Comparing nitrogen management on dairy farms – Canterbury case studies

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Abstract

Five Canterbury dairy farmers participate in the Forages for Reduced Nitrate Leaching programme (FRNL) to co-develop options for less environmental impact. Farm practices were adapted and new mitigation options were implemented. To assess farm environmental performance, the Overseer model was used to estimate nitrogen (N) leaching, N surplus and N conversion efficiency (NCE) for each farm and each year. When discussing the results with farmers, it appeared that these indicators for environmental performance are limited when comparing farm management strategies. The Overseer estimates include N fixation, which is influenced by model assumptions, and N leaching, estimates that strongly depend on soil type and climate entered into the model. To enable better comparisons between farms and years, a simplified N surplus and NCE were calculated using farmer recorded N inputs and N outputs, i.e. fertiliser, imported supplement, production and exported supplements. Effects of improved management and new mitigation options are presented. Four of the farms improved their N surplus and NCE and three reduced their Overseer-estimated N leaching over 3 years (2014, 2015 and 2016).

Keywords: nitrogen, surplus, conversion efficiency, dairy systems, nitrate leaching, environmental performance

Introduction

Intensification of agricultural land has been linked to the degrading of water quality in New Zealand (Larned *et al.* 2004) and has resulted in the recent development of central and local government regulation, as well as strong responses from the agricultural sector. Both regulation and industry responses have focussed on controlling contaminant losses, rather than controlling inputs, so that farmers have flexibility to find innovative, research-driven solutions. Regionally, limits are set to nitrogen (N) loss to water (N leaching hereafter, the main component for dairy farms). Farm Environment Plans support uptake of good management practice. Enforcing limits requires practical and affordable monitoring plans. The expense and challenges of measuring the impact of land use on water quality means regional councils require a tool to estimate nutrient losses. In New Zealand the tool of choice is the nutrient budgeting model OVERSEER® (referred to as Overseer hereafter; Watkins & Selbie 2015).

N leaching from land use varies widely depending on soil type and climate, and Overseer reflects these differences. Efforts to determine representative farm systems, soils and climates to develop meaningful benchmarks for N leaching have been unsuccessful to date (Pinxterhuis *et al.* 2015b). Furthermore, mitigation options being explored in research programmes such as Forages for Reduced Nitrate Leaching (FRNL) and Pastoral 21 (P21) target the efficiency with which nutrients are used in the farm system. The impact of these options on N leaching is not necessarily reflected in Overseer, which uses assumptions and generalisations (Watkins & Selbie 2015). These factors make it difficult for farmers to benchmark and compare the efficiency of their farming practices using N leaching values only.

The Overseer model output presents important information, other than N leaching, which can be used for benchmarking and comparing farm performance, including N surplus (the difference between N inputs and N outputs; kg N/ha/year) and N conversion efficiency (NCE, the ratio of N outputs/N inputs, %). The main N inputs in pasture-based New Zealand systems are purchased fertilisers, feed and biological N fixation by legumes. Nitrogen outputs are all crop and animal products exported off-farm. A high NCE and a low N surplus combine maximal productivity with minimal environmental N loss (De Klein *et al.* 2017). N surplus is an indicator of the potential impact on the local environment. Soil type, climate, and factors influencing gaseous losses control how much of the N surplus eventually leaches below the root zone, e.g. the same N surplus results in higher leaching from soils with low Profile Available Water (PAW) than from soils with higher PAW, and the same N surplus results in higher leaching from arable land than from grasslands (Schröder & Neeteson 2008).

Here, data collected from five dairy monitor farms in the FRNL programme are used to demonstrate how to compare farm performance using Overseer output and a simplified N surplus and NCE that include only information that farmers can easily record. While Overseer reports environmental impact, it is suggested that the simplified method engages farmers better with indicators of management performance to which they can relate and influence.

