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The challenges of incorporating urine and dung patches in process-based modelling of grazed agricultural systems

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Abstract: Animals are well known to be important in lateral transfers of nitrogen within the farm boundary. Those transfers can be categorised into those that are: (a) primarily random and small-scale dung and urine patches within a grazed paddock, (b) larger and systematic transfers resulting from preferred grazing and resting areas and (c) those that are additionally mediated by management actions such as manure management from housing systems. We review how key simulation models treat the random category of nitrogen transfers and develop recommendations for usage and further development. While urine patches are clearly understood to be important in N cycling in grazed pastures, few simulation models consider the effect of the patchy urine deposition, primarily because the inclusion of the deposition process greatly increases the complexity of the simulation model. Some modellers choose to ignore the effect – and if the primary aim is to model production rather than environmental effect then that position may be quite justifiable. Some authors have taken an approach to model the pasture and leaching at the scale of an isolated patch and then scale up to the paddock level post-simulation. These solutions require relatively little model development and are computationally-efficient but they cannot capture the effects of feedbacks into the system caused by changes in N fluxes and cycling. Far more complex solutions can be informative but they do not lend themselves to practical application at the paddock or farm level. Routine implementation of urine patches into a simulation model will require a balance between realism and pragmatism as it is not generally practical to include the full complexity involved in a whole farm model.

Keywords*:* APSIM; DairyMod; FASSET; IFSM; Pastoral Farm Systems;

1 INTRODUCTION

Grasslands occupy about 25% of the terrestrial surface (Lemaire et al., 2011) and contribute to the livelihoods of over 800 million people (Reynolds et al., 2005). As such they have an important role to play in satisfying the increasing worldwide demand for high-quality protein (Steinfield et al., 2006). Given their extent, grasslands are a crucial system to consider when evaluating local or global issues related to sustainable land management, especially in the face of on-going land-use changes and climatic uncertainty. Although, compared to other farming types, grazing-based farming systems are often considered to be relatively environmentally benign, they have been following the general trend of agricultural activities with increasing usage of imported nutrients. This importation of nutrients results in an intensification of the farm system, usually through increased stocking rate, and causes increased nutrient losses (Ledgard et al., 1999; Tilman et al., 2002). Thus it is important to consider the environmental performance of pastoral farming systems as well as the ecosystem services that they provide (Lemaire et al., 2011). Simulation modelling has an important role to play in understanding and quantifying the relationships, or trade-offs, between farm inputs, farm management and the production and environmental outputs from the farm, but robust simulation models are needed for that endeavour. Agricultural systems that include grazing ruminants are characterised by a number of features that are not present in arable cropping systems and which present challenges to the experimentation, understanding and simulation modelling of these systems. Here we consider the particular challenge posed by the impact of the animals on nitrogen (N) cycling within the farm.

In this paper we outline this challenge, describe a range of solutions used by different models and consider the strengths and weaknesses of these solutions. We consider four simulation models that are able to simulate pastoral (sheep, beef and/or dairy) farming systems. The models are all process-based, dynamic and deterministic (although some contain some stochastic descriptions of some processes) and they all include some aspect of spatial heterogeneity. The models are:

- the Agricultural Production Systems Simulator (APSIM) (Keating et al., 2003);
- DairyMod (Johnson et al., 2008);
- the Farm Assessment Tool (FASSET) (Berntsen et al., 2003); and
- the Integrated Farm System Model (IFSM) (Rotz et al., 2013).

2 The challenges presented by animal-mediated nitrogen transfers

Animals are well known to be important in lateral transfer of nutrients within the farm boundary (Haynes and Williams, 1993; Snow et al., 2014). While all nutrients are affected, here we concentrate on the transfers of N within the farm system that are mediated through the animal as they convert forage into dung and urine. These N transfers can be categorised as: (a) the primarily random, small-scale dung and urine patches within a grazed paddock, (b) larger-scale (but still within-paddock) systematic transfers resulting from preferred grazing or resting areas and the impact of animals congregating around physical structures such as watering points and gateways and (c) those that are additionally mediated by management actions such as manure management from housing systems and feed pads. Here we concentrate on the impacts and modelling of the first category of N transfers.

Nitrogen cycling in farm systems that are based on *in-situ* grazing of permanent pastures is driven by the deposition of urinary-N (Haynes and Williams, 1993; Whitehead, 1995). Urine patch areas can receive instantaneous N depositions of 30–1200 kg N/ha (Whitehead, 1995). This creates a heterogeneous soil and pasture because the inter-patch areas hold mineral-N amounts of typically <20 kg N /ha (Haynes and Williams, 1993; Ball and Ryden, 1984). Moir et al. (2011) found that, on an annual basis, about 23% of the area of an intensively grazed dairy pasture was affected by urine and that this affected area accumulated through repeated grazing events from individual urine patches of 0.34-0.40 m^2 each. The small size of the individual urine patches adds considerable uncertainty to the measurement of leaching (and therefore also to the validation of leaching models) from grazed pastures as outlined by (Lilburne et al., 2012). This heterogeneity has far reaching effects (Whitehead, 1995) and should be considered in the simulation of nitrification, volatilisation, denitrification (de Klein and Eckard, 2008), leaching and pasture growth (Schwinning and Parsons, 1996).

