A COMPARISON OF APSIM AND OVERSEER PREDICTIONS OF NITROGEN LEACHING FROM A WELL-DRAINED SOIL UNDER A DAIRY FARM

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Abstract

Providing tools to assess farm systems and ensure their impact is within limits is a great challenge for the research community. The aim of this study was to examine whether two contrasting tools, the OVERSEER® Nutrient Budget Model and APSIM (Agriculture Production Systems Simulator) are comparable, in particular on their capacity for predicting N leaching under grazing dairy farming conditions. The study was conducted on a well-drained Manawatu silt loam soil within Massey University's No. 1 Dairy Farm. APSIM is a process-based model that works on a fine scale and daily time-step whereas OVERSEER produces annual averages of relatively large areas, with drainage and leaching calculations computed on a monthly time-step.

Results from both models were analysed in order to obtain long-term estimates of N leaching. Both models produced plausible estimates (i.e. within the same order of magnitude) for the conditions studied, provided that appropriate input data were used. Typically, these models are used for different purposes and with input data of distinct levels of detail, which can often result in outputs that are not readily comparable. The APSIM model estimated N leaching with a high degree of detail. The model showed that most N leaching occurs in winter but indicated that the highest risk of N leaching is from urine deposited in late summer and early autumn. While the APSIM model is more sensitive to environmental conditions and management practices, the model requires many inputs, with many model parameters not readily available at farm level. In contrast, the OVERSEER model is more user-friendly and has the ability to easily upscale nutrients lost from paddock- to farm-scale level, with the assumption that good on-farm management practices have been implemented.

Keywords: APSIM, OVERSEER, nitrogen leaching, dairy farming, urine patch.

Introduction

Dairy production has risen in the last two decades to support its increasing export growth; during the 2013/2014 season, milk production surpassed the 20 billion litre mark for the first time (New Zealand Dairy Statistics 2014). Furthermore, the dairy sector continues to be the top export earner of the country, accounting for 12% of the world's dairy exports. Sustained increases in production have occurred in synchrony with growing environmental concerns from intensified agricultural land use. Regulations are being proposed for intensive pastoral dairy farming to adopt systems and technologies to reduce environmental impact. This process remains a major challenge for the sector (Monaghan *et al.* 2007).

Dairy farms are often characterized by a higher stocking rate and more intensive management relative to other pastoral farming systems in New Zealand (Ledgard *et al.* 1999). Intensification results in a greater potential for impacts on the environment; associated leaching losses of nitrogen (N) to water usually increase, raising community concerns about the impacts on regional water bodies (Abraham & Hanson 2010; Horizons Regional Council 2014). Water quality of lowland streams in New Zealand dairy farming catchments has been found to be negatively impacted (Davies-Colley & Nagels 2002; Wilcock *et al.* 1999). Furthermore, nitrate concentrations exceeded the health-based maximum acceptable value (11.3 mg NO_3-N/L; set by the Ministry of Health) in 26 (8%) of the wells sampled in spring 2009 in Canterbury (Abraham & Hanson 2010).

Urination events, and to a lesser extent agricultural N fertilizers and livestock manure, are the major non-point sources of N losses from New Zealand dairy farms (Cichota *et al.* 2013). Direct measurements of deep drainage and N leaching are costly, site-specific, and labour-intensive. Given the spatial and temporal variation of N leaching, the use of dynamic and mechanistic biophysical models that capture the heterogeneity of this process is rapidly increasing (Vogeler *et al.* 2013). Biophysical models that incorporate the effect of N leaching from urine patches observed experimentally are required to assess the impact of farm management on N leaching (Snow *et al.* 2009). Models such as the Agricultural Production Systems Simulator (APSIM) (Holzworth *et al.* 2014) and OVERSEER® (Wheeler *et al.* 2006) are biophysical models that incorporate these effects. APSIM is a process-based model that works on a fine scale and daily time-step whereas OVERSEER produces annual averages of relatively large areas, with drainage and leaching calculations on a monthly time-step. As OVERSEER has been calibrated for New Zealand's farming systems and uses inputs that are easily accessible by farmers, it is the favoured tool for assessing compliance of dairy farms to proposed new regulations (Doole 2012). The two models have been designed for quite distinct purposes and may not be readily comparable. The objectives of this study were to examine the comparability of two contrasting simulation tools, APSIM and OVERSEER, and to identify weaknesses and strengths of both models in their ability to estimate N leaching losses from Massey University's No.1 Dairy Farm in the Manawatu region of New Zealand.

