A REVISED LEACHING MODEL FOR OVERSEER® NUTRIENT BUDGETS

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Introduction

OVERSEER® Nutrient Budgets (*Overseer*) is a whole-farm nutrient budgeting tool, calculating budgets on an annual basis (Wheeler *et al*., 2006). The model is structured around 'management blocks', i.e. areas of the farm where management, soils and climate are similar. Previous versions of the model have separated pastoral and cropping based farms, but users have requested a number of changes to *Overseer* so that it is better able to represent a wider range of farms. These changes have included: integration of cropping and pastoral modules; inclusion of pasture blocks used mainly to grow supplement; and blocks for winter/summer forages. However, to accommodate these changes whilst still providing reliable estimates of N leaching under all the management options available, the N model needed to be modified. This paper outlines the approach that is being adopted.

Requirements of the N leaching model

Overseer is an empirically-based nutrient budgeting tool, rather than a detailed process-based model. The challenge continually is being able to model the transfer and fate of nutrients around the farm system whilst maintaining a level of user input that is practical and achievable (Shepherd & Wheeler, 2010). Amongst other outputs, *Overseer* calculates the long-term annual average N leaching from the management block(s) and the farm. Thus, the model has to respond to the full range of inputs that *Overseer* has (e.g. stocking rate, soil-type, and rainfall) and it has to be driven by parameters that the user knows, or suitable defaults need to be available.

Overseer estimates the amount of N returned to the soil surface each month for each animal enterprise, as described below. The model then needs to estimate the proportion of each month's excretal N load that is leached. The challenge is that leaching of N could occur months after the N is applied, depending on the pattern of drainage (Snow *et al*., 2011) and in the meantime will be subjected to a range of other processes (immobilisation, volatilisation, denitrification and plant uptake). Much of the N leaching in a grazed system will be due to losses from urine patches (Monaghan *et al*., 2007). However, the model also needs to be able to account for losses from different sources of N inputs added to a block such as excreta, fertiliser, effluents and N in irrigation water.

Basis of the N leaching model

Overseer calculates the nitrogen intake for the grazing herd as a mass balance (Figure 1). The energy requirements of the herd are first calculated using a standard metabolic model (Freer *et al*., 2006). This is then converted to dry matter (DM) intake based on the feed sources fed to the animals and default values for their metabolisable energy (ME) contents. Based on these DM intakes and default values for N content of the feed sources, N intake can be calculated. This is then partitioned between animal products (based on user-provided production data) and excreta. Routines within *Overseer* partition this between urine and dung deposition back onto blocks and also account for excreta that are recycled via effluent management or feed pad systems.

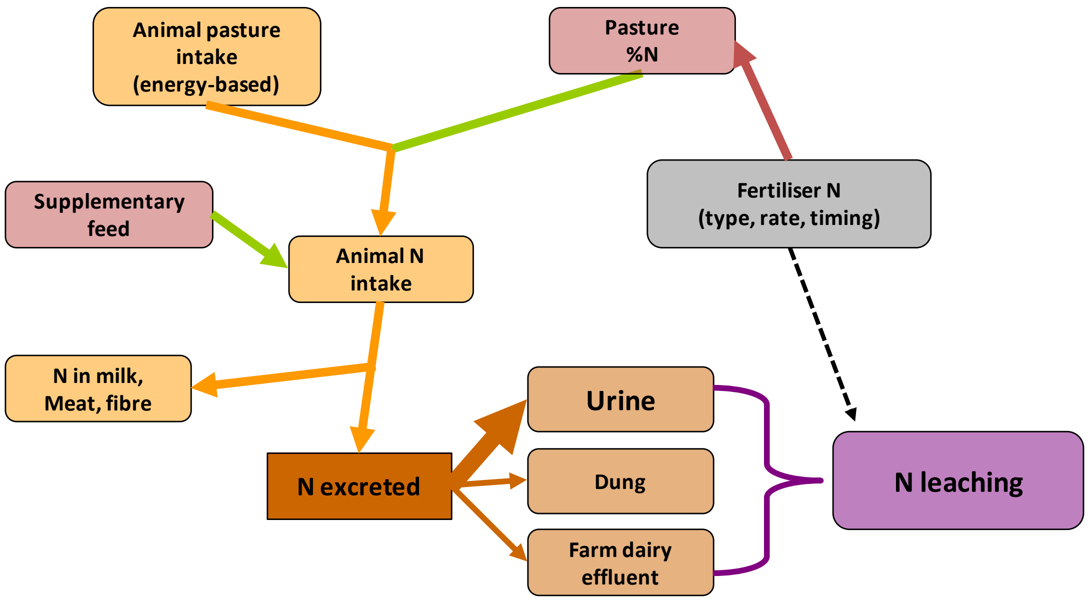

Figure 1. *Representation of the approach used to calculate the N excreted by a grazing herd.*

To estimate the subsequent N leaching of these sources, the N leaching model was split into background and urine patch models. These are described in the following sections.

