Appendix MC3

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A COMPENDIUM OF NEW ZEALAND PASTURE FARMLET EXPERIMENTS MEASURING NITROGEN LEACHING

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Abstract

Farmlet experiments are valuable for developing and testing farm system models. This paper provides a summary of New Zealand pasture farmlet experiments that have involved measurements of nitrogen (N) leaching losses and which could be used for comparing with outputs from farm-scale models such as OVERSEER® Nutrient Budgets (*Overseer).*

The majority of New Zealand farmlet experiments have been undertaken in the Waikato, Manawatu and Southland regions, with some also in the Bay of Plenty, Canterbury and Otago regions. Typical duration of experiments is 2-5 years, although N leaching measurements have been undertaken for over 10 years at Tussock Creek (Southland). The range of management factors tested include stocking rate, N fertiliser rate, grazing management practices, use of nitrification inhibitors and effluent management.

The method of measurement of N leaching has been a function of the soil-type; porous ceramic cups/lysimeters on free draining soils or hydrologically isolated plots on drained clay soils. It is important to understand the implications of methodology for assessment of measurement error. Farmlet experimental data can be considered as representing the farm block scale within *Overseer*, not the total farm. Although they are a critical source of data for model evaluation, there remain practical and theoretical challenges of comparing data from farmlet experiments with whole farm system modelled data.

Introduction

Farmlet experiments aim to mimic a farm system but at a smaller, experimental scale, and are generally used for testing hypotheses relating to the effects of management practices on productivity, profitability and, when incorporating environmental measurements, sustainability. The rationale for the development of farmlet experiments was based on the need to integrate 'component' research into an analysis of what is an economically feasible farm management system and, more recently, environmental analysis of different farm management systems (Clark, 2010). Farmlet experiments can generally be classified into four main categories: animal evaluation, feed supply, feed demand and environmental monitoring, with the latter only occurring since the early 1990s (Clark, 2010). Examples of some farmlet experiments that have occurred in New Zealand over the past 60 years include evaluating different levels of N and P inputs on productivity, evaluation of genetic strains and different pasture species on productivity and understanding the consequences of dairy intensification (Clark, 2010).

The aim of this paper is to identify and catalogue pasture farmlet experiments that have focussed on measuring N leaching losses as well as including measurements of productivity. These experiments serve as a critical resource for (a) testing the principles behind farm system models such as *Overseer* and (b) calibrating or validating such models.

Approach

A literature review was carried out to establish a list of pasture farmlet experiments within New Zealand where N leaching was measured. The farmlet experiments were then classified on their suitability for validating or calibrating farm systems models such as *Overseer*, based on (a) the experimental design and amount of supplementary farm information supplied and (b) the method of measuring N leaching. The following section documents those that were considered suitable.

Results

Dairy experiments

The majority of farmlet experiments that include N leaching measurements in New Zealand have focused on the dairy farming industry. Experiments to date have focussed on the effects of stocking and N fertiliser rates, a range of mitigation options to reduce N leaching (such as wintering off, DCD application and strategic grazing) and the impact of effluent applications on N leaching (Table 1). Nitrogen leaching within these experiments has either been measured using hydrologically isolated plots or porous ceramic cups, depending on the soil type.

One of the first farmlet experiments investigating N leaching losses under dairy farm systems was carried out on No.2 Dairy, Hamilton (1993-97). This experiment measured the impact of different application rates of N fertiliser (0, 200 and 400 kg N/ha). Porous ceramic cups sampled soil water at 1000 mm depth. This experiment showed that N leaching increased with higher N fertiliser application rates. The average concentration of nitrate-N leached was 9, 12 and 22.5 mg/L for the 0, 200 and 400 kg N/ha fertiliser treatments respectively over a two year (1993-1994) period (Ledgard *et al.*, 1996). Further data was published in 1999 (Ledgard *et al.*, 1999).

A similar experiment was established in Southland near Edendale in 1996, using hydrologically isolated plots to measure N leaching from the drained clay soil. During the initial year of the experiment, no N fertiliser was applied (Monaghan *et al.*, 2002). Non-lactating dairy stock rotationally grazed the plots (2.3 cows/ha) from November 1995 to late-May 1996 and no winter grazing occurred. During the initial year (1995-96), the amount of nitrate-N lost in drainage water was 25 kg N/ha (Monaghan *et al.*, 2002). In the following years the experiment investigated the impact of N fertilisation (0, 100, 200 and 400 kg N/ha/yr) and stocking rates on N leaching during 1996-99 (Monaghan *et al.*, 2005). As in the previous experiment, the plots were rotationally grazed by non-lactating dairy stock, at approximately four-week intervals from August to May and no winter grazing occurred. The results showed that increasing N fertiliser and stocking rate resulted in a significant increase in the amount of N leaching. The mean N leaching rate over the course of the experiment was 30, 34, 46 and 56 kg N/ha/yr, for the 0, 100, 200 and 400 kg N fertiliser treatments respectively (Monaghan *et al.*, 2005). These authors noted that the results of this trial may not accurately reflect those in a system that has been in long-term (>20 years) equilibrium, as this trial site had recently undergone conversion from sheep to cattle farming and an improvement is soil fertility had occurred (Monaghan *et al.*, 2005).