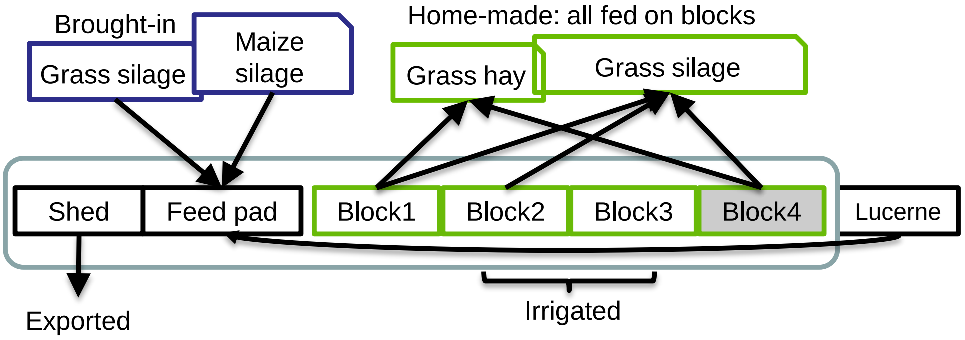
Materials and Methods

Farm System, Weather and Soil Descriptions

The Massey University No.1 Dairy Farm (40.4 S, 175.6 E) is located adjacent to the Massey University and AgResearch Grasslands campuses; it is also adjacent to the Manawatu River (north and west boundaries; inner margin of low terrace on Manawatu river flats) on the outskirts of Palmerston North. The farm is 35 m.a.s.l. and long-term (1987-2011) mean rainfall is 1011 mm (± SD 129 mm), with monthly minimum and maximum soil temperatures of 7^{o}C (July) and 18.5^{o}C (January), respectively. The total farm area is 138.6 ha (effective area = 119.6 ha).

The farm can be divided into 7 blocks (for setting up OVERSEER): Lower terrace, dryland (31.0 ha); Lower terrace irrigated (12.9 ha); Upper terrace irrigated (13.6 ha); Lower and upper terrace dryland (52.7 ha), Lucerne cut and carry (9.4 ha); Houses (16.3 ha); Trees (2.7 ha). The first four blocks constitute the grazing area (110.2 ha) and the first five blocks (including the Lucerne block) constitute the farm effective area (**Figure 1**). Imported silage (plus on-farm produced lucerne) is offered to cows on a feed pad. Grass silage and hay made on-farm is fed directly in the paddocks.

Figure 1. Schematic diagram of Massey University's No.1 Dairy Farm. Blocks 1 through 4 are the grazing blocks, and Block 4 (highlighted in grey) is the up-scaled area subject to model comparison (see text for more detail).



The farm holds a complex association of riverbed-type soils including Rangitikei loamy sand, Manawatu fine sandy loam, Manawatu sandy loam/gravelly phase, Manawatu mottled silt loam, and Karapoti brown sandy loam. These soils types are well to excessively-well drained and prone to summer drought. For the model simulation and comparison, Block 4 (with Manawatu silt loam soil; highlighted in grey in Figure 1) was up-scaled to represent the whole farm with a single grazing block in OVERSEER (110.2 ha). This procedure was used to limit inter-block transfers and reduce the complexity of the farm system, facilitating the modelling comparison. The Manawatu silt loam is a weathered fluvial recent soil, a medium-textured, well-drained and highly productive soil. The basic soil description was obtained from the New Zealand soil database (www.nzsoils.org.nz) and soil parameters were obtained from Landcare Research (www.landcareresearch.co.nz).