Background N leaching

A crop module for *Overseer* was developed and validated against field trials (Cichota *et al*., 2010) and implemented in *Overseer* version 5.4. This was then used as the basis for developing a 'cut and carry' model for cut and carry blocks where pasture is grown and harvested for supplement in the absence of grazing animals (Wheeler *et al*., 2010). Cut and carry systems tend to be more N efficient than grazed paddocks when considered at the paddock scale (Ball & Ryden, 1984; Grignani & Laidlaw, 2002). This is because the applied N fertiliser is taken up by the pasture and then harvested without excretal return from the grazing animal. Within *Overseer*, the inter-urine patches are considered as a cut and carry system with grazing animals, rather than machinery, removing the forage. The background pasture N module is therefore based on the cut and carry sub-routine developed for a pasture cut and carry block (Wheeler *et al*., 2010).

This module allows the timing of N fertiliser to be better incorporated into the model. In the previous model, N applied in winter (April-June) had higher leaching than N applied at other times. In the upgraded model, the amount of N leached responds to the drainage and uptake that occurs at each site. Thus, for a given farm set up, N fertiliser applied in early winter would have less effect in Northland than Southland as typically plant N uptake would be higher over this period in Northland. By assuming that the inorganic fraction of effluent is similar to N fertiliser, and the organic fraction is similar to crop residuals, the effects of different effluent sources, as well as the interaction between effluent and fertiliser, are also accounted for in the background model.

N leaching from urine patch

To work effectively, *Overseer* requires an estimate of the proportion of urine N added in a given month that is leached. APSIM, a detailed process-based model (Keating *et al*., 2003), was used to identify key factors that drive N leaching from the monthly urine deposition calculated by the model. To do this, thousands of simulations were run for combinations of soils and climates across New Zealand. Nitrogen was applied in different months at a concentration of 750 kg N/ha and simulations run for three years to capture the full amount of the N that was leached from the applied N. These factors could be summarised as those that affected the amount of drainage at a site (mainly soil-type, rainfall amount and distribution), and those that affected rate of N removal from the urine patch (time of N application, growing conditions). It was determined that the major soil property that affected leaching was the plant available water capacity. This approach therefore firstly allowed the identification of key factors that *Overseer* needed to capture to adequately describe the movement of N through the soil profile.

Based on the multiple APSIM simulations across a wide range of conditions, a transfer function (TF) or 'breakthrough curve' was identified, which defines the relationship between cumulative N leached (relative to the maximum amount of leachable urine N for that system) and cumulative soil water drainage expressed as pore volumes (PV) drained. Here, PV is based on the soil's available water capacity rather than its total water-holding capacity value. Breakthrough curves are typically smooth sigmoid functions. Examination of the TFs generated by APSIM and from experimental data suggested that, in most cases, these curves could be estimated using two straight lines (Figure 2).

