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The impact of potential nitrous oxide mitigation strategies on the environmental and economic performance of dairy systems in four New Zealand catchments

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Abstract

The expansion of the New Zealand dairy industry has resulted in growing concern about the environmental impacts. As such, efforts are being made to design environmentally and economically sustainable management strategies. In this desktop study, the performance of two management strategies was assessed for dairy systems in four New Zealand catchments. Survey and monitoring information on farm management, farm production, and soils was used to estimate nitrous oxide (N_2O) and total greenhouse gas (GHG, i.e. N_2O, methane and carbon dioxide) emissions, nitrate leaching and profitability of farms under current management, and of farms using wintering pads and nitrification inhibitors. Under the wintering pad option, it was estimated that N_2O emissions decreased by up to 8%, total GHG emissions increased economic performance, wintering pads slightly decreased farm Earnings Before Interest and Tax (EBIT) on three of the four catchments. On the other hand, the use of a nitrification inhibitor has the potential to reduce N_2O emissions, total GHG emissions and nitrate leaching losses from all catchment case study farms while increasing the EBIT. This study suggested that nitrification inhibitors can be a cost-effective mitigation strategy for reducing dairy farm N emissions to air and water. The analysis also illustrated the importance of assessing environmental mitigation strategies at a farm-systems level, including relevant off-farm activities.

Keywords:

