this change has on the farm system, and if this is acceptable, or if secondary changes are needed.

Both Allen *et al*. 2012 and Journeaux & Wilson 2014 lowered the use of nitrogen fertiliser by removing fertiliser applied over the winter period, resulting in N leaching reductions of 15% and 12% respectively. In comparison, Perrin *et al*. 2012 and Monaghan *et al*. 2008 either lowered nitrogen fertiliser further or completely eliminated it, resulting in reductions of 26-43%. Differences between studies are explained by the magnitude of reduction in nitrogen fertiliser, and given this the studies align well.

With the exception of the first study by Perrin *et al*. 2012 the removal of nitrogen fertiliser was not countered by an increase in supplement so production was reduced, showing a greater reduction in nitrate leaching, and presumably greater impact on profit.

Profit decreased between 1-10% with a larger reduction corresponding with a greater reduction in nitrogen fertiliser use. It also appears that reducing fertiliser over the winter period was most effective in reducing leaching losses while having a minor impact on profit.

Table 2. Impact of manipulating nitrogen fertiliser application on nitrate leaching losses

Report	Catchment	Mitigation strategy	% change in N leaching	% change in profit
Perrin *et al*. 2012	Lake Rotorua	Reduce to 100kg N/ha, replace feed with maize silage	-26%	
Perrin *et al*. 2012	Lake Rotorua	Reduce N usage to 100kg N/ha (if currently above 150kg N/ha)	-33%	
Perrin *et al*. 2012	Lake Rotorua	Eliminate N Usage (10:1 response for last 100kg N)	-42%	
Perrin *et al*. 2012	Lake Rotorua	Eliminate N Usage (15:1 response for last 100kg N)	-43%	
Allen *et al*. 2009	Upper Waikato	No winter use and lowered overall use	-15%	
Journeaux & Wilson, 2014	Southland	No Winter N fertiliser	-12%	-1%
Monaghan *et al*. 2008	Toenepi	Nil N fertiliser	-33%	-10%
Monaghan *et al*. 2008	Waiokura	Nil N fertiliser	-33%	-3%
Monaghan *et al*. 2008	Waikakahi	Nil N fertiliser	-35%	-2%
Monaghan *et al*. 2008	Bog Burn	Nil N fertiliser	-28%	-7%

On/Off Grazing

Standing cows off pasture over critical periods enables effluent to be captured and stored, and then applied back to pasture when the risk of leaching has declined.

The studies presented in Table 3 show a large variation in the reduction in leaching. The low reduction found by Journeaux and Wilson 2014 was due to cows already being grazed off over the winter period. If this is adjusted for, the difference is a -10% change in N leaching. Monaghan *et al*. 2008 found the largest reduction in leaching of up to 56%; similarly Dalley *et al* 2015 found a large 25% reduction. Both studies are based in Southland so it is possible the climate and soils in the area show a greater reduction in losses compared to the Waikato and Bay of Plenty where the other studies were based.

Impact on profit was minimal and in the case of Macdonald *et al*. 2015 profit increased. Monaghan *et al*. 2008 assumed a feed pad was already present on the farm and Macdonald *et al* 2015 did not consider capital required, so presumably made a similar assumption. Journeaux & Wilson 2014 considered both the operational and capital costs, but interestingly did not show a large decrease in profit.

It is commonly recognised that to justify the capital cost of wintering facilities the farm system needs to intensify to offset these costs. Journeaux and Newman 2015 analysed 14 case study farms with barns across New Zealand finding the Internal Rate of Return averaged 6% (ranging from -10% to +15%), and leaching varied from -33% to +31% with 11 of the 14 farms increasing leaching losses. All except two farms increased stocking rate, and all farms increased supplementary feed and milk production.

It does not appear that any of the studies summarised in Table 3 considered an increase in stocking rate. In the case of Journeaux and Wilson 2014, they considered the benefits to be a reduction in pugging, reduced grazing costs, and travel costs to winter grazing areas, increased milking period, and a lowered amount of bought in supplements. These benefits showed a 4% reduction in profit (including capital cost), in this case moving from payment of a winter grazing contract to costs of a wintering barn. These additional benefits show an increase in stocking rate is not an essential part of wintering facilities, but generally speaking in the case of Journeaux and Newman 2015, does help to dilute the capital costs of the barn and increase profit, but increases nitrogen leaching.

