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NEW ZEALAND DAIRY FARM SYSTEM SOLUTIONS THAT BALANCE REDUCTIONS IN NITRATE LEACHING WITH PROFITABILITY – A CASE STUDY

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Abstract

The purpose of this study was to test management solutions for reducing nitrate (NO_3^-) leaching by 20%, in comparison to an existing farm management baseline for the 2017/2018 dairy season, whilst maintaining profitability. Nitrate leaching and profitability were estimated for a south Canterbury case study dairy farm using the models FARMAX Dairy and OVERSEER® Nutrient Budgets. Principles and management practices from the Forages for Reduced Nitrate Leaching (FRNL) programme were modelled to achieve this target: (1) reducing nitrogen (N) in cows' diets through low-N feed (fodder beet), (2) recapturing N from soils through catch crops (oats) and (3) diluting urinary N through ingested plantain. While most treatments reduced NO_3^- leaching, significant management inputs were required to achieve a 20% reduction from the Baseline. Plantain was identified as the key forage for reducing NO_3^- leaching. While fodder beet and oats had little impact on NO_3^- leaching when grown on the milking platform, they increased profitability relative to the Baseline. Only one scenario – using fodder beet, catch crops and maintaining high plantain content in pasture – achieved the target by reducing NO_3^- leaching by 21% and increased profitability by 2% compared to the Baseline.

Keywords: nitrate leaching; plantain; fodder beet; catch crop; oats; modelling; dairy farm system; mixed pasture; profitability; Canterbury

Introduction

In the last few years, animal and field trials under the Forages for Reduced Nitrate Leaching (FRNL) programme have examined a range of potential management practices to reduce NO_3^- leaching from farm systems. The approach was to incorporate forages with particular characteristics into the every-day and long-term management of farm systems (DairyNZ n.d.). The FRNL mitigations investigated in this study target NO_3^- leaching from dairy cow urine patches by (1) reducing nitrogen (N) intake by feeding fodder beet during late lactation, (2) capturing N from soils at risk of leaching over winter by catch-cropping with oats and (3) diluting N loading in urine patches by incorporating plantain into the pasture base (Beukes *et al.* 2017; Beukes *et al.* 2018). Animal and field trials and modelling showed that when plantain makes up at least 30% of a cow's diet, the N load of her urine patches (the main source of N loss to water from agricultural land; Di and Cameron, 2002) is significantly reduced (Judson and Edwards 2016; Box *et al.* 2017; Dodd *et al.* 2019a).

Previous studies (Beukes *et al.* 2017; Beukes *et al.* 2018; Pinxterhuis and Edwards 2018) explored the use of fodder and catch crops, but the role of plantain on NO_3^- leaching has not been fully examined. In particular, the persistence of plantain in the sward has not been included in any published modelling studies to date, which is not surprising considering interest in plantain as a tool for NO_3^- mitigation is relatively new. Methods for establishing and maintaining plantain (Bryant *et al.* 2019) and associated costs (Edwards and Pinxterhuis 2018) in mixed pastures have been explored, but the implications of plantain persistence in mixed pastures for NO_3^- leaching have not.

The objective of this study was to provide management examples where combinations of FRNL solutions could reduce NO_3^- leaching by 20% from the Baseline and maintain profitability. This was done within a modelling framework for a case study dairy farm in south Canterbury. Based on the results of the FRNL programme and preliminary budgeting, it was hypothesised that integrating fodder beet, oats and plantain into the existing farm system would reduce NO_3^- leaching by 20% and increase profitability compared to the Baseline.

Methods

This study modelled the application of FRNL principles to an existing south Canterbury dairy farm. Farmax was used to assess the physical and financial feasibility of scenarios. Overseer was used to estimate NO_3^- leaching from each scenario. All scenarios were assumed to be at steady state, *i.e.* no transition period was factored into the analyses.

Baseline scenario description

The Baseline scenario (the reference system) was based on the 2017/2018 observed dairy season for a farm in Canterbury. Soil type was dominated by Claremont moderately deep silty-loam soils (poorly drained). The climate modelled had an average of 13.7° C with 1130 mm rainfall/year. The Baseline farm system was simplified to allow representation in the model and to generalise the results (especially the financials) for the Canterbury region. The system modelled was an irrigated 312.8 ha milking platform, producing 1,600 kg MS ha^{-1}, stocked at 3.7 crossbred cows ha^{-1} (1,142 peak milking cows) with standard perennial ryegrass/white clover (PR/WC) pastures fertilised at 280 kg N ha^{-1} yr $^{-1}$. No changes were made on the support block for any scenario, hence the support block is not included in the results or discussion.