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Methods

The FRNL monitor farm network was established in the 2014/2015 season, as part of the FRNL programme. FRNL investigates options to reduce N leaching through reduced animal N intake, urinary N concentration, and improved plant N uptake by using mixed-species pasture, low-N forage crops and catch crops. In Canterbury, the network has nine farms: four dairy farms, a mixed arable-dairy farm, two arable farms and two mixed livestock farms. This paper presents data from the milking platforms of four dairy farms and the mixed arable-dairy farm, located from North to South Canterbury: near Culverden, Oxford, Dunsandel, Ruapuna and St Andrews (see www.dairynz.co.nz/frnl for a map and further information). Detailed data were recorded by the individual farmers, such as type and amount of supplement fed and when it was fed, timing and amount of fertiliser, effluent and irrigation applied/paddock, and stock movements. A comprehensive data collection spreadsheet was developed and a researcher visited the farms monthly to ensure data recording was complete and accurate. Data from the first season (2014/2015) were used to set up Farmax and Overseer models; alternative scenarios were developed with the farmers and modelled. Farmax models the effects of farm system changes on production and economic variables (Bryant *et al.* 2010). Results were presented to the farmers in sufficient time to make management changes for the second season (2015/2016). The intention of this exercise was to increase the efficiency of the farms before adopting new practices as part of FRNL, and for the monitor farmers to become familiar with the modelling process and interpreting results. It was during this process that the farmers concluded N leaching numbers from Overseer alone were not sufficient to compare and assess environmental performance of their farms and management.

A similar process was used at the start of the third (2016/2017) season, but using the DairyNZ Whole Farm Model to enable modelling of the FRNL options of plantain, fodder beet and catch crops. Some of the modelling results have been presented elsewhere (Beukes *et al*. 2017; Pinxterhuis *et al.* 2017; Beukes *et al*. 2018). Following this feedback, most of the farmers adopted some of or all the mitigation options (Table 1). Monitoring continued to assess the impact of these changes on farm performance.

The detailed data were used to prepare Overseer nutrient reports at the end of each season. This paper reports two versions of N surplus and NCE: the Overseer estimates, which include irrigation, rain and biological N fixation, and a simplified calculation that only includes the fertiliser and supplement inputs and products sold off-farm, i.e. a surplus or efficiency of purchased N (Hansen *et al*. 2016).

Results

Descriptions of the changes made by each of the farmers are given in Table 1, and key performance indicators for the farm systems are given in Table 2 (all data are

Table 1 Changes implemented by FRNL dairy monitor farmers. MP = milking platform; SB = support block. Unless stated otherwise, fodder beet on the MP was used for low-N feed in autumn and transitioning cows onto the crop in preparation for winter grazing, and plantain was established in mixed-species pasture as part of the regular pasture renewal.

Farm	Changes made in 2015/2016 from 2014/2015	Changes made in 2016/2017 from 2015/2016
A	More imported supplement, but less grain used. Similar amount of N fertiliser. Continued to lift fodder beet from SB to feed on MP in autumn and spring.	More N fertiliser and imported supplement. Continued to lift fodder beet from SB and feed on MP in spring and autumn; used maize silage.
B	Similar amount of N fertiliser. Less imported supplement. Lifted fodder beet from SB to feed on newly constructed feed pad on MP.	Less N fertiliser. More low-N imported supplement. Grew 12 ha of fodder beet on MP. Established plantain on 25 ha (7% of MP).
C	Less N fertiliser and imported supplement. Lower stocking rate accordingly. Grew 8.5 ha of fodder beet on MP.	More fertiliser and imported supplement. Grew 8.5 ha of fodder beet on MP. Followed fodder beet with catch crop of oats and Italian rye grass. Established plantain on 17 ha (5% of MP), and on 60 ha under sown into existing pastures (16% of MP).
D	No change in N fertiliser. Less imported supplement. Established plantain on 21 ha (6% of MP).	Similar amount of N fertiliser and imported supplement. Established plantain on an additional 16 ha (4% of MP). Grew 14 ha of fodder beet on MP. Followed the fodder beet with a catch crop of oats.
E	Similar amount of N fertiliser. Less imported supplement. Lower stocking rate, allowing establishment of plantain on 70 ha (22% of MP). Already included plantain in pasture seed mix before start of FRNL.	No change in N fertiliser. Less imported supplement. Grew 6 ha of fodder beet on MP, followed by catch crop of oats and Italian ryegrass. Established plantain on an additional 22 ha. Ran replacement animals on MP to control surplus pasture for parts of October, December, January and March.

Table 2 Physical and environmental indicators of five Canterbury dairy milking platforms (A to E) for 3 years (1 = 2014/2015, 2 = 2015/2016 and 3 = 2016/2017); Ovs = Overseer 6.3.0.; PAW_{60} = Profile Available Water (mm water/60 cm soil depth); NCE = nitrogen conversion efficiency.