In 1998 a farmlet experiment was established at No.2 Dairy in Hamilton further investigating the impact of stocking rate on N leaching (Sprosen *et al.*, 2002). This experiment consisted of five farmlets with the following stocking rates, 2.2, 2.7, 3.2, 3.7 and 4.3 cows/ha on a free-draining allophanic soil. It was concluded in this paper, that stocking rate may be a poor indicator of N leaching with limited imported feed, given that N leaching was greater at lower stocking rates in this experiment (Sprosen *et al.*, 2002).

The longest running farmlet experiment in New Zealand investigating N leaching is the Tussock Creek experiment in Southland. This experiment has tested a range of management options to reduce N leaching under dairy farm systems. Hydrologically isolated plots were established in 1999, and the effects of various grazing strategies were tested 2000-2003 (N leaching results unpublished: see Houlbrooke *et al.*, 2009 for treatment descriptions). Findings were that restricted autumn grazing reduced N leaching by 42-60%; this work is currently being written up for submission to a peer reviewed journal.

From 2004, the site was used to test the effects of dicyandiamide (DCD) (Monaghan *et al.*, 2009), although this work has stopped since the withdrawal of DCD from the market. The results showed that DCD reduced the amount of N in drainage water by between 21 and 56% (2004-2007). Over the four year period, 13 kg N/ha and 7 kg N/ha was measured in the drainage water from the control and DCD treatments respectively (Monaghan *et al.,* 2009). Data from later years is currently being written up (C. Smith., pers. comm.).

Three other farmlet experiments have investigated the impact of DCD in limiting N leaching, the Resource Efficient Dairy (RED) trial, a Sustainable Farming Fund (SFF) trial at Wharenui, Rotorua, and a Nitrous Oxide Mitigation Research (NOMR) trial. Both the RED and Wharenui trial are discussed later. The NOMR trials were a national series of experiments seeking to obtain consensus on the likely efficacy of DCD on pasture growth, N leaching and nitrous oxide (N_2O) emissions. They commenced in autumn 2009 and were conducted in the Waikato, Manawatu, Canterbury and South Otago dairy regions. The Manawatu and South Otago sites measured the effects of DCD application on N leaching through hydrologically isolated plots with mole-pipe drainage systems from which the drainage water was collected for analysis. Results showed DCD decreased N leaching from urine patches, measured by lysimeter experiments in the Waikato and Canterbury regions by around 40% and in grazed pastures farmlet experiments (Manawatu and South Otago) by 21%; these experiments are being written up for submission to peer reviewed journals.

A three year (2005-07) SFF experiment in the Bay of Plenty region (Wharenui), investigated the impact on N leaching by dairy cows being removed from paddocks in May until September, compared to a normal grazing and fertiliser regime (Ledgard *et al.*, 2008). Porous ceramic cups were used to sample soil water at 600 mm depth whenever 40-50 mm of drainage had occurred. A reduction in N leaching of 33-38% was achieved by removing dairy cows from May till September (Ledgard *et al.*, 2008). This trial also looked at the effectiveness of DCD at reducing N leaching. DCD was applied twice in 2005 and 2006 (May and July) and three times in 2007 (May, June and July). The DCD treatment had 25% less N leaching compared to the control; this was only marginally significant ($P < 0.1$) (Ledgard *et al.*, 2008).

Another long-term source of data has come from investigations into ‘strategic grazing’, along with a variety of other mitigation strategies to reduce N leaching and improve N use efficiency, has been a sequence of farmlet experiments at DairyNZ’s Scott Farm near Hamilton. The first of this sequence was the RED trial (‘Resource Efficiency Dairying’: (Ledgard *et al.*, 2006). One part of this trial looked at the impact of utilising a stand-off pad over winter and found a 25% reduction in N leaching compared to the control farmlet (Ledgard *et al.*, 2006). A modification of the RED trial continued 2007-2009, known as the

'Tight N' farmlet study. This included nil N, control (i.e. a 'typical Waikato production system) and stand-off treatments. In 2011, this site developed two new farmlets ('current and future'), which are due to run until 2016 as part of the Pastoral 21 programme, and are described later in this paper. There has therefore been a long run of measurements made across this site over several soils types. Productivity measurements from nil N farmlet for the nine years of the RED and Prototype experiments have been reported by Glassey (2013).