Simulation Tools Compared

APSIM Model and Parameterisation

APSIM (version 7.7; available from www.apsim.info/) was used to simulate the soil-plant-animal interface processes occurring on the dairy Farm. Briefly, APSIM is a process-based model that simulates physical and biological processes in agricultural systems (Holzworth *et al.* 2014). The model is a modular framework developed and maintained by the APSIM Initiative and its predecessor the Agricultural Production Systems Research Unit (APSRU, Australia). In New Zealand, the model has been tested against a wide range of leaching conditions from pastoral systems (Cichota *et al.* 2013).

AgPasture is the pasture growth module used in this study (Li *et al.* 2011). It describes a multi-species sward which interacts with other APSIM modules to produce estimates of water and nitrogen uptake and pasture production. The SWIM3 module (Huth *et al.* 2012) describes the transport of water and solutes in the soil based on Richard's equation (Verburg *et al.* 1996). The soil setup follows the basic procedure described by Cichota *et al.* (2012). The soil parameters used to parameterise the SWIM3 module in APSIM are shown in Table 1.

Table 1. Manawatu silt loam soil parameters used in the APSIM simulation.

Depth (cm)	Bulk density (cm^3/cm^3)	Air dry[1] (cm^3/cm^3)	LL15[2] (cm^3/cm^3)	DUL[3] (cm^3/cm^3)	SAT[4] (cm^3/cm^3)	KS[5] (mm/day)
0-10	1.171	0.05	0.11	0.30	0.43	2015
10-20	1.248	0.12	0.15	0.30	0.47	900
20-30	1.306	0.16	0.16	0.32	0.47	299
30-40	1.344	0.17	0.17	0.31	0.46	267
40-70	1.433	0.07	0.07	0.17	0.38	1312
70-97	1.411	0.06	0.06	0.21	0.38	1609
97-117	1.439	0.08	0.08	0.25	0.37	335
117-131	1.362	0.11	0.11	0.29	0.39	156
131-150	1.375	0.08	0.08	0.24	0.40	408

[1] Soil water content following air drying; [2] Soil water content at 15 bars; [3] Drainage, upper limit (i.e. field capacity); [4] Saturated water content; [5] Saturated hydraulic conductivity.

The pasture, a ryegrass/white clover mixture, was grazed rotationally to a varying residual herbage mass that ranged from 1300 (in winter) to 1600 kg DM/ha (in summer), depending on the grazing dates, and with a target pre-grazing herbage mass set at 2500 kg DM. The farm-scale model Farmax® Dairy Pro (version 6.6.0.0) was used to ensure that the upscaling of Block 4 to whole farm (as well as changes due to the addition of irrigation) was physically feasible. Farmax was also used to estimate daily dry matter (DM) intake, N intake and N removed in saleable product (milk protein/6.38) by lactating cows. The difference between the amount of N intake and N removed as product was assumed to be excreted, with deposition on different paddocks proportional to the time spent in each area. The intake values were used to estimate N assumed to be in urine, calculated in a similar way to OVERSEER, which was based on the approach by Ledgard *et al.* (2003):

$$f_{Nurine} = 31.8 + 11p_{Ndiet} \qquad (1)$$

where, f_{Nurine} is the proportion of N excreted in urine (% of excreta N) and p_{Ndiet} is the N concentration in the diet (%). The urinary N loading rate (N_{Load}, kg N/ha) was calculated according to the following equation:

$$N_{Load} = \frac{(N_{Excreta} f_{Nurine}) t_{paddocks}}{a_{Urine}} \qquad (2)$$

where $N_{Excreta}$ is the amount of N deposited as excreta (kg N/ha, on a paddock area basis), $t_{paddocks}$ is the fraction of time expended in the grazing paddocks, and a_{Urine} is the fraction of the paddock affected by urinations. The fractional area affected by urination events was computed using the following equation (Pleasants *et al.* 2007):

$$a_{Urine} = S_{density} R_{deposition} A_{patch} \qquad (3)$$

where $S_{density}$ is the stock density (cows/ha per grazing day), $R_{deposition}$ is the urinary deposition rate (assumed to be 10 events per day), and A_{patch} is the average urine patch area (assumed to be 0.5 m^2). The time spent on the grazing block varied over the year, with a mean estimate of 20.6 hours per day. The urine patch applied in APSIM was simulated as an application of urea with the addition of 5 mm of water.