3 Current modelling approaches

<u>APSIM:</u> The currently-released version of APSIM does not have an automated approach to model urine patches within a paddock (a system to do this is in development and should be released in late 2014) and much of the development work to date in this topic has focussed on improving the modelling of the important processes within the patch itself (e.g. Cichota et al., 2013a; 2013b; Vogeler et al., 2013b). The flexible management component that is included in APSIM could be used to replicate the methods implemented by DairyMod and IFSM as described below.

<u>DairyMod:</u> DairyMod has implemented an implicit approach for modelling the impact of urine patch dynamics in which the paddock is divided into ‘patch’ and ‘bulk’ categories which are simulated separately with the proportionate area of the patch increased by grazing activities and decreased using a time-based decay approach. This approach is depicted in Figure 1a. Paddock area, and the associated N, is transferred between these categories to implicitly simulate the effect of the urine patches. This implicit approach has been tested against the explicit description (Snow et al., 2009)

and this testing has indicated that it is a pragmatic approach for many uses. While the implicit approach might not be suitable for detailed studies, it captures the larger effects and the computational requirements are only double that of a homogenous paddock and so places no practical limitation in whole-system studies.

FASSET: Explicit consideration of the bulk and patch area of a grazed paddock is included in FASSET as described by Hutchings et al. (2007) and shown in Figure 1b. Because FASSET is coded using object-oriented techniques, it is possible to clone the grass and soil models, add the appropriate amount of nutrients and then model these new areas individually. This system presents both scientific and technical challenges. The scientific challenge was to model the grazing and pasture off-take from the areas individually – i.e. model how the livestock selected where and how much to graze. The technical challenge was to devise a method for incorporating areas back into the part of the model used to describe the area unaffected by excreta when the effect of the excreta was no longer of practical significance. This reincorporation was never satisfactorily achieved, and this limited the run length of the model.

IFSM: IFSM considers the effects of the random transfers of nutrients by dividing the area of grazed paddocks into that affected by excreta and that unaffected (Rotz et al., 2013) (Figure 1a). The area covered by excreta is determined by the amount of urine N excreted and thus varies with stocking rate. The area unaffected by excreta is simulated first to predict mineralization, nitrification, denitrification, volatilization, and leaching processes. The area under excreta is then simulated to predict the same processes under the higher level of soil N. The sum of emissions from the two areas predicts total losses from the pasture. Daily plant uptake and growth are predicted assuming uniform distribution of applied N.

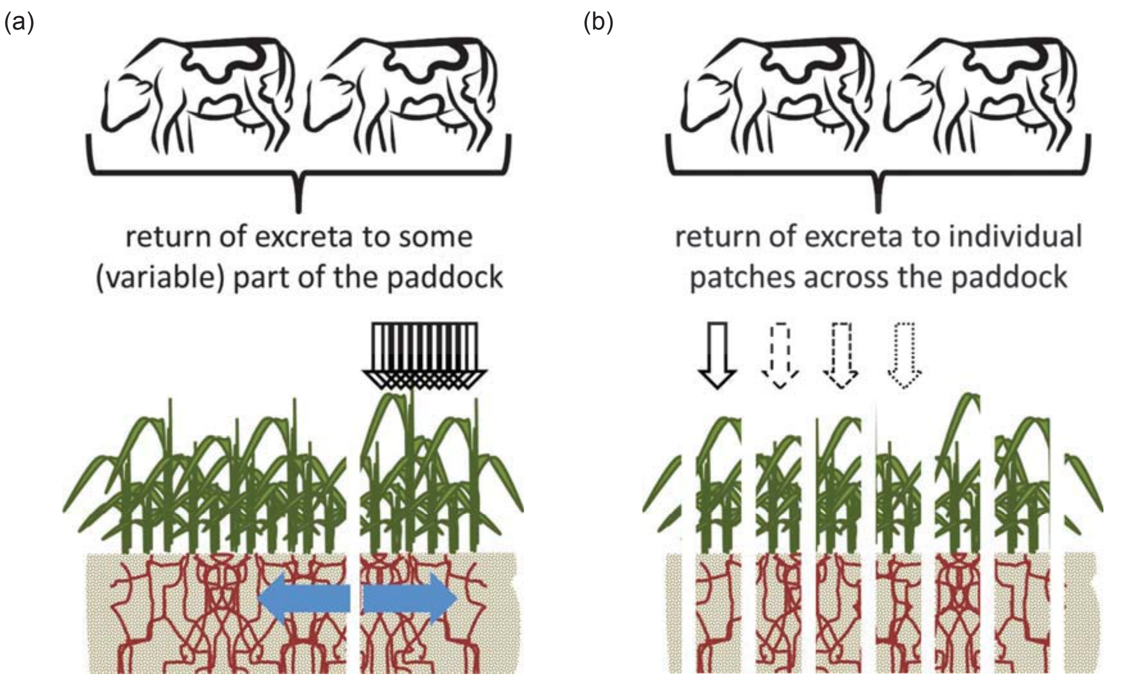

Figure 1. Schematic diagrams of (a) the separate ‘bulk’ and ‘patch’ areas used by DairyMod and IFSM and (b) the explicit patches used in FASSET and being developed in APSIM.