Treatments

The crop and plantain treatments applied to the Baseline are described in

. Milksolids production was maintained between all treatments through isoenergetic calculation. This made it possible to observe the impacts of each treatment on NO_3^- leaching. Fair comparisons were able to be made between the treatments because most management factors were unchanged. Where crops were grown on the milking platform, some imported feed was removed from the system (the crops were substituted for select imported feeds). The substitutions were made based on data from DairyNZ (2017), Dalley *et al.* (2017) and Edwards *et al.* (2017) feed characteristics and popularity in Canterbury.

Crop treatments

Two crop treatments, Fallow (F) and Both Crops (BC), were introduced as part of the regrassing scheme. As for the Baseline, 10% of the milking platform area was regrassed each spring in all subsequent treatments. Where Fallow crop treatments were applied, 6% of the farm was regrassed with permanent (new) pasture and 4% of the farm was cropped in fodder beet, followed by a fallow period and then new pasture. Where Both Crops treatments were applied, 6% of the farm was regrassed with new pasture and 4% of the farm was cropped in fodder beet, followed by oats and then new pasture. Sowing of fodder beet and new pastures occurred in October. Fodder beet was grazed *in situ* in April and May. For Fallow, the paddocks were left fallow until new pasture was sown in October. For Both Crops, oats were sown as paddocks became available, beginning in June. The oat crop was harvested in stages from September to October for silage, and followed by permanent pasture.

Plantain treatments

Four treatments were applied to introduce plantain to the milking platform in the Baseline and the two crop treatments. Treatment 1 involved incorporating plantain into the pasture base by sowing a mix of plantain (PL), perennial ryegrass (PR) and white clover (WC) seed during spring regrassing. As plantain does not persist well in RG/WC + PL pastures (Dodd *et al.* 2019b), and it was impractical to sow pure plantain across the entire farm (Mangwe *et al.* 2019), plantain treatments 2-4 were based on increasing the frequency of plantain maintenance (

). Maintenance involved direct drilling of existing PR/WC + PL pastures with plantain seed in spring to increase the proportion of plantain in the pasture.

Table 1: Modelled scenarios and descriptions of the crop and plantain treatments applied to the Baseline. “Maintenance” means that pastures are direct drilled with plantain seed in spring to maintain/increase the proportion of plantain in the pasture sward.

Crop treatment	**Plantain treatment**			
	No maintenance	Maintenance of new pastures in 4th year	Maintenance of new pastures in 4th and 7th year	Maintenance of new pastures every 2nd year
Proportion of milking platform maintained per year	0%	10%	20%	40%
Baseline (B), no crops.	B1	B2	B3	B4
Fallow (F), fodder beet only.	F1	F2	F3	F4
Both Crops (BC), fodder beet and oats.	BC1	BC2	BC3	BC4

Plantain persistence assumptions

The persistence curve, representing the proportion of pasture DM as plantain in PR/WC + PL pastures, was a major assumption for this case study. It was assumed that plantain made up 50% of pasture DM in the first year, 40% in the second year, 20% in the third year and 10% in the following years (personal comms: D. Chapman, 24th June 2019 and M. Dodd, 1st July 2019).

Plantain maintenance, beginning in October, was assumed to return plantain populations to those of first-year pastures, *i.e.* 50% pasture DM as plantain.

Nitrate leaching estimation

For the Baseline, Fallow and Both Crops – treatments with no plantain – NO_3^- leaching values were estimated using Overseer. At the time this research was carried out, plantain was not an available option in Overseer. In OverseerScience, the generic urine patch N loading rate could be changed from the standard 750 kg N ha^{-1} yr^{-1}. This was used as a proxy for the presence of plantain (Box *et al.* 2019).

Results

Nitrate leaching from the milking platform (312.8 ha) for the Baseline (no crops) was 38 kg N ha^{-1} yr^{-1}.