To simulate N leaching from urine patches (in contrast to areas that did not receive urine), a parsimonious approach was used. For each treatment and each replicate year, 13 paddocks were simulated: one represented the area without urine while the remaining represented a urine deposition in each month of the year. This procedure approximately mimics the approach used by OVERSEER (Selbie *et al.* 2013; Wheeler 2014). Urinary N load varied over the year following equation (2) and whole paddock estimates of N leaching were obtained from weighted averages (based on area urinated) of the leaching from each of the 13 paddocks. To account for the full effect of urine deposition, the simulations were followed for two years (without adding urine in the second year). A more detailed description of a similar approach can be found in Vogeler *et al.* (2013). To estimate long-term averages, APSIM simulations were replicated over 25 years.

OVERSEER Model and Parameterisation

OVERSEER (version 6.1.3; available from www.overseer.org.nz) is a farm-scale nutrient budget model developed to aid in designing soil nutrient balances and soil nutrient budgets for the main soil nutrients (N, P, K, S, Ca, Mg and Na) applicable to most New Zealand farming enterprises (Wheeler *et al.* 2006). Leached N accounts for the N moving below the root zone, calculated on a monthly basis (Shepherd & Wheeler 2012). The model has become the standard framework used for estimating nutrient emissions from New Zealand agricultural industries (Doole 2012). Of particular interest to this study is the model's predictive ability to estimate on-farm nitrate-N (NO_3-N) leaching losses below the root zone.

An OVERSEER simulation file, initially produced by a fertiliser consultant describing the Massey No.1 Dairy Farm and its management as of 2011/2012, was used as the base for this study. The characteristics and basic management of Block 4 were up-scaled to represent the whole farm (110.2 ha effective area). Changes in management and stock density were checked for feasibility using Farmax. To produce comparable simulations to APSIM, the weather parameters of OVERSEER were manually set to represent the long-term averages of the same period used in APSIM (1987 – 2011). These were mean annual rainfall of 1011 mm, mean annual temperature of 13.1^{o}C and annual potential evapotranspiration (PET) of 836 mm. Following the farm management, all dairy effluent was exported from the system, and the solid effluents from the feed pad were applied on the lucerne cut-and-carry block.

Farm Management and Scenarios Tested

Massey's No.1 Dairy Farm management has changed in recent years; it currently holds a spring-calving Friesian herd with some crossbreds (240 cows) under once-a-day milking. The herd is kept year-round on-farm (lactating and dry cows) and young stock and replacements are reared and bred elsewhere. To reduce the number of variables to reproduce in the two models, the farm was simplified by making the whole farm to have the same characteristics and basic management of Block 4 (Figure 1). The grazing block was fertilised with a blend of ammonium sulphate and urea (37 kg N/ha) in August and urea (32 kg N/ha) was applied in November.

In addition to the basic dryland setup of Block 4, the possibility of irrigation was analysed. Irrigation needs were simulated in APSIM based on a centre pivot setup (applying 20 mm each day, with a return period of 5 days between December and March). The monthly averages were used as input in OVERSEER, namely 45, 55, 55 and 35 mm during December, January, February and March, respectively. As mentioned above, the farm-scale model

Farmax Dairy Pro was used to examine the carrying capacity of the farm scenarios based on home-grown and imported feed, adjusting livestock numbers when necessary, and to examine the biological feasibility (i.e. matching feed supply with feed demand) of the farms modelled (Table 2).

Table 2. Key biophysical measures of Massey University's No.1 Dairy Farm (from Farmax).

Item	Dryland	Irrigated
Grazing area (ha)	110.2	110.2
No. of cows (1st July)	240	303
Stocking rate (SR; cows/ha)	2.2	2.7
Milksolids (kg/ha)	775	979
Milksolids (kg/cow)	356	356
Supplements as a % of feed offered	35	39
Purchased feed as a % of feed offered	15	19

Results and Discussion

Limitations of Model Comparison

Validation of models with experimental data is an integral part of a model development process. In our study, however, models were solely compared against each other as appropriate measured data was not available. Model comparison plays a vital role in understanding different module integration, their weaknesses and strengths in capturing temporal and spatial variations of processes, and how these processes interact. Caution, however, is required when comparing models to ensure that appropriate data was provided to parameterise the models (Giltrap *et al.* 2013).