EBIT greenhouse gas modelling nitrate leaching nitrous oxide

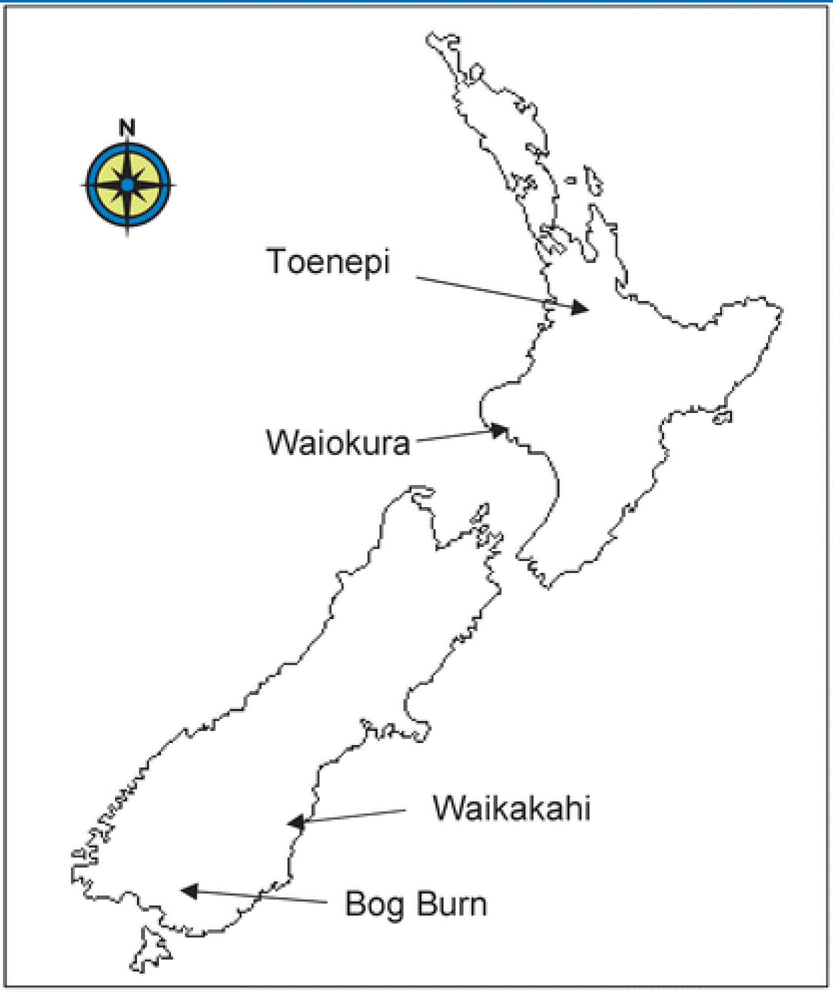
1. Introduction

In past decades, the dairy industry in New Zealand has rapidly expanded, in particular in the South Island, where many farms shifted from relatively low-intensity sheep and beef farming to higher-intensity dairying. This rapid expansion and the New Zealand dairy industry's policy of increasing farm business productivity have resulted in a growing concern about the impacts of intensive land use on soil and water quality, and on emissions of methane (CH_4) and nitrous oxide (N_2O). These non-CO_2 greenhouse gases (GHG) currently contribute 49% of New Zealand's total GHG emissions (New Zealand Climate Change Office 2005a). New Zealand's target under the Kyoto Protocol is to reduce total greenhouse gas emissions to 1990 levels, but current projections are that by 2010, agricultural GHG emissions could be 26% above 1990 levels (New Zealand Climate Change Office 2005b). In 2003, N_2O emissions alone were 28% above 1990 levels.

In New Zealand dairy systems, cows are generally grazed year-round on grass-clover pastures, with relatively low use of N fertilizer. As a result, over 80% of the direct and indirect N_2O emissions are due to depositions of animal excreta during grazing (New Zealand Climate Change Office 2005a). These emissions occur mainly under wet soil conditions in autumn and winter (de Klein et al. 2003), and mitigation strategies are now targeting this key source of N_2O during these seasons. For example, recent work feed pads (de Klein et al. 2005). In addition, studies by Di and Cameron (2002, 2003) suggested that the use of a nitrification inhibitor in autumn or spring could be an effective means of reducing N_2O emissions (and nitrate leaching) from animal urine. Other potential N_2O mitigation strategies include diet manipulation to reduce the N content of the diet, increased utilization of effluent N, and improved soil drainage (de Klein & Ledgard 2005).

In 2001, the Best Practice Dairying Catchments project was established to integrate environmentally sustainable practices into dairy farming in New Zealand. This project is carried out in four dairy catchments in New Zealand, two in the North Island, and two in the South Island (Figure 1), to study farm productivity and catchment-specific environmental issues. Although the initial focus was largely on water-quality issues, estimates of N_2O, CH_4 and carbon dioxide (CO_2) emissions are also made to assess the wider environmental impact of dairy farming in these catchments. The whole-farm system approach of this project enables an evaluation of dairy systems that optimize farm productivity, while minimizing environmental impacts. This paper reports on a desktop assessment of the impact of two of the suggested N_2O mitigation strategies (the use of a wintering pad and of nitrification inhibitors) on the environmental and economic performance of dairy systems in the four catchments.

Figure 1. Location of the four dairy catchments in New Zealand.



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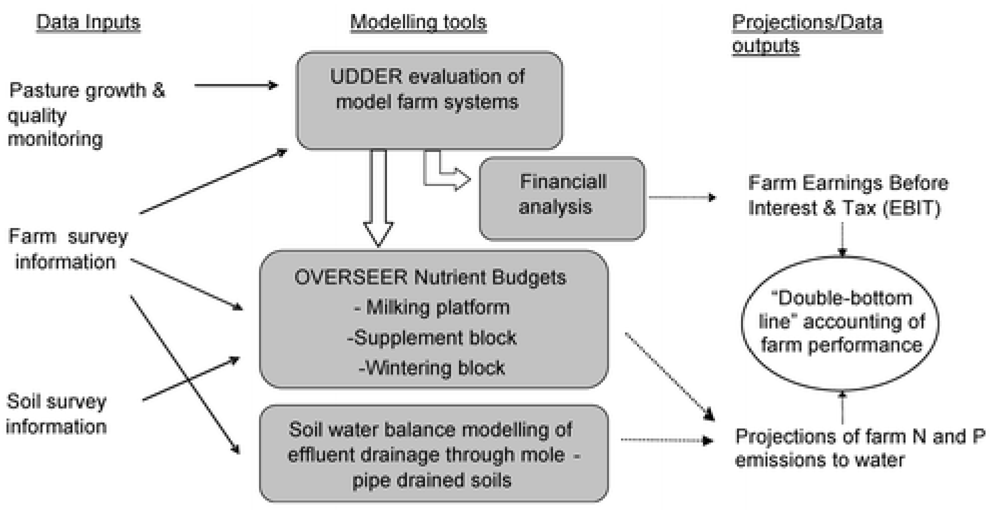
2 Methods

