representatives, armed with correct and relevant information was identified as vital. Some of the information required to address the noted challenges is already well documented, but needs to be transferred to the relevant farmer networks.

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Implications of increased use of brought-in feeds on potential environmental effects of dairy farms in Waikato

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Abstract

The effects of increased use of brought-in feeds were evaluated across 25 dairy farms in central Waikato. Farms were classified into low, medium and high feed-input categories based on <500, 500-1200 and >1200 kg DM/cow, covering a range typical of that in the main dairying regions of New Zealand. Average milksolids (MS)/ha was 1087 and 1900 kg in the low and high feed-input categories, but total land-use/tonne MS was the same when all off-farm land was accounted for. Average estimated on-farm nitrogen (N) leaching increased from 26 to 30 kg N/ha/year between the low and high feed-input categories, but off-farm leaching sources were equivalent to an increase of 20 and 84%, respectively. Greenhouse gas emissions/on-farm hectare were 61% higher on high feed-input farms, but the carbon footprint and N leaching per tonne MS were similar across feed-input categories. High feed-input farms used feed-pads and increased effluent area (66 versus 21% of farm) to increase nutrient efficiency. Mitigation analyses indicated that N leaching could be decreased by optimising effluent area, reducing N fertiliser rate and utilising low-N feeds.

Keywords: nitrogen leaching, whole farm system, greenhouse gases, land use

Introduction

Dairy farming in New Zealand has intensified in recent decades, with increased milk production per hectare associated with the use of nitrogen (N) fertiliser, irrigation and increased use of brought-in feeds. For example, the average use of dry matter (DM) in brought-in feed on NZ dairy farms was 970 kg DM/ha in 2004/2005 and 2550 kg DM/ha in 2014/2015 (source: ProfitWatch and DairyBase from DairyNZ).

The increased feed intake will be associated with increased nutrient intake and excretion by animals, which potentially could lead to greater losses of N and phosphorus (P) to waterways. However, various management practices that affect nutrient losses, such as farm dairy effluent (FDE) management, have improved over time (e.g. PCE 2012). Farmlet research trials in Waikato have shown large increases in N losses with increased use of N fertiliser, relatively small changes on farmlets (milking platform only) with brought-in maize silage and large potential reduction in N leaching with farm management and mitigations (e.g. Ledgard *et al.* 2006; Shepherd *et al.* 2017).

The aim of this study was to evaluate productivity, nutrient losses and wider environmental indicators at on-farm and whole system levels for 25 case study dairy farms in central Waikato with varying levels of use of brought-in feeds.

Methods

Twenty-five case study dairy farms from the Tatuanui area of central Waikato were selected and classified into low, medium and high feed-input levels based on brought-in feed of <500, 500-1200 and >1200 kg DM/cow/year. Farm numbers in each category were 6, 11 and 8, respectively. Farm records were collected from each farm for 2014/2015 and cross-checked with farmers. Thus, it uses real farm data but the wider representativeness for New Zealand in relation to level of brought-in feeds is uncertain.

Data from farms were modelled using the OVERSEER® nutrient budget model version 6.2.3 (hereafter called OVERSEER; Wheeler *et al*. 2003) to estimate N and P losses, and a life cycle assessment (LCA) model that complied with International Dairy Federation (IDF 2015) guidelines to estimate total greenhouse gas (GHG) emissions. The LCA accounted for all emissions from production, transportation and use of inputs including fertilisers and feeds. Modelling accounted for the dairy farm (milking platform), as well as land used for rearing replacements off-farm (based on the MPI intensive beef monitor farm data) and growing crops for the brought-in feed. For the latter, average published data on crop yields and inputs (e.g. Ledgard & Falconer 2015) were used with associated N leaching calculated for crop systems using OVERSEER or from published data (Schmidt 2007). Excretion of N by animals was calculated in OVERSEER from the difference between N intake and N output in products. The FDE component of this calculated in OVERSEER was based on the relative time cows spent in the farm dairy, yards and feed-pad areas. The remaining excreta-N was deposited

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on land and the proportion of this in urine and dung was calculated based on the diet N concentration using the equation in the New Zealand GHG Inventory.

The high feed-input farms were assessed for effects of some single mitigation practices on N leaching. The mitigations were based on: (i) Increasing the FDE area on the farm to reduce N input to below 150 kg N/ha/year and K input to ≤75 kg K/ha/year, (ii) Reducing farm N fertiliser (non-FDE and FDE blocks) to ≤150 kg N/ha/year and replacing reduced pasture growth (assuming 10 kg DM/kg N response) with brought-in maize silage, or (iii) Replacing PKE with maize silage (to reduce N content of brought-in feed).