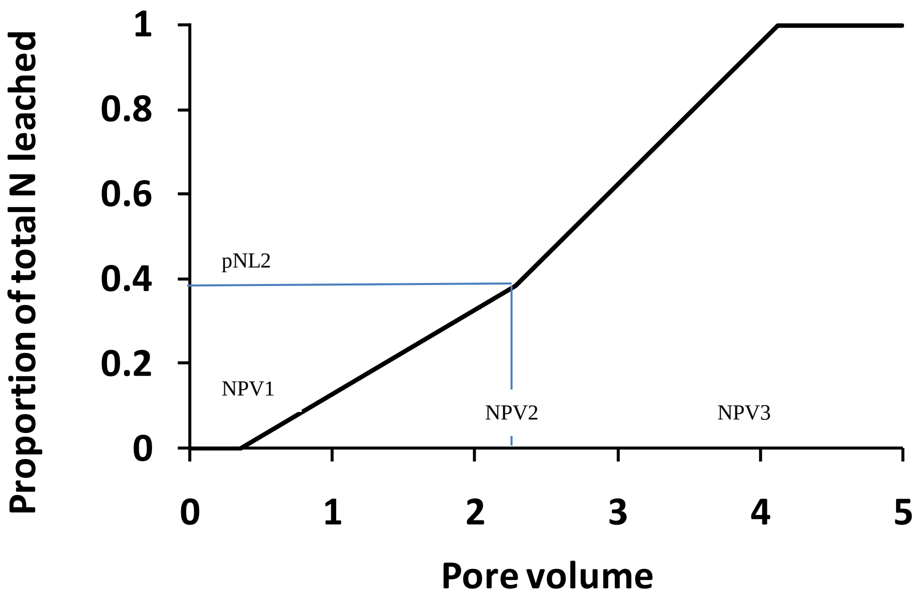

Figure 2. *Relationship between pore volume drained and the proportion of total N leached.*

The curve can be defined by three points: the PV to the start of N leaching (NPV_1); the PV where maximum leaching was reached (NPV_3); and a mid-point (NPV_2) which describes the degree of curvilinearity. Relationships have been developed between annual precipitation and soil properties to describe the values of PV_1 to PV_3. In addition, the maximum proportion of added urine N that could be leached was also estimated.

The revised N leaching within *Overseer* combines this transfer function with other subroutines that calculate the total urinary N pool in the soil and its partitioning to other processes (uptake, immobilisation, gaseous loss), and is currently being implemented for the next *Overseer* release (version 6). Currently, the validation data indicates that the model is working well. The results of the validation will be published separately later.

Discussion

Overseer was developed as a nutrient budgeting tool, but there is an increasing focus on its use to estimate off-farm losses of nutrients and greenhouse gases (Shepherd *et al*., 2009). This brings two particular challenges; development of an empirical model that provides reasonable estimates of losses, based on a level of user inputs that do not compromise usability of the model; and that is able to reflect changes in losses when appropriate mitigations are put in place on the farm (Monaghan *et al*., 2007). In particular, this requires a model that is sensitive to timing of operations (fertiliser N inputs, time of urine deposition) and to the influence of climate and soil-type.

Splitting the model between background and urine patch is a common approach when modelling grazing systems (Hutchins *et al*., 2007; Snow *et al*., 2009). It recognises that the between-urine patch area of the paddock is akin to a cut and carry paddock where N is used very efficiently (Ball & Ryden, 1984; Grignani & Laidlaw, 2002) and recognises that much of the N leaching is driven by the urine patch (Monaghan *et al*., 2007). Typically, this approach requires an estimate of the area of a paddock affected by urine patches each year. Although, there are published data on urine patch dynamics (Haynes & Williams, 1993; Moir *et al*., 2010), the variation is large and is determined by a number of factors. Urinary N concentration (i.e. N load per urine patch) also varies: between animal species, between animals in the same herd, between days and between times in the day (Betteridge & Andrews, 1986; Fillery, 2001; Kume *et al*., 2008; Hoogendorn *et al*., 2010). The above approach alleviates the requirement to do this. However, *Overseer* applies a ‘field factor’, which is an empirical correction factor calibrated against paddock- or farmlet-scale trials that account for differences in urine patch dynamics between experiments or model simulations based on single urine patches and actual farm systems.

Choice of a TF model is appropriate for meeting the aims of *Overseer*, as described above. While TF models are essentially empirical models traditionally used in a more probabilistic setting, depending on the nature of the transfer function, they can be assigned physical meaning. The TF approach fits well with the requirements of *Overseer*. For example, *Overseer* needs to calculate the fate of single urine patch events, which can be considered to be delta functions given that the time step in *Overseer* is one month. Other processes such as delays caused by nitrification processes (e.g. affected by month of deposition) are already incorporated into the TF. Although TF models traditionally use time as the independent variable, use of drainage instead makes the approach broadly applicable to a wide range of soils. The approach also accommodates *Overseer* using its own sub-routines to calculate other losses (e.g. volatilisation and denitrification) as well as *Overseer* determining the mass balance. However, implicit in the TF is that all pore volumes of drainage are equal. We know that this is not always the case because of bypass flow on some soils, and that there is the additional effect of the combination of the monthly drainage time step and source limitation. Further work is therefore required to account for soils with significant bypass flow or that are mole/pipe drained.

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