Describing N leaching under urine patches in pastoral soils

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Abstract

Urine patches are the major source of nitrogen (N) leaching from grazing systems as the nitrogen load under these spots far exceeds the plants needs. The high concentration of nitrogen under urine patches is also challenging for modelling as some processes, such as ion adsorption, cannot be assumed to be linear. We have employed the APSIM model framework with a newly developed pasture module to describe the results of an experiment where lysimeters were treated with a load of 1000 kg/ha of nitrogen as urine. To model this data we used a mechanistic soil model with NH_4 adsorption modelled by a Freundlich isotherm The model showed good agreement with measured drainage and both NO_3 and NH_4 leaching. The effect of the assumption that NH_4 is completely immobile was compared with the Freundlich isotherm and found to underestimate leaching by 20% in this loamy soil. In soils, such as sandy soils, with lower adsorption capacity the underestimation is expected to be greater.

Key Words

Nitrogen leaching, pasture, APSIM, modelling, ammonium adsorption.

Introduction

The high use of fertilisers under intensive dairying is regarded as a major cause of ground-water contamination and eutrophication of surface water bodies adjacent to agricultural areas (Goodlass *et al.* 2003; Monaghan *et al.* 2007). Best management practices can significantly reduce the nutrient losses derived from fertilisers but in pastoral systems, especially with grazing ruminants, considerable losses of N can occur even at low fertiliser input levels. These losses increase exponentially as inputs increase (Ledgard 2001). This occurs because grazing animals have a low efficiency in the utilisation of the N taken in. Some 80 to 95% of the N ingested is returned via excrements, mostly in urine. Urine depositions cover a fairly small portion of the paddock, about 3-5% after one grazing event, and up to 25% over the whole year. Thus animals concentrate N taken up from a larger area into small patches where application rates often surpass the plants needs. The concentration of N under urine patches from dairy cows can range from 500 to 1000 kg/ha. As such, urine patches are by far the biggest source of N leached from grazing systems (Haynes and Williams 1993; Ledgard 2001). Urine patches are not only hotspots for N leaching, but also for other losses, especially greenhouse gases, which have also gaining increased attention recently. These issues are particularly important for New Zealand, given its production system, based on grazing animals, and the relevance of the agricultural sector to the economy. Existing or proposed regulations are increasing the pressure on farmers to improve N management and reduce losses from their systems.

The use of models is crucial for improving N management. However, the current quantification of some processes occurring in the soil and plant under urine patches is not sufficiently understood. The high N loads in these spots put the N concentration in the soil outside the range typically used in research. In this situation, some of the processes, such as ion adsorption, which in most conditions can be reasonably assumed to vary linearly with concentration, will show a non-linear behaviour. Thus, validation of the models under a urine patch conditions is necessary. For instance, in several models ammonium (NH_4) has been often considered to be totally immobile, or to follow a linear isotherm. Under urine patches, however, very high concentrations of ammonium occur and so a nonlinear isotherm should be more appropriate.

The APSIM model (Keating *et al.* 2003) is a well known modelling framework composed of several modules that are added to the simulation according to the experimental needs in order to describe the several processes of the soil-plant-atmosphere system (Holzworth *et al.* 2009). The APSIM model and its modules have been extensively tested and have been widely used to simulate cropping and forestry systems. Simulations of grazing systems are improving with the addition of pasture and animal modules to the framework. One of the water modules in APSIM, SWIM2 (Ross and Smettem 1993; Verburg *et al.* 1996), uses a mechanistic approach based on Richards' equation and the convection-dispersion equation to describe water and solute movement through the soil. This includes the ability to represent a non-linear ion adsorption isotherm.

The objective of this work is to evaluate the performance of the APSIM model, using SWIM2 for describing water and solute transport and the newly developed AgPasture module to simulate pasture growth. The model output was compared with results from a lysimeter experiment simulating urine patches.

Material and methods

Measured data

The measured data were obtained from a lysimeter study (Shepherd 2009) containing undisturbed columns (50 cm diameter×70 cm height) of the Horotiu silt loam soil (from Ruakura Research Centre, Hamilton, New Zealand). The lysimeters received a cow urine application at a volume equivalent to 10 mm and 1000 kg N /ha, simulating a urine patch. The urine amount added is at the high end of the range of a single urine patch typical of that for beef or dairy cattle (Haynes and Williams 1993). There were four replicates.

Prior to the urine application the grass was cut down to 3.5 cm height; subsequently eight other cuts were done through the experiment, which started on 15/05/2008 and continuing until 28/12/2008. During the experiment, the lysimeters received a combination of natural rainfall and irrigation. Irrigation was applied at regular intervals to supplement rainfall so that the lysimeters received enough water to avoid stress during the period of the experiment. Leachate was collected at regular intervals, the amount of drainage was calculated and samples were analysed for ammonium and nitrate concentrations.

Modelling

To model this experiment the APSIM model (version 7.0) was employed (Keating *et al.* 2003). The SoilN and SurfaceOM modules (Probert *et al.* 1998) were used to describe the C-N cycle, and SWIM2 (Verburg *et al.* 1996) for the transport of water and solutes. To simulate pasture development, the AgPasture module (F. Li, AgResearch, personal communication) was employed. AgPasture has been developed using the pasture module from EcoMod (Johnson *et al.* 2008) as a starting point and is designed to simulate the growth of multiple pastures species. It is currently in its final stages of development.