Results

The average milksolids (MS) production per on-farm hectare increased by 75% from the low to high feed-input categories, which was associated with an average eight-fold increase in brought-in feed (Table 1). The average MS production per cow increased from 365 to 469 kg/cow between the low and high feed-input categories.

Pasture intake, estimated from total feed requirements less brought-in feed adjusted for wastage (DairyNZ 2012), was similar across all feed-input categories. For each tonne (t) of MS production, the land area required for off-farm grazing of replacements was lower for low feed-input farms due to more replacements kept on farm. Land for production of brought-in feeds was over six-fold higher per tonne MS on high feed-input farms. The net effect was similar total land area required per t MS across all feed-input categories. There was little difference between categories in the average rate of P or N fertiliser used (Tables 1, 2), although there was wide variation within all categories. There was a large increase in P input from brought-in feeds on high feed-input farms. Average P runoff was similar across categories, while P surplus was lowest on low feed-input farms.

The N budget for the milking platform showed increased inputs of feed-N, similar fertiliser N use and lower calculated inputs from clover N_2 fixation with increased use of brought-in feeds (Table 2). Similarly, there was increased N output in milk and meat by 69% and in gaseous N losses from denitrification and volatilisation by 41% from low to high feed-input, respectively.

There was a relatively small increase in calculated average N leaching from the low to high feed-input farms. In practice, there was some variation in soils across farms, with most being on poor-draining gley soil and some free-draining allophanic soil in all categories. Sensitivity analysis of the effect of changing all soils to gley or allophanic in OVERSEER showed higher calculated N leaching from allophanic soils, but no relative changes between feed-input categories. Values were 19.5, 23.1 and 23.3 kg N/ha/year for gley soils from low to high feed-input, respectively. Corresponding values for allophanic soils were 29.8, 34.7 and 35.3 kg N/ha/year, respectively.

Efficiency of conversion of N inputs to products was similar across feed-input categories, while the N balance (difference between N inputs and outputs/losses) increased with increased brought-in feed. A large amount of N is cycled on-farm via excreta. The excreta-N collected in FDE and applied to land was nearly 3-fold higher on high than low feed-input farms, while dung deposition was 37% higher. In contrast, the corresponding urine-N deposition was only 11% higher. The average rate of FDE-N on effluent blocks on high feed-input farms was 104 kg N/ha/year.

Nitrogen leaching also occurred on land used for rearing replacements and growing crops for brought-in feed. When these were accounted for, the total amount of N leaching in relation to the on-farm area was 72% higher for high versus low feed-input categories, compared to being 13% higher for on-farm N leaching only (Table 3). However, when expressed on an amount of N leached per kg MS basis, it was similar on average across all categories.

Table 1 Summary of some key farm attributes, land use and estimates of P flows from the dairy farm (milking platform only) for 25 case study farms for 2014/2015. Farms are separated into low, medium and high categories based on the amount of brought-in feed. Values are averages, with ranges in brackets.

	Low (<500 kg DM/cow)	Medium (500-1200 kg DM/cow)	High (1200-3200 kg DM/cow)
Farm size (hectares)	88 (40-132)	75 (49-90)	103 (70-157)
Cows/ha	2.9 (2.5-3.2)	3.3 (3.0-3.8)	4.1 (3.0-6.0)
MS (kg/ha)	1087 (893-1320)	1414 (1284-1640)	1900 (1459-2690)
MS (kg/cow)	365 (322-438)	421 (356-461)	469 (388-538)
Brought-in feed (t DM/ha)	1.0 (0-1.4)	2.9 (2.1-3.7)	8.0 (3.8-13.9)
Calculated data:			
Pasture intake (t DM/ha)	14.1 (11.6-15.6)	14.9 (13.4-18.1)	14.6 (13.7-17.5)
Land use (ha/t MS):			
Milking platform	9.4	7.1	5.5
Land for replacements	2.0	3.5	3.6
Crops (for brought-in feeds)	0.3	1.0	2.1
TOTAL	11.7 (9.4-15.0)	11.6 (10.5-12.2)	11.2 (9.9-12.3)
P flows:			
P fertiliser use (kg P/ha)	22 (1-44)	22 (0-50)	14 (0-39)
P in brought-in feed (kg P/ha)	4 (1-7)	14 (7-22)	34 (19-58)
Farm P surplus (kg P/ha)[1]	12 (-9 to +35)	20 (-14 to +46)	26 (+3 to +57)
P runoff risk (kg P/ha)	1.0 (0.4-1.7)	1.3 (0.8-2.0)	1.0 (0.7-1.6)

[1] Sum of external P inputs minus P output in milk and meat.