Taking the strategic grazing technique a step further was a three-year duration controlled grazing study in the Manawatu (Christensen *et al.*, 2012). In this experiment, plots were hydrologically isolated with mole and tile drainage systems and the two treatments had restricted grazing practices (4 hours per day or night grazing) or standard grazing practices (6 hours per day or 12 hours per night). The results showed that duration controlled grazing could reduce N leaching by more than 50% (Christensen *et al.*, 2012). This work is now continuing under the Pastoral 21 (Phase 2) programme.

In Otago, a farmlet experiment (Kelso) measured the impact of effluent application on nutrient losses in hydrologically isolated plots over 3 years (2000-2003) (Monaghan & Smith, 2004). This experiment showed that if effluent was applied when the maximum depth of application exceeded the soil water deficit, relatively large concentrations of ammonium-N, total-P and *E. coli* were found in the resultant drainage (Monaghan & Smith, 2004). Houlbrooke *et al.* (2004a) used hydrologically isolated plots on a Tokamaru silt loam in Manawatu to evaluate deferred irrigation of effluent. There was minimal loss of N and phosphorus from effluent when applied using a deferred irrigation strategy: 1 kg N/ha/year and 0.2 kg P/ha/year, representing c. 1% of the applied nutrients.

The Lincoln University Dairy Farm (LUDF) has in-paddock lysimeters (50 cm diameter by 70 cm deep) that are used to measure nitrate-N leaching losses from grazed pasture. Data has been collected since 2002. Lysimeters contain either Templeton sandy loam above sand/gravel or Eyre stony silt loam above gravel. About two thirds of the lysimeters receive effluent (K. Cameron, pers. comm.).

Additional dairy farmlet experiments are currently underway that will add to the pool of experiments. Four farmlet experiments were established as part of the P21 programme, which started in winter 2011. The farmlets are located in the Waikato, Manawatu, Canterbury and Southland regions. The concept of all four farmlets is to test a 'current system' and a 'future system'. These farmlets are in various stages of implementation but will offer some valuable data at the end of the project. The Waikato and Canterbury farmlets have been described and published (Chapman *et al.*, 2012).

The farmlet experiments discussed above in detail are not the only dairy farmlet experiments where N leaching has been measured. A number of other farmlet experiments have been carried out that measure N leaching, but unfortunately they either do not have sufficient experimental detail supplied to be able to create an *Overseer* file, or the method of measuring N leaching does not appear to be suitable.

Table 1: Dairy farmlet experiments that include measurement of N leaching

Site	References	Brief description	Soil type	Annual[2] rainfall (mm)	Duration
Southland					
Tussock Creek	Unpublished[1]	Effectiveness of various grazing strategies on N leaching.	Pallic soil	900-1150	2000-03
Tussock Creek	Monaghan *et al.* (2009)	Effectiveness of DCD in reducing N leaching from a grazed dairy pasture.	Pallic soil	1097-1257[3]	2004-13
Edendale	Monaghan *et al.* (2002; 2005)	Impact of N fertilisation and stocking rate on N leaching.	Pallic and Brown soils	804-1017	1996-99
Otago					
Kelso	Monaghan & Smith (2004)	Impact of effluent application on nutrient losses in hydrologically isolated plots.	Pallic soil	c. 880	2000-03
Canterbury					
LUDF	Unpublished	In-paddock lysimeters monitoring farm N leaching losses, 2 soil-types and ± effluent	Recent and Pallic soil	c. 600	2003-09
Manawatu					
Massey Uni.	Christensen *et al.* (2012)	Controlled-duration grazing trial investigating impact on N, P and faecal microbes in drainage and runoff.	Pallic soil	c. 1000	2009-11
Massey Uni.	Houlbrooke *et al.* (2003, 2004)	Deferred irrigation of effluent	Pallic soil	c. 1000	2000-03
Massey Uni.	Unpublished	P21 farmlet trial, investigating impact of feed pads and controlled-duration grazing on nutrient losses.	Pallic soil	c. 1000	2013-ongoing
Waikato					
Ruakura	Harris *et al.* (1994) Ledgard *et al.* (1996; 1999)	Investigating the fate of N with varying stocking rates and N fertiliser application.	Allophanic soil	1033-1421	1993-96
Ruakura	Sprosen *et al.* (2002)	Impact of four stocking rates on N leaching.	Allophanic soil	1000	1999-00
Scott Farm	Ledgard *et al.* (2006) and unpublished	'RED' trial investigating mitigation practices to reduce N leaching.	Allophanic, Gley and Podzol soils	c. 1100	2001-05
Scott Farm	Glassey, 2013 and unpublished	Continuation of the 'RED' trial – nil N, control and standoff treatments.	Allophanic, Gley and Podzol soils	c. 1100	2007-09
Scott Farm	Shepherd *et al.* (2014)	P21 farmlet study, investigating various stocking rates, N fertiliser rates and use of stand-off pads on nutrient losses.	Allophanic, Gley and Podzol soils	c. 1100	2011-ongoing
Bay of Plenty					
Wharenui	Ledgard *et al.* (2008)	Investigating options to reduce N & P loss, DCD and wintering off.	Pumice soil	c. 1600	2005-07