For each catchment, detailed information of farm-management practices, pasture and animal production, fertilizer usage, and soils was obtained through farm surveys on seven to 20 dairy farms in each catchment. Pasture growth and pasture quality monitoring and soil surveying information was obtained from these farms for three successive years. This information was then used with various modelling tools to describe the economic and environmental performances of an “average” case study dairy farm within each catchment (Figure 2). First, the UDDER dairy farm simulation model (Hart et al. 1998, Larcombe 1999) was used to characterize farm production by simulating herd characteristics, pasture growth and feed intake, milk production and changes in cow body condition. The pasture and milk production outputs from UDDER and the soil and farm information from the surveys were then used within the OVERSEER® nutrient budget model (Wheeler et al. 2003) to calculate annual budgets estimates of enteric CH_4 emissions, direct N_2O emissions from urine and dung patches, fertilizer use and effluent applications, indirect N_2O emissions from nitrate leaching and ammonia volatilization, and CO_2 emissions associated with fuel and electricity use, processing, and fertilizer use and manufacturing (Wheeler et al. 2003). OVERSEER® estimates the CH_4 and N_2O budgets based on an energy intake model and the IPCC methodology with New Zealand-specific emission factors but also has the ability to assess the impact of on-farm management practices on CH_4 and N_2O emissions (Wheeler et al. 2003). Finally, a purpose-built farm financial model was used to calculate a full farm financial budget based on the current costs of products (milk and meat) and expenses (e.g. imported feed, off-farm grazing) (Ministry of Agriculture and Forestry 2003, Dexcel Ltd 2003). Farm profit was expressed as Earnings Before Interest and Tax (EBIT).

Figure 2. Schematic representation of modelling and assessment process.



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The characteristics of each catchment and case study farm are presented in Table I. In the two South Island catchments, the cows are generally grazed off-farm on forage crops during winter, while in all catchments supplement feed was imported onto the farm. These off-farm wintering and the supplement blocks were included in the assessment of the environmental and economic performance of the case study farms. The impact of the two potential N_2O mitigation strategies, winter feed pads and the use of nitrification inhibitors, on the environmental and economic performance of these farms was then assessed by re-running the models using appropriate assumptions (

can be kept on-farm during wet periods of the year. For this paper, it was assumed that the animals were kept on a wintering pad for 70 days in winter, where they were fed bought-in supplements. The amount of supplementary feed required was calculated assuming that the North Island animals required 8 kg DM per cow per day when non-lactating in winter, while the South Island animals required 9 kg DM per cow per day.

Table I. Characteristics of the four dairy catchments and their case study farms.

Table II. Changes in some farm characteristics of the case study farms in each catchment (Current), under two potential N_2O mitigation practices: (1) cows on feed pad for 70 days during winter (Winter pad) and (2) the use of a nitrification inhibitor (Inhibitor).