Table 3. Impact of using a Feed/Standoff pad on nitrate leaching losses

Report	Catchment	Mitigation strategy	% change in N leaching	% change in profit
Perrin *et al*. 2012	Lake Rotorua	uncovered standoff pad for half the herd over the winter	-12	
Allen *et al*. 2009	Upper Waikato	standoff pad to capture effluent	-9	
Journeaux & Wilson, 2014	Southland	Winter facilities	-5%	-4%
Monaghan *et al*. 2008	Toenepi	Restricted autumn grazing	-24%	-2%
Monaghan *et al*. 2008	Waiokura	Restricted autumn grazing	-23%	-2%
Monaghan *et al*. 2008	Waikakahi	Restricted autumn grazing	-48%	-11%
Monaghan *et al*. 2008	Bog Burn	Restricted autumn grazing	-56%	-1%
Macdonald *et al*. 2015	Waikato (low intensity)	Duration controlled grazing	-15%	+9%
Macdonald *et al*. 2015	Waikato (medium intensity)	Duration controlled grazing	-23%	+10%
Macdonald *et al*. 2015	Waikato (high intensity)	Duration controlled grazing	-14%	+14%
Dalley *et al*. 2015	Southland	On- and off- grazing in autumn	-25%	-5%

Combined Mitigation Approach

The second approach employed to determine the cost of reducing nitrate leaching was to bundle strategies together. The focus of these studies was to determine the cost of reducing nitrogen leaching to levels that would be considered acceptable by Regional Councils to assess the cost of proposed legislation.

Table 4. Summary of studies and base Dairy farm systems data before mitigation strategies applied.

Study	Region	Dairy NZ System	Milksolids Production (kgMS/cow/yr)	Stocking Rate (cows/ha)	Nitrogen (kgN/ha/yr)	Supplementary feed (kg/cow/yr)	Irrigation (% of farm)	N Leaching Losses (kgN/ha)
Vibart *et al*. 2015, System 3	Southland	3	380	3.37	136	415		30.6
Vibart *et al*. 2015, System 4	Southland	4	420	3.46	135	867		32.6
Everest *et al*. 2013, System 4	Canterbury	4	410	3.4	228	338	100%	65
Everest *et al*. 2013, System 5	Canterbury	5	456	4	276	1047	100%	71
Eaton *et al*. 2012	Hawkes Bay	4	440	3.66	150	872	100%	44
Dalley *et al*. 2015, Case study 3	Southland	4	448	3.3		700		39
Dalley *et al*. 2015, Case study 4	Southland	5	461	2.5		1100		32
Journeaux and Wilson, 2014	Southland	5	364	2.6	154	1413		40
Perrin *et al* 2014	Bay of Plenty	2-5	351-444	2.71-3.34	47-181	200 - 1800		35-70

The studies represent a range of farming systems from a system 2 to 5, with supplementary feed and nitrogen inputs varying markedly, as do milk production outputs. These different systems are based in regions across New Zealand and lead to leaching losses that vary between 30.6 - 71 kgN/ha/yr.

The strategies selected were based in most cases on the consultant's knowledge and experience to select the most appropriate strategies for the farm. Although some studies such as Dalley *et al* (2015) involved consultation with the farmer and industry to select strategies together.

Each study took an iterative approach selecting three to four scenarios containing a number of strategies, which progressively decreased nitrogen leaching losses. Perrin *et al*. 2014 used a different approach and selected eight representative farms and for each farm applied mitigation strategies to reduce leaching levels to meet council legislation.

Table 5 outlines the range of strategies selected. A number of general observations have been made about the strategies selected:

- Reduction of nitrogen fertiliser appears to be the most common mitigation strategy suggesting this is perceived to be a low cost effective option.
- Common strategies employed for Scenario 1 were excluding stock from streams, reducing nitrogen fertiliser use, and increasing effluent storage area, perceived as the first strategies to consider.
- Everest *et al* (2013) was the only study to consider changes to irrigation; Eaton *et al*. 2012 did use an irrigated farm system, however did not make changes to the irrigation.
- Most studies progressed to higher cost capital intensive strategies such as increasing the size of the effluent block, installing a feed pad and/or wintering facilities for Scenarios 2 - 4.
- Dalley *et al*. (2015) employed some strategies that would be expected to increase leaching losses (shown in red as N) and combined these with other strategies to decrease leaching. This is an interesting approach moving from solely compliance and accepting lowered performance, to a farm systems review to find how performance could be improved while meeting compliance obligations.