[1]Treatment description in Houlbrooke et al. (2009); [2]Reported value(s) OR site average; [3] Reported range 2004-07

Sheep and beef experiments

Only a limited number of farmlet experiments that involved the measurement of N leaching have been carried out on sheep and beef farms in New Zealand (Table 2). One of the earliest farmlet experiments investigating N losses under sheep grazing was carried out at Grasslands (Palmerston North) by Ruz-Jerez *et al.* (1995) during the years 1989-91. Nitrogen leaching was measured under three pasture types; perennial ryegrass and white clover pasture, herbal ley, and ryegrass + 400 kg N/ha/yr. Pastures were grazed by sheep at a stocking rate which varied with feed availability. The amount of N leached was calculated as the product of the estimated volume of water draining below 450 mm and the nitrate-N concentration in the soil between 300-450 mm depth. Under all three pasture treatments at the beginning of the experiment, nitrate-N concentrations were high, most likely due to mineralisation of organic N associated with soil disturbance during pasture establishment. After the initial effect of soil cultivation had disappeared, nitrate-N concentrations in the soil solution for the rye-grass + 400 kg N/ha/yr treatment were generally much higher and more variable than for the clover-based pasture. The total amount of N lost by leaching during 1990 (May-August) was calculated as 6, 7 and 41 kg nitrate-N/ha for the clover-based, herbal ley and ryegrass + 400 kg N/ha/yr treatments, respectively (Ruz-Jerez *et al.*, 1995).

A gap in research data for low and high fertility soils in hill country grazed by sheep led to a farmlet trial being established at Ballantrae (Palmerston North) in the early 1980s. Two farmlet trials were set-up; no fertiliser control (NF) and superphosphate applied yearly between 1980-2005 (HF). Between 2004 and 2007 a study was carried on this farmlet trial, under sheep-grazed pastures at two stages of N saturation (Parfitt *et al.*, 2009). Within each farmlet, three treatments were established, with five replicates; control, herbicide applied and 300 kg N/ha/yr. N leaching losses were measured by porous ceramic cup samplers at 500 mm depth. The 300 kg N/ha/yr treatment, showed soil N status increased, with the HF farmlet becoming saturated with N and no longer retaining N and the LF farmlet retaining N initially, but by year 2 and 3 it also became saturated with N (Parfitt *et al.,* 2009).

In the late 2000s when the Waikato Regional Council investigated setting an N-cap for the management of Lake Taupo water quality, an influx of research occurred within this catchment. The catchment was predominantly sheep and beef farms and therefore a number of trials were established focussing specifically on sheep, beef and deer farm operations, investigating both expected N leaching rates under land with different stock and various mitigation options.

In the Taupo catchment a three year (2004-07) study investigated N leaching rates from pastures grazed separately by cattle, sheep or deer, with equivalent soils (pumice), climate and grazing management was established (Hoogendoorn *et al.*, 2011). Porous ceramic cups were used to sample soil water at 600 mm depth when 60 mm of drainage had occurred. The results showed no significant difference in annual average amount of either nitrate-N or ammonium-N leached from areas grazed by the three animal species, rates leached were 25, 26, 37 kg nitrate-N/ha/yr for deer, sheep and cattle, respectively. The study also highlighted that spatial patterns of leaching are highly variable with widely different concentrations of ammonium-N and nitrate-N in leachate collected from the porous ceramic cups set-up across the trial site (Hoogendoorn *et al.,* 2011).

Betteridge *et al.* (2007) established a trial (2002-04) in the Taupo catchment assessing the ability to reduce N leaching in a cattle farming situation by grazing off cattle during the winter months. Two farmlet trials were established; cattle grazed on pasture all year round

(AYG) and no winter grazing (May until early September) (NWG). Nitrogen leaching was measured using ceramic cup soil solution samplers inserted at 600 mm depth. The AYG farmlet leached more N than the NWG farmlet, the mean over the three years was 12 and 4 kg nitrate-N/ha/yr, for the AYG and NWG farmlets respectively. This indicated that removing cattle over the winter period reduced annual N leaching from that property.

Betteridge *et al.* (2011) established another trial in the Taupo catchment investigating N leaching rates as affected by the introduction of new high sugar grass pasture in a cattle-grazed trial, the trial went for two years (2007-08). Nitrogen leaching samples were collected using ceramic suction cup samplers at 600 mm depth. Results from the first year showed a significantly larger amount of N was leached in the renovated pasture compared to the control; however, no difference was found in the 2nd year. The authors concluded that the higher rate of N leaching in the first year under renovated pasture was most likely due to accelerated mineralisation.