Model performance is often limited due to incomplete knowledge of the system or processes and to assumptions made by the modeller (Cichota & Snow 2009); these factors have to be taken into account when setting up the model and interpreting the outputs. Cichota and Snow (2009) further point out that when comparing long-term average models with single-point average models, the former tend to present considerably less variation than single point, daily models. It is thus important that the setup of both models is such that the differences in scale are taken into account when comparing their outputs. In the present work, the simulation of the more detailed model (APSIM) ran for 25 years to mimic the long-term average approach of OVERSEER. Concomitantly, the weather and irrigation parameters of OVERSEER were set up to reflect the averages of the same period simulated by APSIM. Without these precautions, the two models can produce outputs that diverge considerably. Notwithstanding these differences, the two contrasting simulation tools produced plausible estimates of N leaching provided the setup is done with care.

Background Calculations and Estimates of N Leaching Losses

Predicted urine patch N loads, as calculated on a monthly basis, ranged from 395 (June) to 841 (October) kg N/ha (mean = 571 kg N/ha) for the non-irrigated scenario and from 396 (June) to 745 (January) kg N/ha (mean = 560 kg N/ha) for the irrigated scenario. These values are within the range reported previously by Vogeler *et al.* (2013), but lower than those reported by Haynes and Williams (1993) (up to 1000 kg N/ha), the most frequently cited reference for urinary N loading. The latter reported urinary N concentrations of 10 g/L, urination volumes of 2 L, and wetted patches of 0.2 m^2, which is considerably smaller than the area considered in this paper (0.5 m^2); this value is in line with more recent measurements (e.g. Moir *et al.* 2011).

In addition to the urinary N load from the different grazing events, the total area affected by urination events also influences N leaching at both paddock and farm scales. Given the previously described urine patch assumptions, the paddock area affected by urination on a given grazing day was, on average, 2.6% and 3.3% for dryland and irrigated scenarios, respectively. Urination events covered 31% (dryland scenario) and 39% of the grazing area on an annual basis, due primarily to livestock numbers carried by each scenario. Similar values (areas affected by urination on a given grazing day) were reported by Vogeler *et al.* (2013) for a Waikato farm that was either stocked at 3 cows/ha (3.5%) or at 2.6 cows/ha (3.0%).

Pasture growth estimated by APSIM for the dryland treatment (mean of 11.2 t DM/ha) agreed well with values reported previously on-site (available at www.massey.ac.nz/massey/about-massey/subsidiaries-commercial-ventures/massey-agricultural-experiment-station/no1-dairy-farm/no-1-dairy-farm.cfm). Adding irrigation during the summer months increased the pasture production in APSIM to 14.2 t DM/ha. The increase in pasture growth over the irrigated months was in agreement with the variation in growth for irrigated Manawatu farms reported by DairyNZ (available at www.dairynz.co.nz/feed/pasture/pasture-growth-data). The values for pasture production estimated by APSIM were also very similar to those predicted by OVERSEER, at 11.7 and 14.3 tonnes DM/ha for dryland and irrigated pastures, respectively (which are inferred from animal requirements with an assumed utilisation of 85%).

Table 3. Annual N balance (kg/ha), drainage (mm) and pasture yield (kg DM/ha) estimates for Block 4, Massey University's No.1 Dairy Farm.

