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MODELLING OF NITROGEN LEACHING WITHIN FARMING SYSTEMS THAT INCORPORATE A COMPOSTING BARN: A CASE STUDY OF THE LINCOLN UNIVERSITY DAIRY FARM

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Abstract

We present Overseer modelling data for the Lincoln University Dairy farm (160 ha milking platform, comprising Templeton, Paparua, Wakanui, Temuka and Eyre soils) assuming a composting barn and duration-controlled grazing systems (six hours grazing April and September, four hours May to August, 12 hours October to March), compared to the current 100 percent paddock-based system but with cows wintered off-platform (eight weeks). Cow numbers were 558 for both systems but with higher liveweights (500 cf. 480 kg), higher days in milk (305 cf. 264) and higher per cow milksolids production (585 cf. 485 kg) for the composting system. For the composting system, 24 ha of maize silage and 12 ha of fodder beet were grown, with a winter green-crop grown between maize and fodder beet. In line with industry experience, all liquid effluent was assumed to evaporate off and solid nutrients were returned to the farm as compost.

Urine-related N leaching decreased from 42 kg/ha for the current system to 3 kg/ha under duration-controlled grazing. However, 'other' sources of N leaching increased from 5 to 29 kg/ha. These other losses were primarily from maize silage (96 kg per crop hectare) and fodder beet (150 kg per crop hectare) and the associated loss of organic soil-pool N from mineralisation. Accordingly, overall N leaching declined from 47 kg/ha to 32 kg/ha. It should be noted that the current figures do not include losses occurring off-platform during winter whereas for the composting system the measures are for the total system.

Overseer estimates for urinary-N leaching from pasture are supported by published science of duration-controlled grazing during late autumn and winter. However, the validation of the cropping sub-models is less developed. Accordingly, the results highlight the importance of further investigations of winter-feed systems that minimise N losses, including from soil mineralisation, and the incorporation thereof within Overseer.

Benefits of duration-controlled grazing are not specific to composting barn systems. However, composting barns provide internationally proven cow-friendly housing without the fit-out costs of free-stall barns, combined with simpler and lower-cost effluent systems than for free-stall systems. Results reported here are part of a larger systems study to be published elsewhere.

Introduction

This paper draws on the environmental findings of a Lincoln University Honours dissertation examining the economic and environmental implications of incorporating composting barns onto the Lincoln University Dairy Farm (LUDF). Composting barns are an alternative loose-housing facility that were first developed in Minnesota in 2001 to improve cow comfort and longevity (Barberg *et al*., 2007). Since then, a few New Zealand farmers have also adopted the barns with cow welfare and farm economic performance in mind. However, the ability to use the barns within duration-controlled grazing systems also promotes improved farm environmental performance. This paper aims to quantify potential nitrogen (N) leaching reductions and identify the critical components of the system that affect N leaching on dairy farms using the LUDF as the model farm.

Background

Composting barns provide a large open resting area typically comprised of sawdust or other high-lignin bedding. The key differentiating principle of these facilities compared to other loose-housing facilities is that dairy manure is excreted directly onto the high carbon bedding and is composted *in situ* with the aid of daily tilling and ventilation (Woodford *et al*. 2018). Provided the key design and management principles are followed, including appropriate infrastructure design, daily tilling and internal composting temperatures between 50 – 60^{o}c, the composting barn will provide a dry, warm and comfortable surface for cows to ruminate and rest on. In a well-managed system, the compost remains inside the barn for up to 12 months before it is taken out, used as fertiliser, and replaced.

Method

Two farm systems (LUDF, with and without a composting barn) were modelled, using the LUDF as the base farm, to compare N leaching and investigate the implications of incorporating composting barns within New Zealand dairy systems. Data required to create the composting barn system were gathered from an existing New Zealand composting barn, overseas literature and industry experts. Overseer Nutrient Budgets version 6.3.0 was used to calculate N losses and understand the critical components that affected the N loss to water.