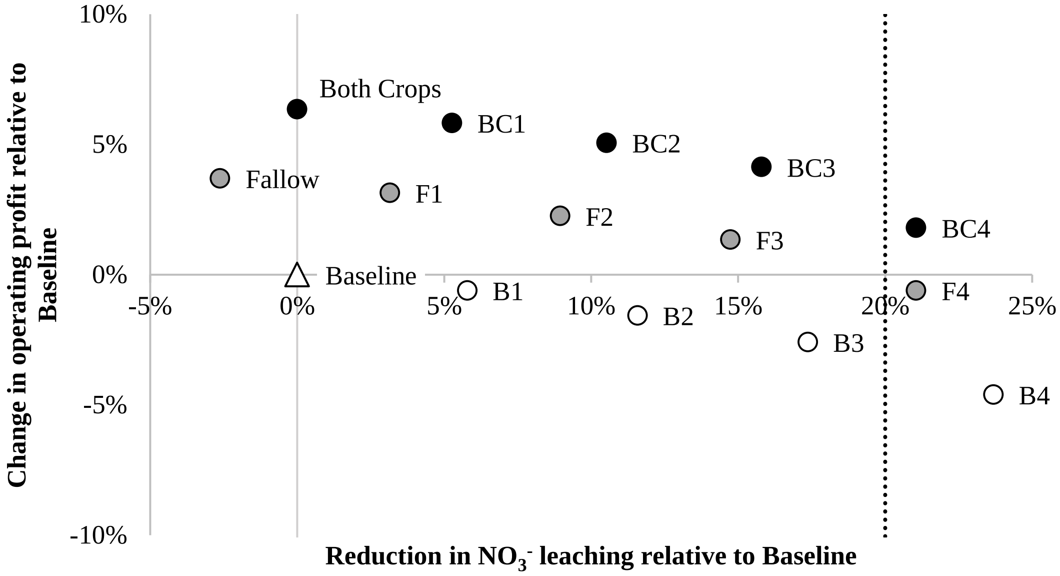

Figure 1: Changes in farm operating profit and nitrate (NO_3^-) leaching relative to the Baseline (white triangle). The dotted line marks the target NO_3^- leaching reduction of 20%. For Fallow, a -3% reduction in NO_3^- leaching loss represents an *increase* of 3%, relative to the Baseline.

Crop treatments

For Fallow, addition of the fodder beet crop resulted in a small increase of 1 kg N ha^{-1} yr^{-1} (to 39 kg N ha^{-1} yr^{-1}) in NO_3^- leaching. Addition of the fodder beet and oat crop resulted in no difference in NO_3^- leaching between Both Crops and the Baseline – both leached 38 kg N ha^{-1} yr^{-1} (

Table 2).

Plantain treatments

When plantain was introduced as PR/WC + PL pastures (with no maintenance), NO_3^- leaching was reduced from the Baseline leaching of 38 to 36 for B1, 37 for F1 and to 36 kg N ha^{-1} yr^{-1} for BC1. More frequent plantain maintenance resulted in greater reductions in NO_3^- leaching (

Table 2 and Figure 1).

To achieve the initial objective of a 20% reduction in NO_3^- leaching, it was necessary to maintain PR/WC + PL pastures every second year, regardless of crop treatment (treatments B4, F4 and BC4) (
Table 2, Figure 1). This frequency of maintenance required 40% of the milking platform pasture area to be maintained and 10% to be renewed each year. The plantain treatments with less frequent maintenance (B1-B3, F1-F3 and BC1-BC3) reduced NO_3^- leaching but did not achieve the 20% reduction target.

Table 2: Milking platform nitrate (NO3-) leaching and operating profit for all treatments. The reductions are reported relative to the Baseline. **Bolded** lines indicate treatments that achieved the targeted 20% reduction in NO3-. N = nitrogen.

Treatment	Description of plantain treatment	NO_3^- leached		Operating profit	
		kg N ha^{-1} yr^{-1}	Reduction compared to Baseline	\$ ha^{-1}	Change compared to Baseline
Baseline	No plantain	38		2,342	
B1	No maintenance	36	6%	2,328	-1%
B2	Maintenance in 4th year	34	12%	2,306	-2%
B3	Maintenance in 4th and 7th year	31	17%	2,283	-3%
B4	**Maintenance every 2nd year**	**29**	**24%**	**2,289**	**-5%**
Fallow	No plantain	39	-3%	2,432	4%
F1	No maintenance	37	3%	2,418	3%
F2	Maintenance in 4th year	35	9%	2,396	2%
F3	Maintenance in 4th and 7th year	32	15%	2,374	1%
F4	**Maintenance every 2nd year**	**30**	**21%**	**2,328**	**-1%**
Both Crops	No plantain	38	0%	2,501	6%
BC1	No maintenance	36	5%	2,487	6%
BC2	Maintenance in 4th year	34	11%	2,467	5%
BC3	Maintenance in 4th and 7th year	32	16%	2,443	4%
BC4	**Maintenance every 2nd year**	**30**	**21%**	**2,385**	**2%**