Table 2 Nitrogen flows (kg N/ha/year) and N conversion efficiency (%) for 25 case study dairy farms (milking platform only) for 2014/2015, estimated using OVERSEER. Farms are separated into low, medium and high categories based on the amount of brought-in feed. Values are averages, with ranges in brackets.

	Low (<500 kg DM/cow)	Medium (500-1200 kg DM/cow)	High (1200-3200 kg DM/cow)
N inputs:			
N fertiliser	110 (3-215)	158 (67-224)	126 (41-195)
N fixation + atmos. deposition	146 (106-191)	121 (56-171)	114 (35-206)
Feed N	18 (4-33)	64 (34-99)	174 (89-309)
N outputs/losses:			
Products (milk + meat)	77 (63-90)	100 (81-128)	130 (98-178)
Denitrification + volatilisation	64 (50-83)	79 (64-108)	90 (62-131)
Leaching	26.3 (20-33)	28.1 (20-43)	29.8 (21-40)
N balance (N inputs-outputs)	106	136	164
N conversion efficiency (%)[1]	28.8	29.2	31.2
Excreted N[2]:			
Urine-N	302	335	336
Dung-N	123	144	168
FDE[3]-N	24	37	67

[1] N outputs/losses ÷ sum of N inputs; [2] average kg N/ha/year across milking platform area. [3] Farm dairy effluent.

Table 3 Total annual amount of N leached for 2014/2015 for each farm feed-input category (low, medium or high), associated with the on-farm milking platform, land used to grow dairy replacements and land for growing the brought-in feeds. Data was estimated using OVERSEER except for some crop N leaching which was from published data (Schmidt 2007).

	Low (<500 kg DM/cow)	Medium (500-1200 kg DM/cow)	High (1200-3200 kg DM/cow)
kg N leaching/on-farm ha equivalent:			
Milking platform	26.3	28.1	29.8
Land for growing replacements	3.4	7.4	10.2
Land for brought-in feed crops	2.0	8.4	14.7
TOTAL	31.7	43.9	54.7
g N leached/kg MS:			
TOTAL	29.1	30.8	28.8

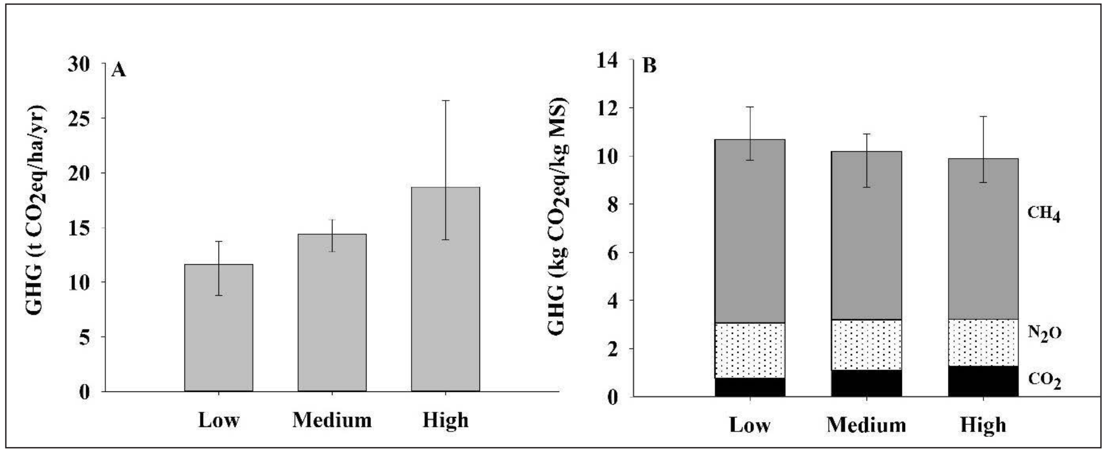

Figure 1 Total GHG emissions (A) and carbon footprint of milk (B) for each farm feed-input category (low, medium or high), expressed as carbon dioxide (CO_2) equivalents per hectare or per kg MS. Contributions from methane (CH_4), nitrous oxide (N_2O) and CO_2 are given. Vertical lines show the range for farms within each category.