The North Island case study farms were smaller and had lower per-cow production than the South Island farms. As a result, UDDER simulations indicated that the wintering pad option could be optimized by importing extra feed and to increase per-cow production. In contrast, the production levels of the South Island farms were not increased under the winter pad option, as the extra imported feed replaced the feed that under the current system was consumed on the off-farm forage crop areas. For the nitrification inhibitor strategy, the assumptions were based on recent studies (Di & Cameron 2002, C Smith, unpublished data) and included a 20% reduction in nitrate leaching, a 75% reduction in N_2O emissions from grazed pastures, and a 10% increase in pasture production. The UDDER model was used to optimize the conversion of the extra pasture production into milk, by matching animal numbers to feed availability.

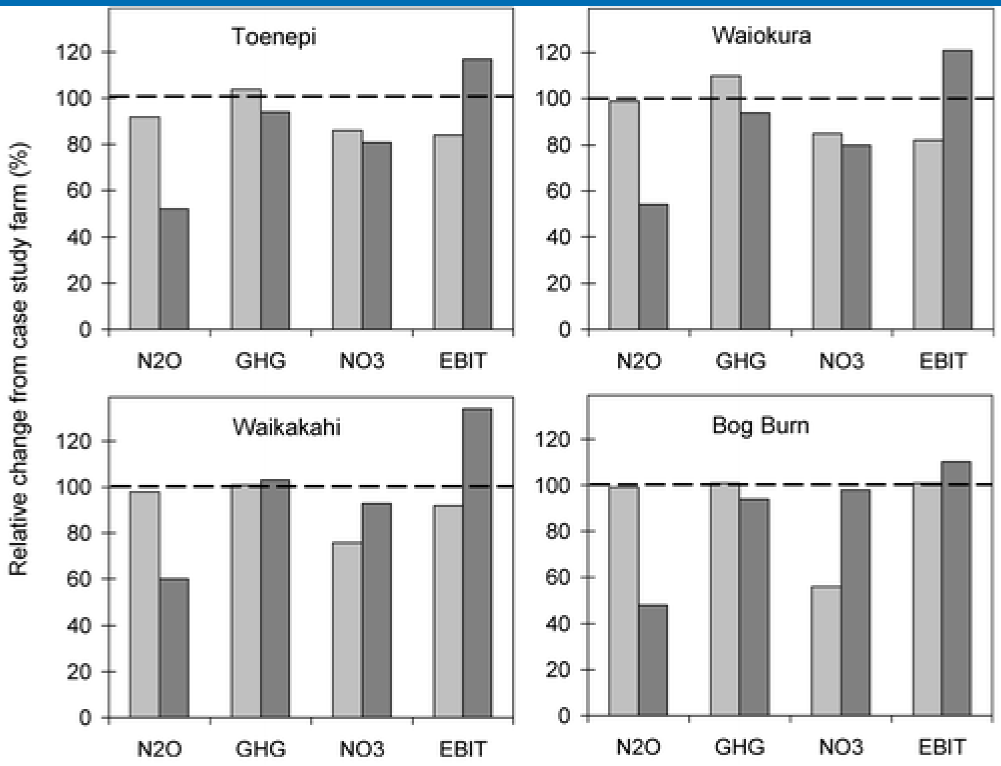
3 Results

The analyses suggested that the use of a wintering pad reduced N_2O emissions from the four case study farms by 1–8% compared with the current system (Figure 3). These estimates included both direct and indirect N_2O emissions and thus also account for the

The wintering pad system reduced these N leaching losses by 14–44%, with the largest reductions achieved in the South Island catchments, where off-farm wintering is common practice. Our analysis estimated large N leaching losses from these off-farm wintering areas, which were substanitially reduced by keeping the animals on-farm on a wintering pad. The reduction in N leaching had a relatively minor effect on reducing N_2O emissions, because the indirect N_2O emissions from N leaching generally contributed less than 12% of the total emissions. In contrast to the N_2O emissions, total GHG emissions were 1–10% higher than under the current system, with the largest increases occurring in the North Island catchments. The increase in GHG emissions was largely due to an increase in CO_2 emissions associated with fuel use, supplementary feed production, and fertilizer use and manufacturing (Table III). Methane emissions did not change significantly under the wintering pad option.