Item	Block 4 – Dryland		Block 4 – Irrigated	
	OVERSEER	APSIM	OVERSEER	APSIM
Inputs (kg N/ha)	215	178	262	179
Fertiliser	69	69	69	69
Rain[1]/fixation	125	131	159	167
Net transfer[2]	21	-21	34	-57
Outputs (kg N/ha)	128	121	169	137
Product[3]	63	63	79	79
Volatilisation	41	11	52	10
Denitrification	3	15	4	16
Leaching	**21**	**32**	**34**	**32**
Soil changes (kg N/ha)				
Organic pool	86	58	93	37
Drainage (mm)	337	338	422	368
Pasture yield (t DM/ha)	10.3	9.6	12.5	13.2

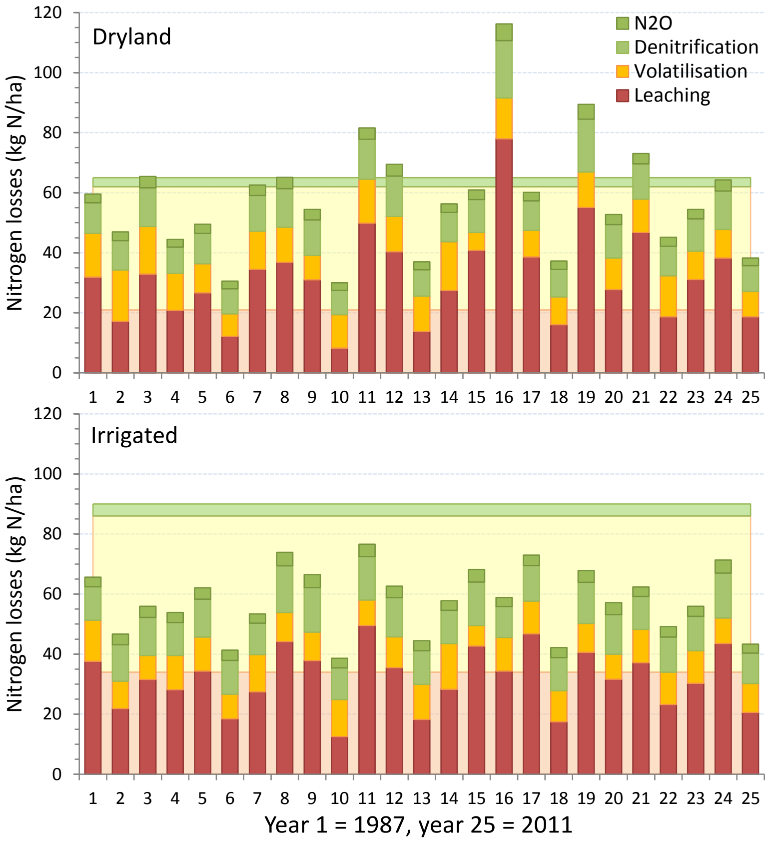
[1] Rainfall + irrigation. [2] Net transfer (kg N/ha) = [(supplements produced + supplements imported + transfer to block) – (removed as supplement + transfer from block)]. [3] N in milk.

In order to compare both models, N leaching losses from individual urine patches and non-urine affected areas were aggregated to obtain total N leached on the grazing block for both (dryland and irrigated) scenarios (Table 3). Both models produced plausible estimates (i.e.

within the same order of magnitude) of N leaching losses below the root zone, although the absolute values cannot be verified as there were no measurements. Disagreements, however, existed. Notably, OVERSEER estimated a 60% increase in N leaching when irrigation was applied, whereas APSIM predicted no changes. From the ASPIM simulations, it could be inferred that the addition of irrigation resulted in an increased N use efficiency (greater herbage growth and therefore N uptake over summer, leaving less N to be leached during winter). This process may have counterbalanced the greater amounts of N deposited as urine for the irrigated treatment that carried a greater number of cows.

