Modelling options to increase milk production while reducing N leaching for an irrigated dairy farm in Canterbury

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Abstract

The Forages for Reduced Nitrate Leaching programme (FRNL) aims to address the challenge of presenting farmers with alternatives for forage production that will sustain milk production and farm profit, but simultaneously reduce nitrogen leaching by 20% from current levels. This paper describes the improvements made to a dairy model comprising three software packages, and how this model was used to evaluate proposed farm system changes on a Canterbury dairy farm (Canlac Holdings) associated with the FRNL programme. After a baseline scenario was sense-checked against actual farm physical and financial data for the 2014-2015 season, alternative options were modelled in an additive way by expanding the effluent area, growing fodder beet on the platform, replacing some pasture with maize silage, growing diverse pastures on 7% of the milking platform, and including a feed pad. The cumulative effect of these changes was an increase of 3 and 13% in production and profit respectively, but only a 5% decrease in nitrogen leaching as estimated for the combined platform and support block areas over 3 climate years. A hypothetical scenario, of a third of the platform in diverse pastures, less nitrogen fertiliser, all fodder beet grown on the milking platform, lifted and fed on the feed pad, and with an oats catch crop following fodder beet, increased production and profit by 2 and 10%, respectively, with a reduction in N leaching of 19%. This result indicates that high-performing farmers have scope to reduce N leaching by ~20% and still increase profit by implementing some of the options emanating from the FRNL programme.

Keywords: diverse pastures, dairy farm system, fodder beet, effluent block, feed pad, catch crop

Introduction

This study forms part of the Forages for Reduced Nitrate Leaching programme (FRNL) that aims to provide new knowledge and technologies for forage production that will contribute to maintaining or increasing production, but simultaneously reducing nitrogen (N) leaching by 20% from current levels.

One specific research aim of FRNL is to develop improved farm models for the arable, dairy, and sheep and beef sectors, and to use these models to evaluate the implications for case study farms that implement N leaching mitigations developed in the FRNL programme. A particular focus for model development is to accommodate diverse pastures (combinations of grasses, herbs and legumes), and alternative crops that can increase N uptake from the soil and result in less N excreted in urine by grazing animals. Furthermore, the models have to predict N leaching for all the hectares occupied by a business unit, including support blocks, and also predict production and profit for that particular unit. A final requirement is that these models be tested with case study farms that form part of the FRNL monitor farm network.

This paper reports on the improvements made to a dairy model comprising three software packages, and how this was used to evaluate N mitigation options for one of the dairy monitor farms (Canlac Holdings) in the Canterbury region. The objective was to test the model against the baseline scenario for Canlac (2014-2015 season), and then use it to predict trends in production, profit and N leaching following farm system changes proposed by the owner-manager at Canlac. The intention was for the owner-manager to sense-check model output, and to consider the model output as part of his decision whether or not to implement the proposed changes.

Methods

The dairy farm model and improvements

Three software packages were used to model production, profit and N leaching: (1) DairyNZ's Whole Farm Model incorporating the Molly cow model (WFM) (Beukes *et al*. 2008), (2) the Urine Patch Framework (UPF) that applies the urine excreted per grazing event as urine patches onto the paddock (Romera *et al*. 2012), and (3) the Agriculture Production System Simulator (APSIM) that simulates water, N and carbon dynamics and predicts N leaching from urine and non-urine patches (Holzworth *et al*. 2014).

Grazing pastures that consist of a mixture of grass, herb and legume species growing together in the sward (diverse pastures) is an important strategy for N mitigation being investigated as part of the FRNL

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programme. It was, therefore, important to incorporate diverse pastures into the capabilities of the model. The WFM has a McCall pasture model (Romera *et al*. 2009) that predicts pasture growth on a daily time step depending on soil, weather and pasture biomass. This model predicts growth rates for a standard ryegrass-clover pasture, however, the model is too simplistic to represent the complex below- and above-ground plant functional traits observed in diverse pastures. The WFM was, therefore, adapted to accept user-defined growth rates for any paddock chosen as a diverse pasture. Default growth rates are provided as guidelines to model users, and were obtained from pasture trials in Waikato and Canterbury (Woodward *et al*. 2012, 2013; Nobilly *et al*. 2013).