Table III. Greenhouse gas emissions (t CO_2 equivalents per farm system per year) from the case-study farm systems and under the wintering pad and nitrification inhibitor mitigation strategies (values in parentheses denote the relative change (%) in total emissions compared with the case-study farm).

Figure 3. Relative changes compared with the case study farms (represented by the dashed lines) in N_2O emissions, total GHG emissions, nitrate leaching (NO_3) losses and Earnings Before Interest and Tax (EBIT) under the wintering pad (light grey bars) and nitrification inhibitor (dark grey bars) mitigation strategies. The changes are based on the annual losses or earnings for the total farm system.



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In terms of financial performance, the wintering pad option had a slightly negative impact on farm profits in three of the catchments, reducing farm EBIT values by 8, 14, and 18% in the Waikakahi, Toenepi, and Waoikura catchments, respectively. These increased costs were largely associated with the increase in imported feed and the capital and operational costs associated with the wintering pad. In the Bog Burn catchment, the wintering pad option did not have any effect on EBIT.

The use of a nitrification inhibitor was calculated to reduce total direct and indirect N_2O emissions by 40–52%, nitrate leaching losses by 6–20%, and total GHG emission by only 0–9%. The reduced effect on total GHG emissions, compared with N_2O emissions, was largely due to an increase in methane emissions from the farms. Nitrification inhibitors were assumed to increase pasture production by 10% and, particularly for the two South Island catchments, the stocking rate of the farms was increased to utilize this extra pasture. This larger number of animals resulted in an increase in methane emissions from the farm system. In terms of financial performance, the nitrification inhibitor strategy appeared to increase farm profits by 10–34%. This increase was again due to the increase in pasture and milk production from the farm systems.

4 Discussion

This study suggested that the wintering pad and the nitrification inhibitor strategies could both reduce N_2O emissions and nitrate leaching losses from the case study farms in the four dairy catchments. The reduction in N_2O emission was limited for the wintering pad option, due to the extra feed that was imported to optimize milk production under this management system. However, for the nitrification inhibitor strategy, N_2O emissions were substantially reduced. The reduction in N leaching was slightly less. Our assessment assumed that N leaching from grazed pastures would be reduced by 20%, which is lower than the 60% presented by Di and Cameron (2002). However, their estimate was based on lysimeter studies of urine patches and is thus likely to represent a maximum potential benefit. Recent field measurements suggest that a 20% reduction better represents the effect of nitrification inhibitors on N leaching losses from grazed pastures (C Smith, unpublished data).

Our analysis further showed that the use of nitrification inhibitors had a limited effect on total GHG emissions reduction, compared with the reduction in N_2O emissions, due to an increase in both CH_4 and CO_2 emissions from the farm systems. Although nitrification inhibitors do not directly affect emissions of these GHGs, their use was estimated to result in an increase in pasture production and thus milk production, which, in turn, increased CH_4 and CO_2 emissions. It should be noted, however, that we assumed that the use of nitrification inhibitors resulted in an increase in stock numbers to utilize the extra pasture production under the inhibitor option. An alternative scenario could be that the extra pasture is used to reduce inputs of N fertilizer and/or supplementary feed in spring when feed shortages can occur. Under such a scenario, the stocking rate and/or milk production would not necessarily increase, and total GHG emissions from the farm systems could be reduced. These and other alternative scenarios with nitrification inhibitors will be analysed in future to optimize their advantages within the total farm system.