The LUDF is a 186 ha (160 ha effective) irrigated property situated in Lincoln, Canterbury. The farm has a range of soil types (Templeton, Paparua, Wakanui, Temuka and Eyre soils) ranging from free-draining stony soils to heavy and poorly-drained soils. In 2017/18, the farm ran 558 crossbred cows at peak milking (3.5 cows/ha) producing 451 kg MS/cow (1571 kg MS/ha) in a spring calving system. However, as the 2017/18 year was a below-average season due to poor weather and reduced pasture quality, the previous five-year production average of 485 kg MS/cow was used for Overseer modelling (Table 1). All cows were wintered-off from around mid-May through to late July, depending on calving date. N leaching losses from wintering-off were not included in the study.

The key changes to this model with the incorporation of a composting barn on the LUDF included wintering of all cows on-farm on fodder beet (12 ha), increased milk production, lactation length and cow live weight. Home-grown maize silage (24 ha) was also added to the farm system to support an extended lactation. In addition, a duration-controlled grazing system was implemented to reduce N leaching during the high-risk period between late autumn and winter. This consisted of 12 hour grazing from October to March, four hours grazing from May to August and six hours grazing in the shoulder months of April and September.

Milksolids per cow were assumed to increase from 485 to 585 kg MS/cow with the incorporation of the composting barn. This was a function of increasing the days in milk from 264 to 305, increased supplementary feeding and less energy wasted on maintenance. The 41 day increase in lactation length was assumed in line with industry experience of housed systems, as a result of housing the cows nearer the dairy shed, providing shelter from the environment, reducing the energy required for maintenance and adding maize silage into the feed system. Cow live weight also increased from 481 kg to 500 kg under the composting barn system to help facilitate the increase in milk production (Table 1).

Table 1 Production summary for LUDF with and without a composting barn.

	LUDF (without composting barn)	LUDF (with composting barn)
Peak cows milked	558	558
Stocking rate (cows/ha)	3.49	3.49
Live weight (kg)	481	500
Herd average days in milk	264	305
kg MS/cow	485	585
kg MS/ha	1,690	2,039
kg MS/kg LW	1.01	1.17

Modelling of the composting barn within Overseer Nutrient Budgets required a large number of assumptions to be made as Overseer was not capable of modelling such a system within its defined parameters. The parameters used to model the composting barn are displayed in Table 2. In order to model the composting process, whereby liquid effluent is evaporated and solid effluent composts *in situ* with the bedding before being removed and used as fertiliser, all solid and liquid effluent was exported. The solid portion of the effluent was then brought back onto all pastoral blocks as an organic compost fertiliser and spread at a rate of one tonne per hectare. A nutrient analysis of the compost, based on a sample taken from an existing barn, is provided in Table 3. The carbon to nitrogen (C:N) ratio of the compost at application was 19:1. Despite the compost having the potential to replace some fertiliser additions, all fertiliser applications remained the same for both systems, except for the addition of fertiliser to cropping blocks in the composting barn system, with 178 kg N/ha applied in split applications to all pastoral blocks from August through to April.

Table 2 Composting barn set-up parameters in Overseer.

	General
Pad type	Covered wintering pad or animal shelter
Bunker management	Carbon rich (sawdust, bark, woodchips) lining material, 12 months between first adding animals and cleaning out of bunker
Solids management	Exported No storage before solids are spread
Liquid effluent	All exported
	Management
Feeding regime	Wintering pad plus grazing Grazed out most of the farm before moving animals onto pad
Time spent on concrete feeding apron	4 hours per day when feeding apron is in use
Percentage of milking cows on pad	100% when housing in use
Hours per day grazing	Oct-Mar 12 hrs; Apr 6hrs; May-Aug 4 hrs; Sept 6 hrs

Table 3 Nutrient content of compost (DM %).