4 Possible Modelling Solutions

There is broad consensus (see literature above) that the random animal-mediated nutrient transfers are sufficiently important in pastoral systems that they should be included in simulation models and there are a variety of solutions to this challenge. While urine patches are clearly understood to be important, few simulation models consider the effect of the patchy urine deposition (Cichota and Snow, 2009) and this is primarily because the inclusion of the deposition process greatly increases the complexity of the simulation model. Some modellers have decided to ignore the effect – and if the primary aim is to model production rather than environmental effects, then that position may be quite justifiable (Snow et al., 2009). Some authors (McGechan and Topp, 2004; Romera et al., 2012; Li et al., 2012) have taken an approach to model the pasture and leaching at the scale of an isolated patch and then scale up to the paddock level post-simulation. These solutions require relatively little model development and are computationally-efficient, but they cannot capture the effects of feedbacks into the system caused by changes in N cycling. Far more complex solutions such as Schwinning and Parsons (1996) and Snow et al. (2009) can be informative but they do not lend themselves to practical application or routine usage within models at the paddock or farm level.

Routine implementation of urine patches into a simulation model requires a balance between realism and pragmatism as it is not practical to include the full complexity involved in the model. IFSM and DairyMod have implemented different, but equally pragmatic, solutions as described above. The Hutchings et al. (2007) patching model implemented in FASSET (cloning the grass and soil models on-demand) presented technical challenges that limited the duration of the model run but showed considerable promise. A new solution based on Hutchings et al. (2007) is currently under development in APSIM (R. Cichota, AgResearch, personal communication) but will involve cloning only the soil C-N part of the simulation model to create a patch. This will result in the high-nitrogen concentrations in the excreta patches being preserved and so affecting leaching, denitrification and C-N transformations but with the computationally-intensive water and crop parts of the model 'seeing' only the whole-paddock (averaged across all the patches) N amounts. This solution uses a justification based on Snow et al. (2009) that ignoring the patches will cause an acceptable error in pasture growth as a simplification and will use the information on the range of variation in the functional longevity of urine patches from Cichota et al. (2013b) to drive the reincorporation of patches into the bulk soil. The early results are promising but full testing is not yet complete.

One challenge with any scheme to appropriately simplify the representation of urine patches in simulation models is validation. There are few reliable whole-paddock leaching datasets and those that are in existence have large uncertainties. There are some datasets where leaching has been measured over relatively large areas using artificial drainage systems (e.g. Eckard et al., 2003) but these data also contain uncertainties with respect to the water regime and the hydraulic efficiency of the measurement/drainage system. Given this, we consider that the measurement uncertainties will largely be irreducible unless new measurement systems that integrate over larger areas are developed and successfully tested (Lilburne et al., 2012). Under these circumstances sensibility (or plausibility) testing (e.g. Holzworth et al., 2011) can play an important role, but this is only valid if careful attention has first been paid to validating the more detailed processes. For this we need high-quality data sets that quantify the processes at the urine patch level including a combination of data sets from lysimeters (e.g. Wachendorf et al., 2005; Di and Cameron, 2007) and open-field experiments that permit soil sampling (e.g. Cuttle and Bourne, 1993; Shepherd et al., 2011). Data regarding the effect of nitrogen uptake by the plants at the edges of the wetted area of individual urine patches (Buckthought, 2014) has also been highlighted as an important driver of N cycling in grazed pastures.

5 Conclusions

Robust and flexible process-based simulation models of pastoral and integrated systems are needed to investigate the adaptation of production systems to increase productivity (Bell et al., 2008; Chapman et al., 2008; Rodriguez and Sadras, 2011; White et al., 2010), decrease environmental effects (Vogeler et al., 2013a), assist understanding of climate change issues (Del Prado et al., 2013) and to meet the demand of farmers for a better quality of life (Hostiou and Dedieu, 2012; Martin et al., 2013). Here we have reviewed four simulation models against the challenge of modelling the impacts of spatial nutrient transfers by the grazing animal. Solutions exist that range between simple and pragmatic and highly detailed and complex and these can provide a basis for incorporation into models wishing to simulate the effects of animal transfers. We suggest that an intercomparison of these methods, to examine the strengths and weaknesses of the approaches that vary substantially in complexity, would provide valuable information for model developers needing to make informed and pragmatic decisions about how to include urine patches in paddock and farm-level process-based simulation models.

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