Table 5. Nitrogen mitigation strategies selected for each study

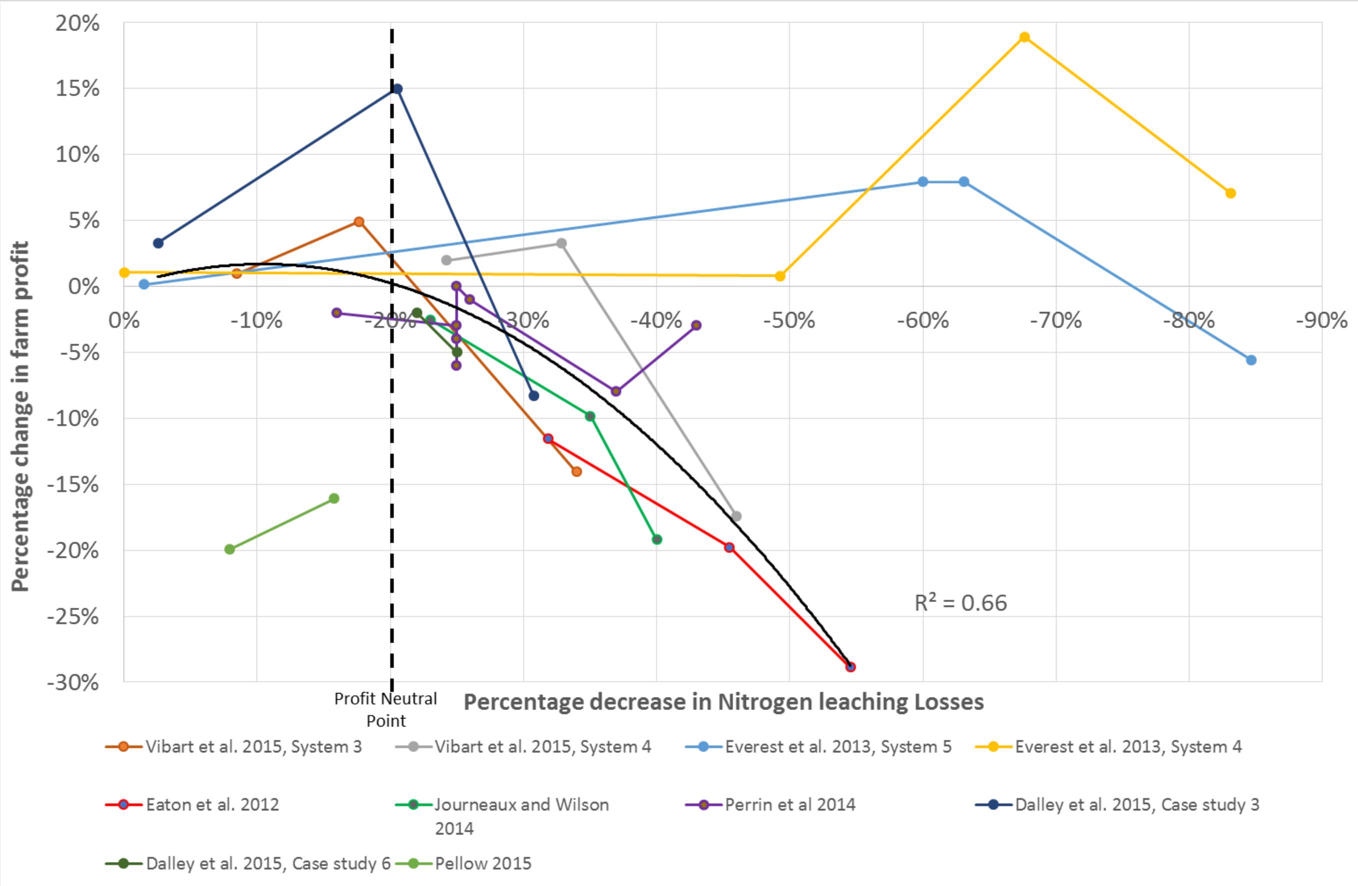
		Livestock						Fertiliser		Effluent			Infrastructure			Irrigation			Supplementary Feed		
Study		Exclude stock from streams	lower Stocking rate	Winter cows off farm	Dry off earlier	Move to spring only calving	Use higher BW cows	Reduce N fertiliser	use DCD	Lower effluent application rate	increase effluent block area	Increase effluent storage	add fenced wetland/ riparian	Add Feedpad	Add housing barn	Monitor soil moisture (for Irrigation	use Variable rate Irrigation		Feed lower protein feed	Lower quantity fed	Reduce cropping area
Vibart et al. 2015, System 3	Base																				
	Scenario 1	Y						Y													
	Scenario 2	Y	Y				Y	Y		Y			Y								
	Scenario 3	Y	Y				Y	Y		Y	Y		Y	Y							
Vibart et al. 2015, System 4	Base																				
	Scenario 1	Y						Y													
	Scenario 2	Y	Y				Y	Y		Y			Y								
	Scenario 3	Y	Y				Y	Y		Y	Y		Y	Y							
Everest et al. 2013, System 4	Base																				
	Scenario 1							Y				Y									
	Scenario 2		Y					Y	Y			Y				Y	Y				
	Scenario 3		Y					Y	Y			Y		Y		Y	Y				
	Scenario 4		Y					Y	Y			Y		Y	Y	Y	Y				
Everest et al. 2013, System 5	Base																				
	Scenario 1							Y				Y									
	Scenario 2		Y					Y	Y			Y				Y	Y				
	Scenario 3		Y					Y	Y			Y		Y		Y	Y				
	Scenario 4		Y					Y	Y			Y		Y	Y	Y	Y				
Eaton et al. 2012	Base																				
	Scenario 1			Y		Y		Y			Y								Y		
	Scenario 2			Y		Y		Y			Y			Y					Y		
	Scenario 3			Y	Y	Y		Y			Y			Y					Y		
Dalley et al. 2015, Case study 3	Base																				
	Scenario 1		Y																	Y	
	Scenario 2				N										Y					N	Y
	Scenario 3		Y		N										Y					N	Y
Dalley et al. 2015, Case study 6	Base																				
	Scenario 1		N	N																N	
	Scenario 2														Y						
	Scenario 3			Y																	Y
Journeaux and Wilson 2014	Base																				
	Scenario 1	Y						Y				Y									
	Scenario 2	Y						Y	Y			Y	Y								
	Scenario 3	Y						Y	Y			Y	Y		Y						
Perrin et al 2014	Farm 1		Y					Y											Y		Y
	Farm 2		Y					Y											Y		Y
	Farm 3		Y					Y											Y		Y
	Farm 4		Y					Y											Y		Y
	Farm 5		Y					Y											Y		Y
	Farm 6		Y					Y											Y		Y
	Farm 7		Y					Y											Y		Y
	Farm 8		Y					Y											Y		Y
Pellow 2015	Base (12/13)																				
	Scenario 1 (13/14)		Y					Y												Y	
	Scenario 2 (14/15)		Y					Y												Y	