Furthermore, the comparison of the impact of the different management strategies was based on the environmental losses and farm earnings for the entire farm system, rather than on a ‘per hectare’ or ‘per unit of product’ basis. This was done to remove the confounding effects of changes in farm areas due to the removal of the off-farm wintering areas, and of changes in milk production between the different strategies. This way, the evaluation of the strategies provided the true environmental and economic performance of the case study farms. However, a comparison of environmental losses on a ‘per unit of product’ basis could be used for assessing the

the reduction in total GHG emissions per unit of product was larger than the reduction in total GHG emissions from the farm systems (c. 15% compared with a maximum of 6%; Table III). This indicated that nitrification inhibitors are likely to increase a farm's efficiency as the increase in milk production was larger than any increase in total GHG emissions from the farm. An assessment of environmental losses ‘per unit of product’ can thus identify management strategies that have the largest reduction in environmental emissions for a given production level.

The economic analyses indicated that the wintering pad option generally reduced the total farm earnings due to increased costs associated with imported feed and capital and operating costs of the wintering pad. The exception was for the case-study farm in the Bog Burn catchment, where the wintering pad option did not reduce farm financial performance. However, our calculations did not account for any potential benefits of reduced soil physical damage from grazing in wet winter conditions, which can decrease spring pasture and animal production, and increase N_2O emissions (de Klein et al. 2005). In addition, the economic analysis did not include an assessment of potential savings (or costs) associated with a reduction (or increase) in GHG emissions or N leaching losses. In New Zealand, the value of GHG emissions is currently set at $25 per tonne of CO_2-equivalent. However, since GHG emissions under the wintering pad option increased in all catchments, this would result in a further reduction in farm earnings. On the other hand, N leaching losses decreased by up to 44%, and potential savings associated with this reduction could have a positive impact on the farm earnings, but there is currently no mechanism in New Zealand to accrue these potential savings.

The economic analysis further showed that the use of nitrification inhibitors appeared to be a cost-effective mitigation strategy, as farm profitability was maintained or enhanced, while environmental losses were reduced. If the financial impact of the reduction in environmental emission was accounted for, farm profitability would further increase. It should be noted, however, that the assumed 10% increase in pasture production due to nitrification inhibitor use was largely based on findings from small-scale lysimeter studies (Di & Cameron 2002) and needs to be verified in field measurements under grazing. In addition, the long-term impacts of nitrification inhibitors on N cycling and losses from New Zealand dairy systems are unknown. The high reduction in N_2O emissions and N leaching assumed here might not be sustained longer term (Ledgard & Menneer 2005).

Finally, our study emphasized the importance of evaluating management strategies for the farm system as a whole to ensure that environmental and economic impacts are fully accounted for. A similar conclusion was made by Schils et al. (2005), who presented a farm-level approach for defining successful GHG mitigation strategies from ruminant livestock systems. For example, their analysis showed that a management strategy to reduce N_2O emissions (reduced grazing hours) indeed reduced N_2O emissions but increased CH_4, CO_2 and total GHG emissions, as well as ammonia volatilization. Schils et al. (2005) also suggested that an increase in milk production per animal resulted in a reduction in all on-farm GHG emissions. However, the increased milk production per animal was achieved by increasing the amount of concentrate brought onto the farm, and any GHG losses associated with the production of this extra concentrate were not included in their assessment. In contrast, in the analysis presented here, any off-farm areas that are directly linked to on-farm management (e.g. wintering and supplement blocks) were included in the overall assessment.

5 Conclusions

The use of wintering pads and nitrification inhibitors has the potential to reduce N leaching and N_2O emissions from New Zealand dairy farms, but they had a limited effect on reducing total GHG (i.e. N_2O, CH_4 plus CO_2) emissions. It is therefore important that strategies designed to reduce N_2O emissions are assessed at a farm-systems level, and include relevant off-farm activities, to account for the wider environmental implications of these strategies. The nitrification inhibitor option appeared to be a cost-effective and environmentally beneficial strategy, although the impact of their long-term use on N losses is unknown. The wintering pad option generally reduced farm profitability when the economic implications of savings in nitrate leaching losses and reduced soil physical damage were not taken into account. To fully account for the economic impacts of farm systems, an assessment of the cost of environmental losses is required.

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