The five farmlet experiments outlined above all have the ability to be used to help evaluate *Overseer*, as the experiments were described in sufficient detail to enable an input file to be created; and, also, the measurement depth and method of N leaching was appropriate. Of these five farmlet experiments, two were from the Manawatu region and three from the Waikato (Lake Taupo) region. A number of other farmlet experiments have been carried out investigating N leaching losses under sheep and beef farms (Table 3), but either insufficient management detail was reported or the method (mini-lysimeters) and depth (< 300 mm) of N leaching measurements places significant uncertainty around the estimates of N loss obtained.

Farmlet experiments have been undertaken in arable cropping systems and fodder cropping systems, but these are not considered in this paper.

Table 2: *Sheep and beef farmlet experiments that include N leaching measurements*

Site Name	Reference	Brief description	Soil type	Annual rainfall	Trial dates
Manawatu					
Ballantrae	Parfitt *et al.* (2009)	Effect of soil fertility on N leaching on hill country	Brown soil	1200 mm	2004-07
Grasslands	Ruz-Jerez *et al.* (1995)	N leaching under clover-based pasture and N fertilised pasture grazed by sheep	Recent soil	950 mm	1989-91
Waikato					
Lake Taupo	Betteridge *et al.* (2007)	All round grazing vs. wintering off	Pumice soil	1400 mm	2002-04
Lake Taupo	Betteridge *et al.* (2011)	N leaching under undisturbed control pasture and high sugar ryegrass	Pumice soil	1400 mm	2007
Lake Taupo	Hoogendoorn *et al.* (2011)	Compare N leaching from sheep, cattle and deer	Pumice soil	1400 mm	2004-07

Table 3: Additional sheep and beef farmlet experiments that were unsuitable to use for creating Overseer files

Site Name	Publication	Brief description	Soil type	Annual rainfall	Trial dates
Manawatu					
Woodville	Lambert *et al.* (1985)	Impact of P fertiliser rate and grazing management (rotational grazed sheep or cattle and set-stocking sheep) on nutrient losses (N, P and sediment) from hill country.	Brown soil	1280 mm	1975-79
Ballantrae	Sakadevan *et al.* (1993)	Fate of nutrients in sheep excreta once deposited on the soil	Brown soil	1200 mm	1990
Castle point	Crofoot *et al.* (2010)	Impact of fertiliser rate (0N, 60N and 120N) on N leaching in East Coast hill country.	Brown and Pallic soils	1020 mm	2004-07
Ballantrae	Hoogendoorn & Devantler (2011)	Impact of grazing intensification and slope on nutrient losses in sheep grazed hill country	Brown soil	1270 mm	2010-13
Waikato					
Limestone downs (Port Waikato)	Puha *et al.* (2008)	Impact of slope, aspect and strategic winter N applications (late autumn + winter) on N leaching	-	1300 mm	2004-07

Discussion and conclusions

Farmlet experiments measuring N leaching are usually comprised of large plots that are managed as part of the farm system. The location of the majority of farmlet experiments measuring N leaching has been generally confined to three regions – Waikato, Manawatu, and Southland, with fewer experiments undertaken in the Bay of Plenty, Canterbury and Otago regions. The majority of the experiments have been undertaken on dairy systems; relative to the number of research experiments undertaken at the urine patch level (i.e. lysimeter studies); there is a paucity of data at the grazed paddock/block level.

Farmlet experiments represent research data that is suitable for calibrating and/or validating (evaluating) the N leaching model in *Overseer* at a farm block scale. Nitrogen leaching losses from a farm system are a result of many complex interrelated processes; therefore it is important that farmlet experiments have sufficient relevant supplementary farm system data available (e.g. feed intake and drainage) to be sufficiently robust for comparing modelled with measured N outputs. The N leaching measurement method must also be suitable and it is important that measurements are taken at an appropriate depth (generally >500 mm) because, otherwise, this could overestimate N leaching losses if 'leached' N is subsequently recovered by deeper roots.

Common methods for measuring N losses in drainage include lysimeters, porous ceramic cups, and drainage plots (Table 4). No method is perfect and leaching results need to be interpreted recognising the limitations of the chosen method. Quantifying the integrated effects of urine and non-urine areas on N leaching from a grazed paddock offers immense challenges due to the uneven distribution of urine within the paddock. Because subsurface drainage systems integrate the effects of spatial variability at the field-scale, hydrologically isolated plots are a better tool for studying the field scale effects of agricultural management on water quality than are lysimeters or soil sampling (Richard & Steenhuis, 1988). Porous ceramic cups are used in free draining soils and provide an estimate of drainage nitrate-N concentrations (Poss *et al.*, 1995), as well as leaching loads at a paddock scale, when combined with an estimate of drainage. However, because their area of measurement is small, large numbers are required for a reliable estimate of nitrate-N leaching from grazed paddocks (Lilburne *et al.*, 2012), and data generally requires transformation for statistical analysis because distributions are non-normal (Anger, 2002). Lysimeters are commonly used to measure losses from individual urine patches, but can also be installed *in situ* in paddocks to measure losses under grazing. As with porous ceramic cups the challenge is having sufficient replication within the paddock to obtain a representative estimate of losses from that paddock.