Farm-Year	A1	A2	A3	B1	B2	B3	C1	C2	C3	D1	D2	D3	E1	E2	E3
Physical indicators															
Area (ha)	327	327	327	342	334	346	382	382	382	404	404	404	325	325	325
Pasture	319	319	319	335	334	334	353	345	344	377	377	362	313	313	307
Crop	0	0	0	0	0	12	0	8	9	0	0	15	0	0	6
PAW_{60} predominant soils		84-87			84			63			69			93	
Stocking rate (cows/ha)	3.7	3.8	3.7	4.0	4.3	4.3	3.9	3.3	3.2	3.9	3.9	3.7	3.8	3.3	3.5
Milksolids (kg/ha)	1710	1677	1707	2043	2087	2152	1662	1399	1406	1746	1757	1678	1531	1514	1522
Pasture intake (Ovs; kg DM/ha)	16.2	16.5	15.9	19.2	20.5	19.9	15.3	14.7	13.8	16.3	17.3	15.6	14.2	15.2	16.4
Imported feed (t DM), total	1130	1115	1282	1280	1202	1479	1145	300	788	1411	1105	1290	1309	694	500
per hectare	3.5	3.5	4.0	3.8	3.6	4.4	3.2	0.9	2.3	3.7	2.9	3.6	4.2	2.2	1.6
per cow	1.0	0.9	1.1	1.0	0.8	1.0	0.8	0.3	0.7	1.0	0.8	1.0	1.1	0.7	0.5
Nitrogen budget Ovs															
Inputs (kg N/ha)															
Fertiliser	271	271	282	285	288	228	344	227	237	274	274	269	288	286	288
Imported supplements	79	75	86	86	84	93	60	17	41	61	53	54	72	44	31
Irrigation	7	7	7	11	11	11	10	9	9	4	4	3	9	9	9
Rain + Fixation[1]	72	90	68	123	149	155	23	91	61	92	108	79	57	57	79
Outputs (kg N/ha)															
Product	115	112	114	128	134	132	102	85	84	107	108	104	99	100	101
Exported supplements	3	11	6	5	7	3	0	8	8	7	4	12	18	12	11
Atmosphere	107	108	107	126	139	130	101	84	80	97	103	93	105	102	110
N loss to water	43	46	50	75	75	62	88	56	61	84	91	74	38	34	40
Efficiency[2]															
Surplus_Ovs (kg N/ha)	312	319	322	372	391	352	335	250	253	316	327	289	309	284	294
NCE_Ovs (%)	27	28	27	26	27	28	23	27	27	27	25	29	27	28	28
Surplus_simple (kg N/ha)	232	223	248	238	231	186	302	151	186	221	215	207	243	218	207
NCE_simple (%)	34	36	33	36	38	42	25	38	33	34	34	36	33	34	35

[1]Rain = 2 kg N/ha; [2] Overseer estimates include irrigation, rain and biological N fixation; the simple estimates do not.

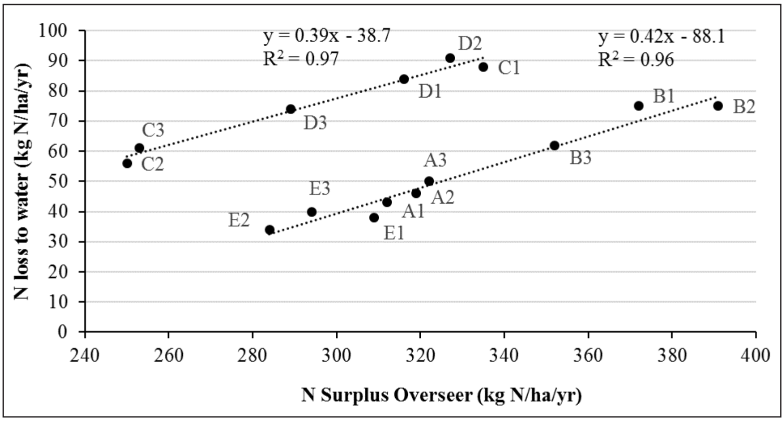

Figure 1 Nitrogen (N) loss to water (predominantly N leaching) from five Canterbury dairy farms (A to E) in relation to farm N surplus. Both parameters as estimated by Overseer 6.3.0. Three data points are given/farm: (1) 2014/2015, (2) 2015/2016, and (3) 2016/2017. Farm N surplus = (fertiliser + supplement + irrigation + biological N fixation + rainfall) – (animal and plant products). Equations and R2 for linear regressions are given for farms on extremely light soils (top line) and farms on light soils (bottom line).

on an annual basis). Estimates of N leaching during the 'base' 2014/2015 season varied widely between farms (28 to 88 kg N/ha). Three farms reduced their N leaching in the course of the 3 years studied; the other two had small increases in leaching. N surplus and NCE improved on four farms.