Cost of mitigation: nitrate leaching vs. operating profit

While increasing operating profit, adding fodder beet and oats had minimal effect on NO_3^- leaching of the milking platform. Including plantain in pastures reduced NO_3^- leaching. Increasing the frequency of plantain maintenance reduced NO_3^- leaching even further, but relative operating profit declined due to an increase in the total cost of plantain maintenance.

For the three treatments that achieved the initial objective of reducing NO_3^- leaching by 20%, the following changes in operating profit are reported relative to the Baseline. The relative cost for B4 was \$103 ha^{-1} and \$14 ha^{-1} for F4. The relative benefit for BC4 was \$43 ha^{-1}, *i.e.* this treatment increased operating profit. In these treatments, plantain was maintained every second year (the most frequent maintenance schedule). Out of all treatments explored, BC4 was the only treatment that reduced NO_3^- leaching beyond 20% and increased operating profit above that of the Baseline.

Discussion

The results of this study showed that in a modelling framework under the assumptions described in the methods, it was possible to reduce NO_3^- leaching by >20%. In two cases, this resulted in a reduction of operating profit by \$103 ha^{-1} (B4) and \$14 ha^{-1} (F4). However, there was one case (BC4) where it was possible to reduce NO_3^- leaching by 21% and increase profitability by 2% (\$43 ha^{-1}). In all three cases, to achieve >20% reduction in NO_3^- leaching, renewal of PR/WC + PL pastures followed by plantain maintenance every second year was required.

Nitrate leaching from crop treatments

Nitrate leaching from the milking platform was similar between the Baseline and the two crop treatments without plantain (Fallow and Both Crops). This lack of difference in NO_3^- leaching between the crop treatments was not surprising given that the crop area on the milking platform was small (only 4% of the effective area). Consequently, the addition of cropped land had only a very small contribution to NO_3^- leaching when expressed at the milking platform level.

Nitrate leaching from plantain treatments

Plantain treatments had greater impact on N leaching than crop treatments, due to the greater due to the greater area (100% instead of 96% of the milking platform) that was sown in PR/WC + PL pastures. Plantain was the most important forage for reducing NO_3^- leaching, achieving up to a 24% reduction (9 kg N ha^{-1} yr^{-1}) in B4 (29 kg N ha^{-1} yr^{-1}) from the Baseline (38 kg N ha^{-1} yr^{-1}).

Financial feasibility

For the modelled scenarios, it was more profitable to grow fodder beet and oats on the milking platform than import supplemental feeds – note that income did not change as MS production was maintained.

The cost of plantain maintenance was estimated assuming that direct drilling was the most effective method for establishing new plantain plants into existing pastures (Bryant *et al.* 2019). Note that maintained pastures could be grazed as part of the normal rotation as the new plantain plants could establish between grazings (see Bryant *et al.* 2019 for further explanation). For this case study, the cost of maintenance via direct drilling was estimated to be \$200 ha^{-1} maintained, *i.e.* \$20 effective ha^{-1} across the whole farm when 10% of the farm was maintained each year.

Conclusions

The hypothesis of this study was that the use of fodder beet and oats in the existing dairy farm system with the addition of plantain in perennial ryegrass/white clover + plantain (PR/WC + PL) pastures could achieve a 20% reduction in NO_3^- leaching, whilst profitability was maintained. The modelling approach used here showed that it was possible to reduce NO_3^- leaching by 21% from a Canterbury dairy farm by including these three forages in a modelling context. Profitability was increased by 2% (\$43 ha^{-1}), where fodder beet and oats were cropped on 4% of the milking platform area and plantain in pastures was maintained every second year.

Overall, most of the reduction in NO_3^- leaching was attributed to the presence of plantain in PR/WC + PL pastures. The use of plantain as a mitigation tool is relatively new and improving the persistence of plantain in PR/WC + PL remains a major research gap. Analysis of the plantain treatments showed that frequent re-drilling of plantain was necessary to maintain populations high enough to promote a substantial reduction in NO_3^- leaching.

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