There was a relatively large difference in the estimated values for g N leached per kg DM associated with the production of the different feed crops, varying between 5.0 for soybean, 3.5 for PKE and barley grain, 1.5 for maize silage and <0.1 for by-products such as brewers grain.

The total GHG emissions (including from all off-farm sources and production of inputs) per hectare increased with increased brought-in feed (Figure 1a). However, there was little difference in the average carbon footprint of milk (i.e. total GHG emissions/kg MS, after allocation between milk and liveweight sold for meat) between feed-input categories (Figure 1b). The high feed-input farms had relatively greater CO_2 emissions from fuel use associated with crop production and use, while methane emissions/kg MS were lower associated with greater MS/cow.

Effects of mitigations

Across the high feed-input farms, the mitigation option of increasing FDE area and reducing N fertiliser use decreased N leaching by an average of 16% (range 0-29%). Corresponding single mitigation analysis for reducing N fertiliser rate on all areas and replacing reduced feed grown with maize silage also reduced N leaching by an average of 17% (range 0-32%) relative to the base farm system (with differences between farms compared to that for the FDE mitigation). Switching feed input from PKE to maize silage was estimated to decrease N leaching by an average of 9% (range 4-18%).

Discussion

This study has provided an opportunity to examine the effects of increased use of brought-in feed and the association with production, resource use and potential environmental effects. There was a strong positive correlation (R^2=0.71) between MS/ha (milking platform) and level of brought-in feed across the 25 dairy farms. This equated to an average increase of 102 g MS /kg DM, which is higher than the typical average of about 60-80 g MS/kg DM (Hedley *et al*. 2006). This is an indirect association only and not a direct comparative trial, therefore it cannot be considered as a direct effect because of many other differences across the range of studied farms. However, it suggests that, on average, the farmers in this study were efficient in utilising their brought-in feeds, which was associated with a higher average MS/cow for the high feed-input group of 469 kg/cow, compared with the low feed-input group of 365 kg/cow.

Land use

While there was a large increase in MS/ha on the milking platform from low to high feed-input, the whole system analysis revealed no overall difference in efficiency of use of total land resources (i.e. total hectares used per tonne MS). The high feed-input farms had greater use of land for grazing replacements and in particular for production of the brought-in feeds. While some feeds (e.g. maize silage) produce more DM/ha than the average for pasture, others (e.g. cereal grains, soybean) are lower. Thus, the high feed-input farms have a greater reliance on land off-farm, which may be associated with greater risk for future availability with increasing environmental constraints. It can also be associated with greater economic risk with price fluctuations in milk and feed prices, as highlighted in the Resource Efficient Dairying (RED) trial (Jensen *et al*. 2005).

Potential effects on water quality

An important potential environmental effect of increasing farm production is on water quality and various catchments in New Zealand have plans (e.g. Lake Taupo, Rotorua lakes) or proposed plans (e.g. Waikato River, WRC 2017) that limit inputs via N leaching from land.

This study showed large variation in N leaching per hectare between farms, which was influenced by a range of multiple site and management factors (as evident by the lack of strong correlation with single input factors). One factor affecting the calculated absolute N leaching values was the soil characteristics and most farmland in this study was on poorer-draining gley soils, where denitrification losses are high relative to N leaching. However, the sensitivity analysis showed that this factor had little effect on the relative difference in N leaching associated with level of brought-in feeds (13-19% higher on high than low feed-input farms on average).

The relatively small difference in farm N leaching with feed-input level can be explained by the determining factors for N leaching and management practices relating to brought-in feeds and FDE. A major determinant of N leaching calculated by the OVERSEER model is the amount of urine-N deposited on soil, due to the high rate of deposition of N that is rapidly converted to leachable N (Wheeler *et al*. 2011). In contrast, dung-N is only slowly mineralised to soluble N over time and leads to low losses (Selbie *et al*. 2015). Use of brought-in feed with a low N concentration relative to pasture (e.g. 2.2%N for average across feeds in high feed-input farms compared to about 3.7%N in pasture) results in greater relative utilisation by animals and proportionally more N excretion occurring in dung than urine (e.g. Selbie *et al*. 2015). Additionally, in the high feed-input farms, the greater use of feed-pad facilities resulted in much greater capture of excreta-N in FDE, which was applied across land in multiple applications during the season at relatively low N rates (annual average of 104 kg N/ha). In general, FDE was managed well with the average proportion of the farm receiving FDE (range in brackets) at 21 (10-35%), 31 (23-42%) and 66% (39-100%) for low, medium and high feed-input farms, respectively.