There are a number of operational challenges when comparing N leaching data from farmlet experiments with modelled output. Firstly, it is important to remember that uncertainty and errors also exist in terms of the experiments themselves. To actually quantify N leaching from a soil is difficult, particularly at a paddock scale, as discussed above. Experiments also tend to be short-term and generally less than five years. Ledgard *et al.* (1996), emphasised the need for long-term measurements of N leaching due to the variations in annual rainfall, drainage and changes in immobilisation in soil organic N. Monaghan *et al.* (2005) also raised immobilisation potential as a factor at the Edendale site. In terms of annual climate variability, Wheeler *et al.* (2014) discuss the implications of matching management data (which may vary year to year in response to annual weather) with available climate datasets. A further practical consideration is access to sufficiently detailed management data to allow the system to be adequately modelled. Access to additional measurements (e.g. DM intake) is also useful to interpret the model output. This level of detail is rarely available in a published paper of the experiment; and some of the data are not in the public domain.

Conclusion

This paper highlights the limited number of farmlet experiments that can be used to evaluate farm system nutrient management models, such as *Overseer*. It also highlights that the majority of farmlet research experiments have been done in a limited number of regions (therefore soil types and climatic conditions) and also that the majority of farmlet experiments have been carried out on dairy farm systems. The uncertainties associated with model outputs are generally accepted as increasing as the differences between a modelled site and calibration and validation sites increase (Shepherd *et al.*, 2013). More sites with different environments/soils would decrease uncertainties and increase the reliability of N leaching estimates for such locations. However, this benefit has to be balanced against the cost of running complex long-term experiments.

Table 4: Summary of methods used for measuring N leaching from grazed paddocks

Method, description and example reference	Advantages	Disadvantages	Operational considerations
Drainage plots *(Mulla and Strock, 2008)* Large hydrologically isolated plots with vertical barriers to avoid surface and sub-surface flow between plots and mole/tile drains to intercept drainage. Drains monitored for drainage volume and solute concentrations.	- Good representation of a paddock at a realistic scale for agricultural management; stock can graze the surface and deposit urine and dung under true field conditions.	- Expensive to install. - Drainage tiles commonly intercept only part of the water flow.	- Water recovery needs to be accounted for in the calculation of N losses.
Porous ceramic cups *(Webster et al., 1993)* Ceramic suction cups are buried at a 45° angle in the soil and a vacuum is applied to extract soil water into the cup.	- Inexpensive per unit, and can be installed in situ in large numbers, allowing for replication and direct measurement from grazed pasture.	- Unsuitable in soils with significant bypass flow. - Small area of measurement. - Indirect measurement of drainage required.	- Large numbers are required in grazed paddocks.
Monolith lysimeters *(Cameron et al., 1992)* Undisturbed monoliths of soil contained within a cylindrical casing used for the collection and integrated measurement of the amount and composition of drainage water in a known soil volume. More typically used for urine patch scale studies but can be installed in paddocks to estimate losses from grazed paddocks.	- Accurate measurement of drainage and solute concentration. - Allows a wide range of treatment comparisons. - Can be adapted for gas flux measurements from the soil surface.	- Limited depth in relation to the field soil pore system, with implications for drainage processes. - High cost and labour required for collection and installation. - Large numbers may be required.	- May accentuate macropore flow if they have zero tension.

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References

Anger, M. 2002. Nitrate leaching from intensively and extensively grazed grassland measured with suction cup samplers and sampling of soil mineral-N II Variability of NO_3 and NH_4 values and degree of accuracy of the measurement methods *Journal of Plant Nutrition and Soil Science,* 165, 648-657.

Betteridge, K., Hoogendoorn, C., Thorrold, B. S., Costall, D. A., Ledgard, S. F., Park, Z. A. & Theobald, P. W. 2007. Nitrate leaching and productivity of some farming options in the Lake Taupo catchment. *Proceedings of the New Zealand Grassland Association,* 69, 123-129.

Betteridge, K., Crush, J., Ledgard, S., Barton, M. & Barton, S. 2011. Nitrogen leaching implications of poor pasture persistence. *Pasture Persistence - Grassland Research and Practice Series,* 15, 79-84.

Cameron, K. C., Smith, N. P., Mclay, C. D. A., Fraser, P. M., Mcpherson, R. J., Harrison, D. F. & Harbottle, P. 1992. Lysimeters without edge flow: an improved design and sampling procedure. *Soil Science Society of America Journal,* 56, 1625-1628.

Chapman, D., Clark, D., Beukes, P., Edwards, G., Dalley, D., Pinxterhuis, I., Romera, A., Shepherd, M., Cameron, K., DI, H., Woodward, S., Glassey, C., Roach, C., Curtis, J. & Lynch, B. 2012. Strategies for increasing dairy system productivity while controlling environmental footprint: a common systems research approach in two regions of New Zealand. *Proceedings of the 5th Australasian Dairy Science Symposium*, pp. 417-421.