Based on these mitigation strategies, each study was able to quantify the impact on nitrogen leaching and farm profit. Because of the large variation in base farm leaching losses and profitability the percentage change in both has been calculated.

Figure 1 shows the relationship between percentage decrease in nitrate leaching and percentage change in farm profit. A number of observations have been made about this relationship:

- Everest *et al*, 2015 shows a large decrease in nitrogen leaching of up to 90%, in most cases with an increase in profit. This was the only study to manipulate irrigation moving to monitoring soil moisture to schedule irrigation, and to the use of variable rate irrigation. In OVERSEER this will have reduced the overall drainage volume, which will reduce the amount of nitrogen leached. This shows that the irrigation strategies employed here are worthwhile to improve both profit and decrease leaching.
- Pellow 2015 considered the real impact on the Lincoln University Dairy Farm (LUDF). The baseline considered for this review was the 2012/13 season, then mitigation measures applied over the 2013/14 and 2014/15 (forecast) seasons. This differs from the other studies considered, as it is based on real data over successive seasons, although the amount of nitrogen leached was modelled using OVERSEER, but based on actual production data. Mitigation measures were not applied until mid-way through the 2013/14 season and it was noted the weather was cooler and wetter than normal. A consistent milk price of $6.10 was used across all years. Compared to the other studies, there was a larger negative impact on profit, and it is not apparent if this is caused by external influences, such as the weather, or if these changes do in fact have a larger impact than theory suggests.
- Excluding Everest *et al*, 2013 and Pellow 2015 there is a very good correlation between studies; a best fit trend line has been drawn with an R^2 of 66% showing a reasonable fit.
- The studies show that a reduction of 0- 20% leaching could have a neutral impact on profit, suggesting there are small changes that could be made on farm to reduce leaching losses without impacting profit.
- Over a 20% reduction in leaching most studies suggest there will be an increasingly negative impact on profit.