The net effect was that the average amount of urine-N excreted on high feed-input farms was only 11% higher than that on low feed-input farms, which was of similar magnitude to the difference in farm N leaching. Measurements and modelling (using OVERSEER) of N leaching in the RED trial similarly showed a small increase in N leaching from the milking platform with feeding of maize silage at 5.5 t DM/ha/year (Ledgard *et al*. 2006). However, the farm N balance (N inputs minus N outputs/losses; Table 2) showed a larger average increase in soil organic-N accumulation by 58 kg N/ha/year in high feed-input farms than in low feed-input farms and in the long-term this will represent a greater risk for soil-related N losses.

The previous comments refer to the milking platform and do not recognise that the whole farm system includes N leaching from off-farm areas (used for rearing replacement animals and growing brought-in feed crops). When these were included and equated back to the milking platform area, it represented a 72% increase in total N leaching from the high feed-input farms compared to the low feed-input farms. However, this does not relate to the potential effects from the farm system on the waterway associated with the farm, since the off-farm areas likely occur outside the local catchment. When expressed on an efficiency basis, i.e. kg N leached per kg MS, there was no difference on average across the feed-input categories.

The whole-system N leaching (i.e. including off-farm sources) was influenced by the choice of brought-in feed, with N leached per tonne DM from the production of feeds being of the order: soybean > PKE ≈ cereal grains > maize silage > by-products.

Greenhouse gases

An environmental issue of global concern is climate change related to emission of GHGs (e.g. Gerber *et al*. 2011). This study showed an increase in GHG emissions per hectare between low and high feed-input categories of 61%, which was closely related to MS/ha. Increasing GHG emissions with increased feed use and production has implications for New Zealand's commitment for meeting GHG reduction targets (30% decrease relative to 2005 levels by 2030; MfE 2017).

However, when evaluated as GHG emissions per kg MS (i.e. the carbon footprint of milk), there was little difference between feed-input groups. This can be attributed to the greater emissions associated with feed production and use in the high feed-input group being balanced by the lower enteric methane emissions per kg MS associated with the higher MS/cow. The average values for the carbon footprint of milk are at the low end of the range reported for global milk production (Gerber *et al*. 2011).

Effects of mitigations

This study showed that average per hectare N losses were higher from the high feed-input farms, but that there are practical mitigation options that could bring the N leaching from these farms down to similar levels to that from the low-feed-input farms. Most farms in the high feed-input category had a relatively large proportion of the farm used for FDE application (66% on average), but there were some farms that could benefit from increasing their FDE area (and reducing N fertiliser use accordingly), thereby reducing N leaching by up to 29%. Nevertheless, the much greater capture and use of FDE on the high feed-input farms creates greater potential risk and increases the importance of optimal timing and efficient low-rate application of FDE (particularly on the gley soils which are sensitive to direct losses from FDE).

Nitrogen fertiliser use is a relatively cheap way of increasing pasture growth but it is inefficient in that its effect on N leaching per kg extra feed utilised is high (e.g. Ledgard *et al*. 2011). Thus, the largest average decrease in N leaching calculated for the high feed-input farms was from reducing N fertiliser to 150 kg N/ha/year and replacing lost feed with maize silage. However, such analyses also need to recognise that an overall system benefit from this practice depends on efficient production and minimising N leaching from the maize silage crop (e.g. Williams *et al*. 2007).

As noted earlier, the choice of brought-in feed can also influence the on- and off-farm N leaching and changing from PKE to maize silage showed an average decrease in N leaching from the high feed-input farms of 9%.

Overall, this study indicated that dairy farms with increased use of brought-in feeds were associated with increased production through increased MS/cow. They utilised practices to increase nutrient use efficiency through increased capture of excreta as FDE and spreading across a greater proportion of the farm on average than the low feed-input farms. This resulted in only a small increase in per hectare N leaching and mitigation analyses indicated that this could be reduced on relevant farms through increased FDE area, reduced N fertiliser use replaced by low-N feed and switching from PKE to a low-N feed such as maize silage.

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