Christensen, C. L., Hanly, J. A., Hedley, M. J. & Horne, D. J. 2012. Three years of duration-controlled grazing: what have we found? *In:* Currie, L. D. & Christensen, C. L. (eds.) *Advanced Nutrient Management: Gains from the Past – Goals for the Future.* Occasional Report 25. Palmerston North, New Zealand: Fertilizer and Lime Research Centre, Massey University.

Clark, D. A. 2010. Contribution of farmlet scale research in New Zealand and Australia to improved dairy farming systems. *Proceedings of the 4th Australasian Dairy Science .* Caxton Press, pp. 112-124.

Crofoot, A. N., Crofoot, E. W., Hoogendoorn, C. J., Litherland, A. J. & Garland, C. B. 2010. N-leaching in hill country; farmer led research. *Proceedings of the New Zealand Grassland Association* 72: 55-60

Glassey, C. 2013. The impact of farming without nitrogen fertiliser for ten years on pasture yield and composition, milksolids production and profitability; a research farmlet comparison. *Proceedings of the New Zealand Grasslands Association,* 75, 71-78.

Harris, S. L., Penno, J. W. & Bryant, A. M. 1994. Effects of high rates of nitrogen fertiliser on dairy pastures and production. *Proceedings of the New Zealnad Grasslands Association,* 56, 27-31.

Hoogendoorn, C. J., Betteridge, K., Ledgard, S. F., Costall, D. A., Park, Z. A. & Theobald, P. W. 2011. Nitrogen leaching from sheep, cattle and deer grazed pastures in the Lake Taupo catchment in New Zealand. *Animal Production Science,* 51, 416-425.

Hoogendoorn, C. J. & Devantler, B. P. 2011. Leaching losses of nitrogen and carbon from low and medium sloped areas in sheep grazed North Island hill country. *In:* Currie, L. D. & Christensen, C. L., (eds). *Adding to the knowledge base for the nutrient manager.* Occasional Report No. 24. Palmerston North, New Zealand. Fertilizer and Lime Research Centre, Massey University.

Houlbrooke, D. J., Horne, D. J., Hedley, M. J., Hanly, J. A. & Snow, V. O. 2003. The impact of intensive dairy farming on the leaching losses of nitrogen and phosphorus from a mole and pipe drained soil. *Proceedings of New Zealand Grassland Association*, 65, 179-184.

Houlbrooke, D. J., Horne, D. J., Hedley, M. J., Hanly, J. A., Scotter, D. R. & Snow, V. O. 2004. Minimising surface water pollution resulting from farm dairy effluent application to mole pipe drained soils. I. An evaluation of the deferred irrigation system for sustainable land treatment in the Manawatu. *New Zealand Journal of Agricultural Research*, 47, 405-415.

Houlbrooke, D. J., Drewry, J. J., Monaghan, R. M., Paton, R. J., Smith, L. C. & Littlejohn, R. P. 2009. Grazing strategies to protect soil physical properties and maximise pasture yield on a Southland dairy farm. *New Zealand Journal of Agricultural Research,* 52, 323-336.

Lambert, M. G., Devantler, B. P., Nes, P. & Penny, P. E. 1985. Losses of nitrogen, phosphorus, and sediment in runoff from hill country under different fertiliser and grazing management regimes. *New Zealand Journal of Agricultural Research,* 28, 371-379.

Ledgard, S. F., Clark, D. A., Sprosen, M. S., Brier, G. J. & Nemaia, E. K. K. 1996. Nitrogen losses from grazed dairy pasture, as affected by nitrogen fertiliser application. *Proceedings of the New Zealand Grasslands Association,* 57, 21-25.

Ledgard, S., Penno, J. & Sprosen, M. 1999. Nitrogen inputs and losses from clover/grass pastures grazed by dairy cows, as affected by nitrogen fertilizer application. *The Journal of Agricultural Science,* 132, 215-225.

Ledgard, S., Sprosen, M., Judge, A., Lindsey, S., Jensen, R., Clark, D. & Luo, J. 2006. Nitrogen leaching as affected by dairy intensification and mitigation practices in the Resource Efficient Dairying (RED) trial. *In:* Currie, L. D. & Hanly, J. A. (eds.) *Implementing sustainable nutrient management strategies in agriculture.* Occasional Report No. 19. Palmerston North, New Zealand: Fertilizer and Lime Research Centre, Massey University. 263-268.

Ledgard, S. F., Ghani, A., Reading, M., Sprosen, M., Balvert, S. & Smeaton, D. 2008. Farmers taking control of their future: Research into minimising nitrogen and phosphorus from pasture land into Rotorua Lakes. *In:* Currie, L. D. & Yates, L. J., (eds). *Carbon and nutrient management in agriculture.* Occasional Report No. 21. Palmerston North, New Zealand. Fertilizer and Lime Research Centre, Massey University. 500-510.