Figure 1. Percentage decrease in N leaching losses and percentage change in farm profit



Note: The black trend line and R^2 value excludes the studies by Everest *et al*. 2013 as these were the only studies to consider irrigation, and Pellow 2015 because the OVERSEER model and financial budget were based on an actual performance rather than a modelled change.

Conclusions

The purpose of this study was to summarise research analysing nitrogen mitigation strategies, their impact on nitrogen leaching losses and financial performance for dairy farms. Plus provide general conclusions, identify key similarities and explain differences.

Three individual mitigation strategies were considered:

- Supplementary feeding – use of lower protein feeds showed a large variation in nitrogen leaching reductions of 3-42% were possible. Some differences were explained by the base N leaching, where a lower base meant a lower % reduction, and the amount of supplement fed in the base; lower levels of supplement use lead to a lower % reduction. However not all differences could be explained. Change in profit was small at 0-7% reduction.
- Nitrogen fertiliser – reducing nitrogen fertiliser aligned well between studies. Eliminating winter nitrogen use reduced leaching by 12-15% while having a minor reduction on profit of 1%. Reducing inputs throughout the season or eliminating them completely increased the leaching reduction to 26-43%. Studies did not replace the reduced pasture growth with supplements so milk production was also reduced. Impact on profit was small at 1–10% reduction, with a greater impact on profit resulting from greater reductions in nitrogen fertiliser and hence milk production.

- On/off grazing – was influenced by location. Southland showed the greatest reduction of 25-56%, with reductions lower for the Waikato/Bay of Plenty at 9-23%. Impact on profit was marginal at -11% to +14%, if facilities already existed. If facilities did not exist and capital costs were factored in profit declined. To offset this decline the practical approach was to intensify the farm system which in turn increased leaching losses.

Comparing individual mitigation studies highlighted some of the reasons behind the differences in the % change in leaching and profit.

- Location of the farm and the climate – strategies to target autumn/winter management had a greater impact in regions such as Southland with greater rainfall.
- Base farm system - the level of inputs currently used in the base farm system will determine the reduction that is possible. For example, unless a farm is using a reasonable level of supplement, moving to a low protein supplement is not worthwhile.
- Secondary changes to a strategy - reducing an input into the farm such as supplementary feed or nitrogen impacts on the feed available. This means a secondary decision needs to be made as to whether the feed will be replaced with an alternative or if a drop in production is accepted. These decisions varied between studies leading to differing results.
- Magnitude of change is important as a larger magnitude will have a greater impact.
- How 'profit' is defined and calculated is important, particularly if this accounts for capital and infrastructure cost as well as operational costs.

Combined mitigation strategies were used to quantify the impact of reaching set levels of nitrate leaching, normally proposed by Regional Councils. There was a large variation in farm systems, locations across New Zealand and leaching levels. A range of strategies were utilised, commonly selected by the consultant using their judgement of the best strategies to adopt.

Despite these large differences in farm systems and strategies the reduction in leaching and impact on profit were surprisingly similar. Reducing leaching by 0-20% resulted in a neutral impact on profit of 0 to +2%, whereas above a 20% reduction the impact on farm profit becomes increasingly negative. Notably these studies were theoretical and differed to Pellow (2015) who showed a greater negative impact on profit, although it was unclear if there were other factors influencing this impact.

Overall there is a large number of mitigation strategies available to farmers to reduce nitrate leaching. There is not one size that fits all, all farms are different, and the effectiveness of the strategy will depend on the farmer, the farm system, and location.

Clear guidelines for farmers, rural professionals, and Regional Councils on each strategy and the impact it will have on nitrate leaching and profit are needed. However, to do this to a reasonable level of accuracy would require quite a granular level considering each region and farm type separately.

Secondly a clear procedure on how to model and quantify each strategy is required. The studies considered for this report showed differing results due to differing methods and assumptions used. The OVERSEER Best Practice Data Input Standards outlines how to establish an OVERSEER file based on actual farm data, but does not provide guidance on how to complete scenario analyses. Some studies were requested by Regional Councils to inform policy; if consistent and realistic policy is to be delivered these studies need to also be consistent.

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