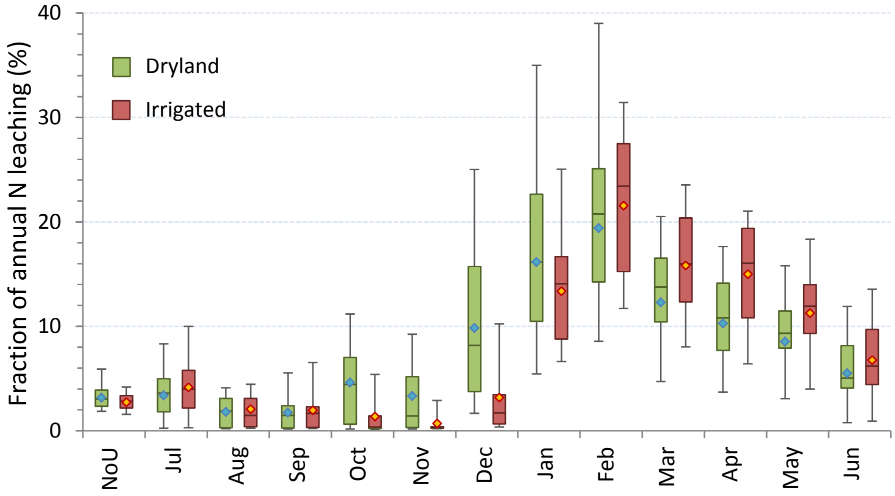
It is important to note that urine patch N returns in APSIM were specified based on N intakes inferred from Farmax/OVERSEER, and were quite simplified in this modelling exercise. The number of urinations per day and the area of patches were fixed and there were no overlaps. Other possible sources for the divergence in N leaching estimates between the two models are the description of irrigation and its effect on drainage. Both OVERSEER and APSIM produced very similar amounts of drainage for the dryland treatment (Table 3). In APSIM the addition of 190 mm/year of irrigation water resulted in less than a 9% increase in drainage, whereas the increase was over 25% in OVERSEER. This could help explain the difference in N leaching in OVERSEER. Additionally, differences between the magnitudes of various N transformation processes were predicted by the models, particularly volatilisation and denitrification (Table 3 and Figure 2). These differences make comparisons of the whole N balance of the two models difficult.

Figure 2. Annual N loss estimates from different soil N transformation processes for Block 4, Massey University's No.1 Dairy Farm. Outputs from APSIM are represented by stacked columns (year 1 = 1987, year 25 = 2011); outputs from OVERSEER are represented by stacked colours present in the background.



The monthly contribution to N leaching from urinary depositions, as calculated by APSIM, is presented in Figure 3. The timing of urine deposition throughout the year has been shown to have a sizeable impact on N leaching from urine deposition (Shepherd *et al.* 2011; Vogeler *et al.* 2013). The highest risk of N leaching originates from urine deposited in late summer and early autumn, although actual leaching commonly occurs over the following winter months. These finding are in agreement with those reported previously under simulated (Vogeler *et al.* 2013) and measured (Shepherd *et al.* 2011) urine patch depositions. The use of irrigation alters the shape of this response, markedly reducing the contribution of depositions in spring and early summer.

Figure 3. Monthly contribution from urinary depositions on annual N leaching, as calculated by APSIM. The boxes show the 25th, 50th and 75th percentiles, and the whiskers the 5th and 95th percentiles.



Even in the absence of experimental data, as in our modelling exercise, model comparisons can differentiate those N transformation processes that behave similarly from those that behave differently, highlighting potential knowledge/development gaps. The exercise also highlights the difficulties of comparing both models, and great care should be taken when comparing outputs from different sources. There are still considerable unknowns that require further research; such studies are justified as these models are increasingly used in policy/regulatory situations, and thus likely to be questioned and contrasted in legal queries. Any further work should also include measured data. It has been pointed out that no model has been validated for all processes under New Zealand grazed pasture conditions (Giltrap *et al.* 2013).

Conclusions

Two models of contrasting level of detail, APSIM and OVERSEER, were analysed in order to obtain long-term estimates of N leaching. Although the model inputs were set such that both models were under similar weather and management conditions, which resulted in very similar pasture production and the same order of magnitude for N leaching, there were considerable differences between the models regarding the effect of irrigation on N leaching. These differences were attributed to differences in how the two models describe irrigation and its effect on drainage and to uncertainties in the calculations of urinary N load. The APSIM model estimated N losses with a high degree of detail; it showed that most N leaching occurs in winter, but indicated that the highest risk of N leaching is from urine deposited in late summer and early autumn. While the APSIM model is more sensitive to environmental conditions and management practices, the model requires many inputs, with many model parameters not readily available at farm level. In contrast, the OVERSEER model is more user-friendly and has the ability to easily upscale nutrients lost from paddocks to farm scale level.

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