The required parameters to set up SWIM2 and SoilN were gathered from the literature (Close *et al.* 2003; Singleton 1991) and from the New Zealand Soil Database (Wilde 2003). Ion adsorption for NH_4 was assumed to obey a Freundlich isotherm. Its parameters were estimated from measurements with the support of a pedo-transfer function derived from data from ten different New Zealand soils, including the Horotiu soil. The pedo-transfer function relates the adsorption parameters with soil texture and carbon content (I Vogeler, personal communication). Climate data was obtained from the Ruakura Weather Station, and the detailed management of the experiments was described using the APSIM manager module.

Results and discussion

The total water input over the experimental period was 1035 mm (962 mm from rainfall and 73 mm from irrigation). This resulted in a considerable amount of drainage, more than half of the water inputs (Figure 1). The drainage amounts were simulated reasonably well with APSIM (Figure 1). In spring drainage amounts were overestimated, which probably was a result of pasture growth being under-predicted at this period.

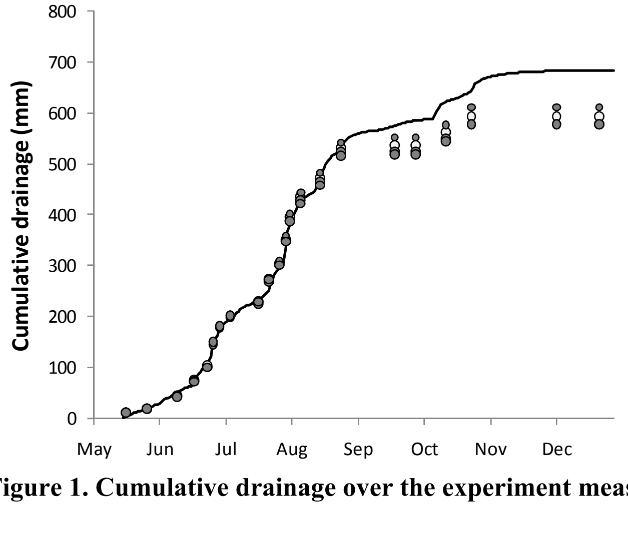

Figure 1. Cumulative drainage over the experiment measured (points) and simulated (line).

Both treatments showed higher variability between replicates for N leaching than for drainage. The relative variability was higher for NH_4 than NO_3 (Figure 2). The model predicted the leaching pattern reasonably well, although the timing for first appearance and the peak of NH_4 leaching was modelled a bit later than was observed. Timing and amount of N leached as NH_4 predicted by the model was quite sensitive to the parameters for NH_4 adsorption and nitrification rate. This emphasises the need for more studies to better understand and quantify these processes under high N loads.

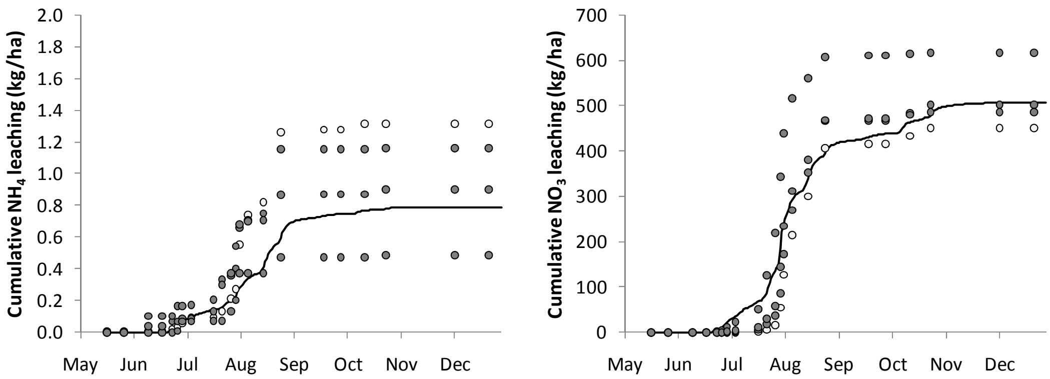

Figure 2. Measured (points) and simulated (lines) values of cumulative N leaching as NH_4 or NO_3.

Many models assume either a linear NH_4 isotherm or that NH_4 is completely immobile. We tested the effect of this using a linear isotherm with the same initial slope as the Freundlich isotherm used above. With the linear isotherm less NH_4 and total N leaching was predicted but for the Horotiu soil the effect was not great. Simulations repeated with an isotherm appropriate for a sandy soil showed a greater effect of a linear isotherm. When NH_4 was assumed to be completely immobile in the Horotiu soil N leaching was under predicted by approximately 100 kg/ha. With complete immobility of NH_4 , the N remained in the layers closer to the soil surface for longer and that resulted in greater uptake by the pasture. This issue will be more important in soils with low NH_4 adsorption and where mitigation options such as nitrification inhibitors are to be considered.

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