Lilburne, L., Carrick, S., Webb, T. & Moir, J. 2012. Computer-based evaluation of methods to sample nitrate leached from grazed pasture. *Soil Use and Management,* 28, 19-26.

Monaghan, R. M., Paton, R. J. & Drewry, J. J. 2002. Nitrogen and phosphorus losses in mole and tile drainage from a cattle-grazed pasture in eastern Southland. *New Zealand Journal of Agricultural Research,* 45, 197-205.

MONAGHaN, R. M. & Smith, L. C. 2004. Minimising surface water pollution resulting from farm-dairy effluent application to mole-pipe drained soils. II. The contribution of preferential flow of effluent to whole-farm pollutant losses in subsurface drainage from a West Otago dairy farm. *New Zealand Journal of Agricultural Research,* 47, 417-428.

Monaghan, R. M., Paton, R. J., Smith, L. C., Drewry, J. J. & Littlejohn, R. P. 2005. The impacts of nitrogen fertilisation and increased stocking rate on pasture yield, soil physical condition and nutrient losses in drainage from a cattle-grazed pasture. *New Zealand Journal of Agricultural Research,* 48, 227-240.

Monaghan, R. M., Smith, L. C. & Ledgard, S. F. 2009. The effectiveness of a granular formulation of dicyandiamide (DCD) in limiting nitrate leaching from a grazed dairy pasture. *New Zealand Journal of Agricultural Research,* 52, 145-159.

Mulla, D. J. & Strock, J. S. 2008. Nitrogen transport processes in soil. *In:* Schepers, J. S. & Raun, W. (eds.) *Nitrogen in agricultural systems.* Madison, USA: ASA-CSSA-SSSA.

Parfitt, R. L., Mackay, A. D., Ross, D. J. & Budding, P. J. 2009. Effects of soil fertility on leaching losses on N, P and C in hill country. *New Zealand Journal of Agricultural Research,* 52, 69-80.

Poss, R., Noble, A. D., Dunin, F. X. & Reyenga, W. 1995. Evaluation of ceramic cup samplers to measure nitrate leaching in the field. *European Journal of Soil Science,* 46, 667-674.

Puha, M. R., King, W. M., Burggraaf, V. T. & Roberts, A. H. C. 2008. Pasture production gains from strategic winter nitrogen applications on a North Island sheep and beef hill country farm. *Proceedings of the New Zealand Grasslands Association.*70: 117-121.

Richard, T. L. & Steenhuis, T. S. 1988. Tile drain sampling of preferential flow on a field scale. *Journal of Contaminant Hydrology,* 3, 307-325.

Ruz-Jerez, B. E., White, R. E. & Ball, P. R. 1995. A comparison of nitrate leaching under clover-based pastures and nitrogen-fertilized grass grazed by sheep. . *Journal of Agricultural Science,* 125, 361-369.

Sakadevan, K., Mackay, A. & Hedley, M. 1993. Influence of sheep rxcreta on pasture uptake and leaching losses of sulfur, nitrogen and potassium from grazed pastures. *Soil Research,* 31, 151-162.

Shepherd, M., Phiilps, P., Lucci, G., Macdonald, K. A., Glassey, C., Roach, C., Woodward, S. & Griffiths, W. 2014. Comparison of two dairy grazing systems in the Waikato region of New Zealand: early results on nitrate leaching. *18th Nitrogen Workshop.* Lisbon.

Shepherd, M., Wheeler, D., Selbie, D., Buckthought, L. & Freeman, M. OVERSEER®. 2013 Accuracy, Precision, Error and Uncertainty. *In:* Currie, L. D. & Christensen, C. L., (eds). *Accurate and efficient use of nutrients on farms.* Occasional Report No. 26,. Massey University, Palmerston North, New Zealand. Fertilizer and Lime Research Centre, 8 pp.

Sprosen, M., Ledgard, S. F., Lindsey, S. B. & Macdonald, K. A. 2002. Effect of stocking rate on leaching of nitrate and associated nutrients. *In:* Currie, L. D. & Loganathan, P., (eds). *Dairy farm soil management.*Occasional Report No. 15. Palmerston North, New Zealand. Fertilizer and Lime Research Centre, Massey University, 183-188.

Webster, C. P., Shepherd, M. A., Goulding, K. W. T. & Lord, E. 1993. Comparisons of methods for measuring the leaching of mineral nitrogen from arable land. *Journal of Soil Science,* 44, 49-62.

Wheeler D., Freeman, M & Shepherd, M. 2014: OVERSEER® data input timescales – using annual and average data. *In:* Currie, L.D. & Christensen C.L., eds. *Nutrient Management for the farm, catchment and community.* Occasional Report No. 27, 2014 Massey University, Palmerston North, New Zealand Fertilser and Lime Research Centre.