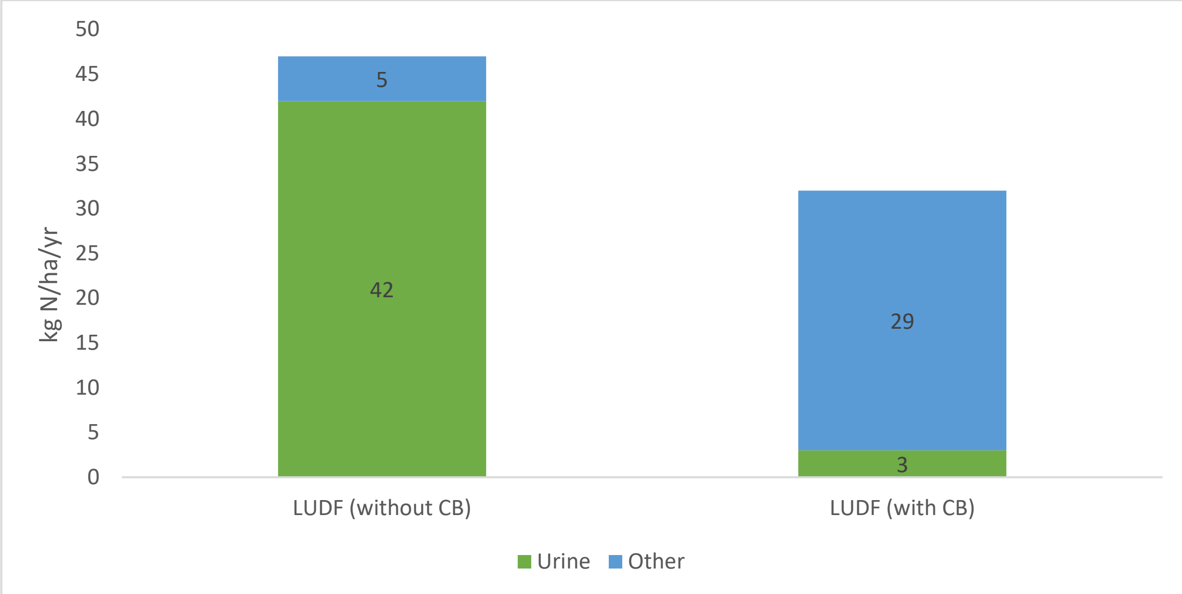
	Nutrient Content (DM %)
Nitrogen	0.68
Phosphorus	0.22
Potassium	1.19
Sulphur	0.13
Calcium	0.53
Magnesium	0.21
Sodium	0.08
Carbon	13.1

Results and Discussion

The incorporation of the composting barn on the LUDF resulted in urine-related N leaching decreasing from 42 kg/ha for the current system to 3 kg/ha under duration-controlled grazing. However, ‘other’ sources of N leaching increased from 5 to 29 kg/ha. These other losses were primarily from maize silage (96 kg per crop hectare) and fodder beet (150 kg per crop hectare) and the associated loss of organic soil-pool N from mineralisation. In Overseer, ‘other’ leaching is described as the leaching of N beyond the 60 cm root zone from inter-urine areas and incorporates the effects of dung, fertiliser, effluent and soil organic matter mineralisation (AgResearch, 2015).

Accordingly, overall N leaching declined from 47 kg/ha to 32 kg/ha (Fig.1). It should be noted that the current figures do not include losses occurring off-platform during winter whereas for the composting system, with cows wintered on-farm, the measures were for the total system.

Figure 1 Profile of N leaching losses (kg N/ha/yr) from the LUDF without a composting barn (CB) and excluding leaching from off-farm wintering, and the LUDF with a composting barn and all cows wintered on farm.



The reduction in urinary N leaching from 42 kg N/ha/yr without the composting barn to 3 kg N/ha/yr with the composting barn is largely a result of the ability to operate a duration-controlled grazing system with the cows able to be housed for significant periods of time. Urinary N leaching of 3 kg N/ha/yr under the composting barn system was similar to previous reports of 6.7 kg N/ha/yr (Christensen *et al.*, 2018) also under a duration-controlled system. By restricting time at pasture to set intervals, grazing time and subsequently urine deposition can be managed so that the volume of urine deposited and nutrients lost from pasture can be reduced. Grazing time was therefore considered a critical component that affected the nutrient leaching profile of a composting barn system. To determine the impact of grazing time on N leaching, alternate scenarios were run in Overseer with varying grazing times. When grazing was restricted to eight hours year-round, no urinary N losses occurred causing total N leaching to drop to 30 kg N/ha/yr. For every one hour of extra grazing per day Overseer estimated N leaching increased by 1 kg/ha/yr. Prior research shows that winter, late autumn and early spring are likely to be the key times affecting N leaching due to high drainage and slow plant growth (Di & Cameron, 2002; Beare *et al.*, 2010).