Pasture quality is important in the WFM because the cow model, "Molly", derives the metabolisable energy content using the feed composition (crude protein, soluble sugars, starch, fat, acid detergent fibre, neutral detergent fibre, ash, lignin) as input to her mechanistic rumen module. Feed compositions are user-entered into a table where all the feeds are listed, and this can be expanded at the user's discretion. The WFM's feed composition table had to be expanded with monthly entries for diverse pastures for Waikato and Canterbury using data from Woodward *et al*. (2013) and Nobilly *et al*. (2013).

Feeding alternative forage crops to provide low-N feed and for removing N from the soil is another important part of the FRNL programme. At the onset of the programme the state of the WFM was that the user could implement a cropping policy that allowed any pasture paddock to be cultivated and sown into one of five crops at any point in time in the simulation; maize, lucerne, kale, chicory or oats. The WFM has mechanistic models for these crops that allow yield predictions based on time in the ground, fertiliser and irrigation regimes, and weather conditions. However, the WFM only allowed grass to crop to grass rotations and only allowed the crop to be harvested and then fed to cows as a supplement from a feed store e.g. no *in situ* grazing of a forage crop was possible. The FRNL programme demanded a complete re-think of the cropping policy in the WFM because of the requirements for (1) alternative crops like fodder beet, Italian ryegrass, forage rape or plantain for which there were no mechanistic models available, (2) more complex crop rotations within a simulation, e.g. starting a simulation on 1 June with a fodder beet crop already in the ground and ready for winter grazing, (3) cows to graze crops, e.g. kale and fodder beet *in situ* so that information about urinary N deposited onto the crop paddock is available from the model.

Canlac scenarios and assumptions

DairyBase information from 2014-2015 season was used to initialise a Baseline or reference scenario in the WFM, which consists of a milking platform (335 ha) and a support block (155 ha), both fully irrigated on a Lismore soil. The farm was stocked at 4.12 cows/ha; 1380 cross-bred cows at peak milk with an average liveweight on 1 December of 480 kg/cow. Planned start of calving was 1 August and dry-off date was 30 May, with young cows milked once-a-day from mid-March until dry-off. On the milking platform, cows were fed mainly pasture, with supplements being fed in the paddock in spring and autumn. The supplements were pasture silage, palm kernel expeller (PKE), lifted fodder beet bulb and maize silage. Wastage varied from 20 to 30% depending on supplement type. All cows were wintered on the support block, from dry-off date until before calving, where they were grazed on kale and fodder beet supplemented with pasture silage. Nitrogen fertiliser use was 290 kg N/ha/year with dairy shed effluent being irrigated onto 42% of the platform. Annually, 10% of the platform was re-grassed. Young stock were grazed on the support block.

The owner-manager wanted to explore system options that would increase production and profit, but decrease N leaching. The proposal was to test several options, and add these options to the Baseline in a stepwise fashion. The first option was to implement a feed pad to reduce supplement wastage. Wastage decreased to 5-15% depending on supplement type. Supplement feeding required cows to spend 3 hours/day on the feed pad in July and August, 1.5 in September, 1.5 in March and April and 3 hours/day in May. It was proposed to increase the effluent block to 100% of the platform because of the greater amount of effluent captured by using the feed pad, and the potential increase in N leaching from the effluent block when more effluent was re-cycled.

The second option was to grow fodder beet on 12.5 ha of the platform. A user-defined fodder beet yield of 22 t DM/ha was assumed, with an utilisation efficiency of 95% (Jenkinson *et al.* 2014). The reasoning for the fodder beet was to feed some of this crop to lactating cows in autumn as part of transitioning them onto the winter fodder beet, and to feed some to lactating cows from August onwards when they came back from the support block. The remainder of this crop would be lifted and the bulbs fed on the feed pad. An additional aim of feeding fodder beet on the platform was to reduce the overall protein content of the diet and, therefore, urinary N excreted. With more feed available, once-a-day milking of part of the herd was not necessary. Also, dry-off could be delayed by one week, with some late-calving cows being milked until 20 June. The owner-manager estimated that these changes would increase production by 15 000-20 000 kg milksolids (MS)/year. Milking into June is likely to increase N leaching, therefore to counteract this it was proposed to replace

most of the pasture silage with low-protein maize silage diluting N intake and, therefore, urinary N amount and concentration (Ledgard *et al.* 2003). As part of the same change it was proposed to switch the winter crop from both fodder beet and kale, to fodder beet only. The hypothesis was that the lower N concentration of the fodder beet would reduce urinary N output (Gregorini *et al.* 2016), and with higher yields compared with kale, a smaller area of the support block would be required for the winter crop. However, some of these benefits could be negated by the high yields and, therefore, high stocking densities and area covered by urine patches.

