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Modelling nitrogen leaching from overlapping urine patches

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ABSTRACT

Urine depositions have been shown to be the main source of N leaching from grazing systems and thus it is important to consider them in simulation models. The inclusion of urine patches considerably increases the complexity of the model and this can be further aggravated if the overlaps of urine patches are also considered. Overlapping urine patches are potentially important sources of N loss because the N load in these areas can be very high. In this work, we investigate a methodology to simplify the process of accounting for overlapping urine patches. We tested a two-stage approach, where, on one hand, the urine of two consecutive depositions could be aggregated and deposited at the time of the second deposition. This was called the Delayed Representation (DR) and would be useful when the delay (T_d) between overlaps is short. On the other hand, if T_d is sufficiently large, the depositions would become functionally independent and the urine patches could be considered separately. We called this the Independent Representation (IR). We tested this methodology by comparing simulations where the overlapping urine patches were considered explicitly and using the DR or IR in several combination of climates, soils and management options, chosen to span the likely range in New Zealand, using the Agricultural Production Systems Simulator (APSIM) model.

The results from the simulations indicated that when $T_d < 20$ days, the DR introduced only a low, acceptable, error in simulated N leaching. When $T_d > 180$ days, the IR was found to be acceptable in all the climates, soils and management options simulated. This left a generic window, $20 < T_d < 180$ days, where explicit simulations would be required. In some conditions, that window was considerably shorter. In a dry climate and shallow soil, the window was found to be $75 < T_d < 180$ days, while for the simulations with a wetter climate and deep soils, that window was about $70 < T_d < 90$ days, except for depositions in the middle of winter. These limits should apply only to long-term simulations where the user is interested in the average behaviour of the system, as considerable year-to-year variability was observed. We suggest that these windows can be used to guide the development of simulation models that include representations of urine patches under many conditions but where the soil and/or climate conditions vary markedly from those used here the analysis should be repeated.

1. Introduction

Urine deposited by grazing ruminants is a major contributor to the high heterogeneity in soil nitrogen conditions found in pastoral systems (Haynes and Williams, 1993; Bogaert et al., 2000; McGechan and Topp, 2004; Hutchings et al., 2007). The areas affected by urine depositions receive much larger quantities of nitrogen (N) than the remaining area, typically from 500 to 1000 kg N/ha for dairy cows (Haynes and Williams, 1993). Such quantities are far in excess of the pasture's ability to take N up before leaching occurs and thus urine patches are the major sources for N loss in grazing systems (Ball and Ryden, 1984; Di and Cameron, 2002; van Groenigen et al., 2005). The N load and the timing of deposition have been shown to be important factors defining the fate of N in urine patches (Cuttle and Bourne, 1993; Shepherd et al., 2011; Snow et al., 2011).

The heterogeneity arising from the deposition of urine patches complicates the measurement of N loss from a grazed paddock (Lilburne et al., 2012). The high spatial variability makes it difficult and costly to quantify N loss from pastoral systems and means that estimates of N loss from grazed paddocks are often associated with large uncertainties. These large uncertainties are a cause for controversy when defining environmental policies and evaluating the efficacy of mitigation actions. Simulation modelling can be an effective adjunct to experimental methods for monitoring N cycling and estimating N losses. Computer models of various levels of

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complexity have increasingly been used to estimate N losses worldwide. Most of these models, however, do not account for field heterogeneity. This is mainly because the complexity of the modelling setup required to simulate heterogeneity presents a technical challenge in terms of computing resources (Addiscott, 1995; Hutchings et al., 2007; Wang, 2008; Romera et al., 2012). Furthermore, the importance of heterogeneity and methodologies for the use of information with uncertainty for decision making has not been well established (Beven, 2002; Lowell, 2007).

It has been shown that for estimating N leaching from systems with grazing animals it is necessary to account explicitly for the effects of urine patches (Ryden et al., 1984; Haynes and Williams, 1993; Snow et al., 2009). However, accounting for the heterogeneity created by urine depositions is not trivial. Describing such a system within models places a high demand on computing resources and has been attempted only with considerable simplifications (McGechan and Topp, 2004; Hutchings et al., 2007; Snow et al., 2009), Apart from the variability created by single urine depositions, urine overlaps can further alter the load of N deposited onto the soil and so are potentially important for defining the amount of N leached (Pleasants et al., 2007). Overlapping urine depositions on the same grazing day are likely to be minor because these overlaps typically represent a very small fraction of the grazing area (Shorten and Pleasants, 2007). However, a urine deposition affects the soil and the plants for some length of time, and leaching from a second, overlapping, urine patch deposited some weeks or months after the first deposition will be affected by the first deposition. These temporal overlaps are likely to be more significant than those occurring within the same grazing day because the probability of the overlap and therefore the area affected greatly increases. For example, Pleasants et al. (2007) using a statistical approach estimated that, at a typical 24-h grazing density of 100 cows per ha, less than 1% of the area grazed would be affected by overlapping urine patches. Considering that there would typically be about 14 grazings per year per paddock, and that in winter the animals could be mobbed with stocking densities of up to 1000 cows per ha, the proportion of a paddock that will experience delayed overlaps rises considerably. Over one year, urine depositions affect about a quarter of the area for a typical dairy farm (Pleasants et al., 2007; Moir et al., 2011) and overlaps can represent 20% of this, according to the statistical approach of Pleasants et al. (2007). Accounting for all temporal overlaps would result in a rapid increase in modelling complexity and thus simplifications are needed. While these issues are of most interest for intensively grazed systems where the animals graze the pastures year round, the principles are applicable to grazing situations in general.