The other major change to the N profile of the LUDF was an increase in 'other' N leaching from 5 to 29 kg N/ha/yr and is related to the incorporation of fodder beet and maize silage onto the milking platform. Total N leaching from maize silage and fodder beet blocks contributed 96 kg N/ha/yr (4.8 kg N/t DM grown) and 150 kg N/ha/yr (7.5 kg N/t DM grown) respectively. These losses comprised 73% of the total N leaching from the farm while only representing 13.7% and 6.8% of the total farm area, respectively. Similar findings of disproportionally large volumes of N leaching ranging from 81 kg N/ha/yr to 173 kg N/ha/yr from fodder beet and maize cropping have previously been reported (Ledgard *et al.*, 2006; Smith *et al.*, 2012; Shepherd *et al.*, 2012). The reason for these losses were attributed both to a lack of plants available to soak up excreted N during the winter drainage season in grazed crops as well as soil N mineralisation during cultivation. However, according to Overseer, no N was leached from urine patches on fodder beet blocks, with this influenced by the cows grazing the crop for only four hours per day. Complete removal of N fertiliser from the fodder beet showed that it accounted for 34% of the N leaching from the block and reduced N loss to water to 120 kg N/ha/yr with the remaining N losses attributable to soil mineralisation.

Research by Di and Cameron (2002) shows that cultivation for crops increases soil aeration, resulting in the mineralisation of organic N to ammonium (NH^{4+}). This NH^{4+} is then rapidly converted to nitrate (NO^{3-}) which is easily leached from the soil. It is therefore likely that cultivation and the resulting mineralisation is responsible for the large increase in ‘other’ leaching as estimated within Overseer. A decrease in the whole farm soil organic pool of 323 kg N/ha/yr in Overseer supports this finding (Table 4). However, this loss of N from the organic bank may also be impacted by limitations within Overseer to correctly model compost applications. It is also notable that Overseer does not currently allow for uptake of N from below 60 cm by deep rooting plants.

Table 4 N losses from soil organic pool with and without a composting barn (CB).

	LUDF (without CB)		**LUDF (with CB)**	
	Change in Organic Pool (kg N/ha)	N Loss to water (kg N/ha)	Change in Organic Pool (kg N/ha)	N Loss to water (kg N/ha)
Whole Farm	113	47	-323	32
Maize Silage	-	-	-259	96
Fodder Beet	-	-	-258	150

While Overseer estimates of urinary N leaching from the composting barn system are supported by published literature of duration-controlled grazing systems, validation of cropping modules is less developed. The results highlight the importance of further investigations of winter-feed systems that minimise losses from soil mineralisation, and reassessment of these crop modules within Overseer.

Theoretical reasoning would also suggest reduced biological GHG emissions from shifting excreta from the paddock to the barn where aerobic bacteria can decompose manure, but this must be quantified. Currently, Overseer does not have the capability to measure this. Future studies must also encompass different soil types to gain a broader understanding of the composting barns performance in varying environments.

Summary

Preliminary work, based on a number of assumptions, has indicated that the incorporation of composting barns on farm could improve the environmental performance of New Zealand dairy farms largely through their ability to enable an animal-friendly duration-controlled grazing system, and hence greatly reduce urinary N leaching. Overseer modelling indicated urinary N leaching reduced from 42 kg/ha to 3 kg/ha on the Lincoln University Dairy Farm. However, N leaching from other sources increased from 5kg/ha to 29 kg/ha. This non-urinary increase resulted from incorporation of cropping systems to produce winter feed for cows in the composting barn, whereas currently the wintering activities occur off the milking platform and these N losses are not currently allocated to the milking platform. All Overseer figures are estimates only, and should be used with caution due to the margin of error within Overseer and the inability of the software to model the specifics of compost from a composting barn. In particular, assessment of the accuracy of the cropping modules within Overseer, and also incorporation of a specific composting module could be considered as R&D priorities.

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