The third option was to change 7% of the milking platform to diverse pasture, in addition to the previous two options. The intention was to graze the diverse pastures using the same grazing decision rules as for the standard pastures. The reason for the diverse pasture was the inclusion of herbs, including plantain, which decrease total urinary N and urine N concentration excreted by the cows (Box *et al*. 2016). This has been reported to have the potential to reduce N leaching by 10-20% on a farm scale when the area sown occupied 20-50% of the farm (Beukes *et al.* 2014; Romera *et al.* 2017). In the model, the growth rates and feed composition of these pastures were derived from trial results in Canterbury (Nobilly *et al*. 2013).

The final scenario comprised a hypothetical farm to reduce N leaching by 20% (the target of the FRNL programme), but still increase production and profit compared with the Baseline. In this scenario a third of the milking platform was sown in diverse pastures to capture more of the benefits of these pastures. All of the 12.5 ha fodder beet was lifted as bulbs and fed on the feed pad. Assumptions were: yield of 18 t DM/ha; harvesting efficiency of 95%; lifting costs of 12 c/kg DM; wastage on the feed pad 5%. The last fodder beet bulb harvest occurred on 2 July, followed by an oats catch crop sown on 15 July and harvested as whole-crop silage on 24 December, with a climate-driven yield of 9.9 t DM/ha for the 2013-2014 season. The oat crop was followed by permanent pasture sown on 1 January under irrigation. The reason for the catch crop was to reduce the fallow period and utilise surplus plant-available N not used by the fodder beet. The oats silage was fed to lactating cows in April and May. With more fodder beet bulb and oat silage being fed, the time on the feed pad was increased from 1.5 to 3 hours/day in September, March and April. This allowed more urinary N to be captured on the feed pad, and later recycled onto pastures. This meant that bought N fertiliser used could be reduced from 290 kg/ha to 220 kg/ha. Furthermore, because of the potential increase in N leaching when grazed cows are milked in the winter months of June and July when pasture growth and N uptake are slow, it was decided to dry all cows off on 30 May.

The WFM calculates farm operating profit using milk price and other economic input data. For this exercise the milk price used was $5.00/kg MS with economic input data for the 2012-2013 season (DairyNZ 2014), which was found to be most applicable for this low milk price. Other input prices were $290/t DM for bought-in pasture silage, $330/t DM for PKE, $310/t DM for maize silage, $80/t DM for harvesting pasture silage or any catch crop, e.g. oats grown on the milking area; and $45/t DM for feeding supplements. Fodder beet growing costs were assumed to be $2600/ha and costs for kale and oats were $1200/ha. Harvesting cost for lifted fodder beet was assumed to be $0.12/kg DM. Depreciation at 4% per year for the feed pad constructed at $300/cow was assumed. Each scenario was run for three climate years using NIWA climate data from the Lincoln weather station to reflect years with different total drainage and N leaching. The 2013-2014 season with predicted drainage of 126 mm, rainfall of 725 mm and irrigation of 565 mm; the 2014-2015 season with drainage of 10 mm, rainfall of 389 mm and irrigation of 783 mm; and the 2012-2013 season with drainage of 234 mm, rainfall of 803 mm and irrigation of 682 mm.

Results and Discussion

Model-predicted farm physicals for the Baseline scenario were a reasonable approximation of the actual results for the Canlac 2014-2015 season (Table 1), considering the potential differences in metabolisable energy and utilisation of pastures and supplements between the model and what occurred in that season. Predictions of farm working expenses overestimated actual values by $0.78/kg MS, mainly because New Zealand averages were used for input costs, while Canlac Farm has a simple farm layout, with efficient systems and a focus on cost control. This overestimation of working expenses was, to a large extent, responsible for the underestimation of operating profit (OP). Nevertheless, because the objective was to track the trends in production, profit and N leaching as the baseline was incrementally modified, the predicted Baseline results in Table 1 were regarded as a suitable reference point for the rest of the modelling exercise.