The purpose of this study was to investigate options for simplifying the representation of overlapping urine patches in the simulation modelling of grazed systems. While the work here is presented in the context of New Zealand soils and climates, the concepts are generally applicable to any grazed system. We used outputs from the simulation model Agricultural Production Systems Simulator (APSIM) to identify the nature of the interactions between successive urine depositions and how this interaction is affected by the interval between depositions. We hypothesise that when the delay (T_d) between overlaps is short, the first deposition can be delayed and aggregated with the second deposition without significant error; we call this the Delayed Representation (DR). At higher values of T_d, urine patches become functionally independent because the N from the first urine patch is depleted before the second is deposited and in this case, the urine patches can be considered separately with an Independent Representation (IR). We test these simplifications by comparing simulations employing DR and IR against simulations where the overlapping urine patches are considered explicitly (Explicit Representation, ER) in the same simulation. We analyse whether it is possible to define general rules for simplifying the description of urine patch overlaps using DR and IR.

2. Material and methods

2.1. The APSIM model

The APSIM modelling framework (Keating et al., 2003; Holzworth et al., 2010), version 7.3, was used to simulate N leaching from urine depositions in a pastoral system. The primary modules that are relevant for this work are described briefly below. SWIM (Verburg et al., 1996) models soil water dynamics using the Richards' and convection–dispersion equations with a Freundlich isotherm to simulate solute adsorption onto the soil particles. Soil N (Probert et al., 1998) calculates the C and N, organic and mineral, dynamics in each soil layer. The organic C and N transformations are calculated using four conceptual pools; microbial biomass, fresh organic matter, humus, and a functionally inert organic matter fraction. The mineral N transformations include urea hydrolysis using a first-order process affected by pH and organic matter concentration, nitrification using a Michaelis–Menten equation, and denitrification as a first-order process based on pH and organic matter. All transformations, organic or mineral, are also affected by soil water and temperature conditions. More recently a volatilisation component has been added. A full description of this component is available on request. Plant water demand was calculated by the MicroMet module (Snow and Huth, 2004) using the Penman–Monteith equation. MicroMet calculates the effect of competition between plants for light based on crop height and leaf area index using values for these states provided by the crop modules in the system. The canopy conductance of each crop in the simulation is calculated based on light competition using the stomatal conductance model described by Kelliher Kelliher et al. (1995). AgPasture (Li et al., 2011) is an implementation in APSIM of a pasture model which has previously been validated for a range of conditions in New Zealand and Australia (Cullen et al., 2008; White et al., 2008). AgPasture is fully responsive to changes in soil water and nitrogen conditions and has been validated for growth under urine patch conditions (Snow et al., 2011). Full documentation for the modules used can be found at www.apsim.info.

These modules have been validated against pasture growth data (Li et al., 2011), leaching data from urine patches in lysimeter experiments (Cichota et al., 2010a, 2010b) and pasture growth, changes in soil mineral N and leaching from urine patches under field conditions (Snow et al., 2011).

2.2. Modelling setup

2.2.1. Base simulation

Each simulation described the urine patch area alone and for the purposes of this work it was not necessary to scale the results up to the whole-paddock level. A base simulation of a ryegrass/white clover sward using default parameter values was set up in APSIM. The pasture mix was harvested every 21 days down to a residual biomass of 1500 kg dry mass (DM) per ha. Each simulation ran for 3.5 years, which included an initial six months before the nominal experimental start date to allow the effects of initial conditions to be overridden by the model. Urine depositions were made at various times as described below. Urine was added by inserting 7.5 mm depth of water (equivalent to 2 L of liquid) and the accompanying urea N to a depth of 350 mm with the water and N decreasing linearly with depth in the soil. This addition method, rather than treating the urine as irrigation to the soil surface, was chosen to better model the transport of water and N under the ponded conditions that occur at the immediate time of urination, including preferential flow that is not simulated by SWIM.

States and fluxes of water, dry matter and N were recorded daily for three years after the deposition date to ensure that all the effects of the urine on soil and plant conditions, including changes in soil organic matter were fully captured. Urea fertiliser was added to the top 50 mm of soil according to the treatments described below. Irrigation, when applied, was simulated as a centre pivot operation and was triggered between October and April by a critical soil water deficit of 20 mm for the shallower Lismore soil or 40 mm for the other soils. A minimum return period of four days was imposed and each irrigation added water equivalent to half of the critical soil water deficit.

The results presented are the sum over the three years following the urine deposition. Drainage and leaching were recorded at a depth of 1.5 m. We consider only the leaching of mineral N sources (urea, ammonium and nitrate).

2.2.2. Input data

Climate data from two locations in New Zealand, Ruakura (latitude 37.775°S, longitude 175.325°E) and Lincoln (latitude 43.625°S, longitude 172.475°E), representing the diversity of farming regions of New Zealand, were gathered from the Virtual Climate Station database (Tait et al., 2006; Cichota et al., 2008) for the period between 1979 and 2004. Ruakura, in the North Island, has a mild temperate climate with an average annual rainfall of 1164 mm and an average daily temperature of