N leaching comprised a greater proportion of the N surplus for Farm C and Farm D (PAW_{60} 50-80 mm; extremely light free-draining soil types) compared with the farms on the light soils (PAW_{60} 80-110 mm). This is illustrated in Figure 1. This Figure also illustrates the relationship between N surplus and N leaching.

Discussion

Compared with earlier data from Waikato farms (Beukes *et al.* 2012) and the high eco-efficient experimental farm of Pastoral 21 in Canterbury (Pinxterhuis *et al.* 2015a), the FRNL monitor farms had a high N surplus and low NCE. This was due to their high N fertiliser and supplement use (average 274 kg N/ha and 3.2 t DM/ha, respectively) compared with the Waikato farms (average of 121 kg N/ha and 1.3 t DM/ha, respectively) and the Canterbury experimental farm (179 kg N/ha and 1 t DM/ha, respectively), and the associated diminishing return from these relatively high N inputs (Whitehead 1995).

Regulation requires dairy farms in some Canterbury catchments to reduce N leaching by 30-35% from their baseline (average leaching from 2009-2013). To achieve a 35% reduction from their 2014/2015 level, a reduction in N surplus by 24-26% would be required for the monitor farms on low PAW_{60} soils and 12-14% for the farms on higher PAW_{60} soils, using the regressions shown in Figure 1. It is highly unlikely this could be achieved by using a lower N input while maintaining production and current farm systems: an NCE of 60-80% would be required, well above that achieved by experimental farms (Pinxterhuis *et al.* 2015a). Therefore, other options are needed and have been explored in modelling studies.

Modelling implementation of known N leaching mitigation options, such as variable rate irrigation across the farm, early culling and drying-off cows to reduce pasture DM intake/ha in autumn, and reducing N inputs with an associated reduction in stocking rate, resulted in a 30% reduction in N leaching for Farm B, but also reduced production and profit (Pinxterhuis *et al.* 2017, using Overseer 6.2.3). Modelling of options researched in FRNL (mixed-species pastures with plantain, fodder beet and catch crops) reduced N leaching from Farm B by nearly 20% while increasing production and profit by 2 and 10%, respectively (Beukes *et al.* 2017, using the Whole Farm Model). Including plantain in pasture reduced urinary N concentration and N leaching from urine patches (Carlton *et al*. 2017; Woods 2017). Fodder beet is a low-N feed with reduced urinary N excretion (Waghorn *et al*. 2018) and catch crops utilise water and soil mineral N in cooler seasons of the year, thereby reducing the risk of N leaching (Malcolm *et al*. 2016).

Default values for utilisation, N content and metabolisable energy (ME) of pasture and supplementary feed were used to estimate N leaching, N surplus and NCE, in accordance with Overseer best practice data input standards for the model (www.overseer.org.nz). Overseer's calculations of pasture intake use these values, as well as amount of imported supplement and energy requirements for the achieved animal production. Consequently, when farms improve utilisation and quality of pasture and supplement offered, leading to better feed conversion to milksolids production, Overseer will assume increased pasture intake and associated biological N fixation and animal N excretion. This increases Overseer's estimated N surplus (by increasing N fixation) and N leaching (by increased animal N excretion). For example, Farm B consistently achieved high estimated pasture intake compared with the other farms; this was associated with high N fixation, high N surplus (Overseer) and relatively high N leaching compared with the other farms on higher PAW_{60} soils (Figure 1). However, the simple N surplus was on a par with that of the other farms, and relatively low in the third year. The simple N surplus only includes parameters that the farmer can control directly and can also access without a model: fertiliser, imported supplement, production and exported supplement. Assumptions for N content of supplement and product may be used, but values do not change with updates of the Overseer model and can be compared between farms across different soils and climates.

An additional benefit of the simple N surplus is that it may show the effect of new mitigation options before Overseer has been able to incorporate these options in the model. Mitigations such as plantain, low-N feeds and catch crops all work by increasing the efficiency with which N is used within the system. Indeed, the four farms that implemented these options improved their NCE. However, if the N surplus does not change, the same amount of N may be at risk of loss to the environment.

The results of the present study demonstrate Overseer's estimated N leaching is not suitable to compare the efficiency of different farm systems and management practices, because of the effects of soil type, climate and model assumptions. When more years of data are available for the monitor farmers, actual pasture and supplementary feed quality will be used in the model, to make full use of its capability. The simple N surplus is more likely to increase awareness of potential environmental impact and ultimately lead to practice change because it is easier to interpret. Using the simple N surplus, however, does not decrease the need for models such as Overseer. It is still necessary to estimate N leaching to reconcile farm practice with water quality at the catchment level, e.g. for developing regulation to maintain or achieve acceptable water quality.

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