When a feed pad was introduced and effluent applied to 100% of the platform (Opt.1), the scenario showed the effect of lower supplement wastage by importing 16% less supplements compared with the Baseline. There was no effect on production but the lower feed costs reflected in the lower farm working expenses, which resulted in a 10% increase in OP compared with the Baseline. This scenario generated 42% more effluent N applied to land (54 kg N/ha) compared with the Baseline where only shed effluent was captured (38 kg N/ha). However, the extra N only had a minor effect on pasture grown increasing pasture eaten on the platform by 40 kg DM/ha. The use of a feed pad for 1.5-3 hours/day during some months implies that some urinary and faecal N was deposited onto the feed pad instead of onto paddocks. Whilst a larger effluent N load applied to the land should increase N leaching, spreading the effluent over a larger area (100% versus 42%) should decrease leaching. Overall, the model predicted N leaching decreasing by only 1.5% compared with the Baseline. Firstly, it is only the urinary N that is important for N leaching outcomes, and the amount captured on the feed pad was small compared with the annual totals; secondly, with the same effluent N load, the relationship between effluent area and N leaching reduction is one of diminishing returns as the area gets bigger. A substantial reduction in N leaching results as the effluent area increases from 10% to approximately 40%, after which further gains are minimal because the N load is already effectively diluted. Farmers should consider this result before investing capital in effluent irrigation on the assumption that their N leaching will decrease dramatically as they expand the effluent block to 100% of the milking platform.

Total pasture and crop eaten on the platform increased by 0.6 t DM/ha in Opt.2 (growing fodder beet on the platform, longer lactation, and replacing pasture silage with maize silage), because of the higher yield of the fodder beet crop (Table 1). Imported supplements increased from Opt.1 because maize silage had to be imported to replace a large proportion of the pasture silage made on both the platform and support blocks. This surplus pasture silage accumulated in the feed store where it attracted an inventory credit in the economic analysis. Better fed cows, no once-a-day milking, and a longer lactation resulted in a 3% increase in milk production compared with the Baseline, or 18 000 kg MS increase compared with Opt.1. Operating profit increased by 13% compared with the Baseline. The small decrease in N leaching of 2 kg N/ha (3.1%) can be explained by opposing drivers. Replacing a substantial proportion of the diet with low-protein fodder beet and maize silage, especially during the crucial autumn months, reduced urinary N excreted and N leaching. Without a catch crop following the fodder beet on the platform, leaching was high from this block (54-251 kg N/ha depending on the drainage year). Longer lactations, with some cows being milked into June, and in total more feed N going through the herd, caused an increase in N leaching. The change from wintering on 17 ha kale and 8 ha fodder beet on the support block in Baseline to wintering on 20 ha fodder beet in Opt.2

Table 1 Actual (Obs.) and model predicted (Pred.) farm performance for Canlac baseline farm (B), plus three options, and a hypothetical scenario. Operating profit is based on a milk price of $5/kg milksolids and economic inputs for 2012-2013. Option 1 = include feed pad and apply effluent to 100% of platform; Option 2 = grow and feed fodder beet on the platform, milk longer, replace pasture silage with maize silage; Option 3 = grow diverse pastures on 7% of the platform; Hypothetical = grow diverse pastures on a third of the platform, reduce N fertiliser by the effluent N amount, lift all fodder beet on the platform for feeding on the feed pad and follow by oats catch crop, spend 3 hours/day on the feed pad in Sept, March and April, dry all cows off by 30 May.

		Obs. Canlac 2014-2015	Pred. Baseline (B)	Pred. B+1 (Opt.1)	Pred. B+1+2 (Opt.2)	Pred. B+1+2+3 (Opt.3)	Pred. Hypo-thetical
Physicals	Pasture & crop eaten on platform (t DM/ha)	17.8	18.6	18.6	19.2	18.5	18.0
	Imported supplements (kg/cow)	802	1049	885	1075	1092	1118
	Days in milk	274	275	275	283	283	271
	MS to factory (t)	685	674	675	693	691	687
	MS (kg/cow)	500	488	489	502	501	498
	MS (kg/ha)	2044	2012	2015	2069	2064	2051
	Production change from B (%)			0	+3	+3	+2
Financials	Operating profit ($/ha) (OP)	4887	2025	2236	2285	2295	2225
	Farm working expenses ($/kg MS)	3.53	4.31	4.18	4.29	4.31	4.38
	OP change from B (%)			+10	+13	+13	+10
N leaching all hectares (kg/ha)	Low drainage 2014-2015		39	39	34	32	27
	Average drainage 2013-2014		76	75	72	71	62
	High drainage 2012-2013		82	80	82	83	71
	Average for 3 years		65	64	63	62	53
	Change from B (%)			-1.5	-3.1	-4.6	-18.5

reduced the weighted average N leaching from the support block over 3 drainage years from 35 kg N/ha to 33 kg N/ha. It was, therefore, no surprise that these different forces cancelled each other out to some extent, resulting in little change in the leaching metric.

Sowing 7% of the platform into diverse pastures (Opt.3) reduced total pasture and crop eaten compared with Opt.2 (Table 1), because of the lower yield of diverse pastures (user-defined as 17.3 t DM/ha) compared with 20.5 t DM/ha from standard pastures in the 2014-2015 season. Apart from a small increase in imported supplements, this system performed similarly to Opt.2 with a 3% and 13% increase in production and profit, respectively, compared with Baseline. The small block of diverse pasture reduced N leaching slightly, on average by 1 kg N/ha from Opt.2, and 3 kg N/ha from Baseline. This is not surprising since the lower growth rates probably resulted in fewer grazing events, further diminishing the effect over the whole year. It must be noted that the models used to estimate leaching from these pastures do not consider the potential of diverse pastures to extract more N from the soil because of a more diverse and deeper root structure (Sanderson *et al.* 2004).

Total pasture and crop harvested on the platform decreased to 18 t DM/ha (Table 1) with one third of the platform in diverse pastures in the hypothetical scenario, because of the lower yield of the diverse pastures. This, together with less pasture available in November when the oat catch crop following the fodder beet was still growing, resulted in more PKE fed. The shorter lactations reduced milk production compared with Opt.3, but production was still higher by 2% compared with the Baseline. Contributing to this was the absence of once-a-day milking, but also better feeding in October and November and using a combination of PKE and lifted fodder beet bulb in March and April. Although farm working expenses increased slightly, because of the extra costs of lifting the fodder beet and growing and harvesting the catch crop, OP increased by 10% compared with the Baseline. Weighted average N leaching from the platform and support block over 3 drainage years decreased by 12 kg N/ha (18.5%) compared with the Baseline. The main driver of this decrease was the lowering effect of the diverse pastures on N intake, urinary N load onto paddocks (kg N/ha), and urinary N concentration (g/L), which reduced N leaching from platform pastures. No milking in June, coupled with more hours on the feed pad, also contributed to this lower leaching from platform pastures. Another important driver was the leaching from the lifted fodder beet block followed by the oat catch crop, which was much lower than the *in situ* grazed fodder beet (in Opt.2 and Opt.3) and varied between 24 kg N/ha and 139 kg N/ha, depending on the drainage year.

Conclusions

Linking several mechanistic models satisfactorily represent production, profit and N leaching from both milking platform and support block in a high-performing commercial Canterbury farm. Implementing proposed changes to the system that included a feed pad, growing and feeding fodder beet in the shoulders of the season, and milking a proportion of the herd into June resulted in a substantial increase in profit (13%), but N leaching only decreased by 3 kg N/ha (~5%). A hypothetical scenario that included lifted fodder beet on the milking platform followed by an oat catch crop, and a third of the platform in diverse pastures, produced a smaller increase in profit (10%), but N leaching decreased by 12 kg N/ha (~19%) compared with a Baseline as estimated over 3 different climate years. It is suggested this is a positive outcome if N leaching can be reduced by ~19% by implementing some of the principles emanating from the FRNL programme.

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Argentine stem weevil: farmer awareness and the effectiveness of different ryegrass/endophyte associations

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Abstract
Argentine stem weevil (ASW) is a highly destructive pest of ryegrass that has recently been associated with increased incidences of field damage. A survey of farmer awareness and management practices in relation to this pest was carried out. Many (47%) farmers sowed favoured plant hosts such as short-term and tetraploid ryegrasses. A field trial, undertaken near Hamilton, compared the effects on ASW larval damage of 10 different ryegrass/endophyte associations in comparison with an endophyte-free control with and without seed treatment. U2 endophyte in a diploid perennial festulolium and AR37 endophyte in a hybrid tetraploid, an Italian diploid and a tetraploid perennial ryegrass had significantly less damage (<26%) than all other treatments (>42%). NEA2 endophyte in a diploid perennial ryegrass and AR1 endophyte in short-term ryegrasses failed to protect plants from severe damage by this pest. Farmers need to be aware of the risks of ASW damage to short-term and tetraploid ryegrasses.

Keywords: ploidy, short-term ryegrasses, larval damage, endophyte strains, pasture management

Introduction
Argentine stem weevil (ASW) (*Listronotus bonariensis*) is one of New Zealand's most destructive grass and cereal pest. First reported in the country in 1927, this small cryptic insect occurs throughout New Zealand. Adult weevils feed on the emergent cotyledons of newly sown grasses and cereals, killing young seedlings (Goldson *et al.* 1998). The larval stages mine inside tillers, often killing the meristem and causing widespread tiller death in susceptible hosts. Between September and March ASW undergoes at least two generations in most areas except where cool temperatures (e.g. southern South Island) may slow its development allowing only one generation per year (Barker *et al.* 1989; Goldson *et al.* 1998). Damage is particularly apparent in the summer/autumn, but is often wrongly attributed to drought (Whatman 1959).

An important discovery in the early 1980s showed that a seed-transmitted fungal endophyte (*Epichloë festucae* var. *lolii*; formerly *Neotyphodium lolii*) infecting perennial ryegrass (*Lolium perenne*), which had become naturalised in New Zealand, provided its host with resistance to ASW (Prestidge *et al.* 1982; Mortimer & di Menna 1983). To exploit endophytes for control of this insect, however, it was necessary to source endophyte strains that minimised or eliminated the mammalian toxicity caused by the naturalised common toxic strains. New strains were introduced that did not produce the two toxins ergovaline and lolitrem B or produced them at low concentrations. In 2001, AR1, an endophyte producing the ASW deterrent, peramine, but not the toxic alkaloids was commercialised (Thom *et al.* 2012). This was followed in 2007 by the release of AR37 which produces epoxy-janthitrems but not peramine, ergovaline or lolitrem B. Since then seed companies have commercialised their own *E. festucae* var. *lolii* endophyte strains such as NEA2, that rely on low production of peramine and the toxic alkaloids and an *E. uncinata* endophyte, U2, isolated from meadow fescue, which produces loline alkaloids. U2 is now available in a *Festulolium* cv. 'Barrier' which has many of the characteristics of its meadow fescue parent.

A parasitoid (*Microctonus hyperodae)*, that sterilises adult ASW, was imported and released in the early 1990s to provide additional control of this pest, particularly in susceptible plants not protected by endophyte. Popay *et al.* (2011) reported on incidences of ASW damage in the field, concluding that parasitism may no longer be suppressing populations. Recently, a decline in parasitism levels has been confirmed (Goldson *et al.* 2014; Tomasetto *et al.* 2017). Although the reasons for this decline have yet to be identified, the situation has led to concerns about farmers' current awareness of ASW and their decision-making with regard to managing it. Seedling ryegrass and cereals that are susceptible to adult and larval damage at establishment need to be protected by seed treatment. In addition, susceptibility to ASW is higher in Italian and annual species (*Lolium multiflorum*) and tetraploid perennial ryegrasses compared with diploid perennials (Goldson 1982; Barker 1989; Prestidge 1991; Popay *et al.* 1995) that may not always be overcome by endophyte-infection (Popay *et al.* 2003). This paper reports on a survey seeking to gauge farmers' level of knowledge

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