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Assessing nitrogen fluxes from dairy farms using a modelling approach: A case study in the Moe River catchment, Victoria, Australia

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ABSTRACT

Assessment of nitrogen (N) loss forms and pathways from farming systems is important for improved understanding of potential off-farm impacts on high value environmental assets. The objective of this study was to estimate N losses in different pathways in dairy systems across the range of climate, soil and farm management by using west Gippsland (Victoria, Australia) as case study area, and to characterise the sensitivity of the adopted model parameters. We combined the point scale models DairyMod and Howleaky to estimate dissolved N (DN) and particulate N (PN) loads in runoff, and N leaching (LN) in deep drainage from representative dairy farms in west Gippsland. Monte Carlo error propagation with Latin hypercube sampling was performed to identify sensitive model parameters and assess potential uncertainty in N load predictions. The combined model was capable of simulating climate-soil-animal-pasture management interactions and estimating DN, PN and LN at an annual scale; which were estimated at up to 18 kg-N ha^{-1}, 15 kg-N ha^{-1} and 312 kg-N ha^{-1}, respectively. The combined model demonstrated that more intensive feeding as mixed ration, and nutrient budgeting that takes into account the fertiliser equivalent of recycled nutrients can achieve an increase in milk production by up to 13% and a decrease in N loads by up to 31% compared to the intensive system in the case study catchment. Soil type and farm management explained much of the variability (up to 76%) observed in LN and DN loads, whereas climate and soil type had significant influence on PN loads (62–77%). Year-to-year variation, particularly under dry conditions had a marked influence on N loads. Soil N, vegetation cover, rooting depth and soil maximum drainage rate must be well characterised in order to reduce potentially high uncertainty in the estimation of N losses in heterogeneous catchments.

1. Introduction

Over the last two to three decades, as is the case in many countries, Australian dairying has intensified by increased stocking rates, greater reliance on supplementary feeding and increased nitrogen fertiliser usage (Gourley et al., 2012; Christie et al., 2012). This intensification not only increased milk production but also has resulted in greater on-farm nutrient surpluses contributing to increased degradation of water quality in waterways and water bodies and emissions of greenhouse gases (de Klein and Eckard, 2008; Bryant et al., 2011; Doole and Pannell, 2012; Smith and Western, 2013).

While soil nutrient surplus is the "source factor" indicating the potential for nutrient losses, environmental conditions such as climate and landscape characteristics may facilitate or hinder the off-site transport of the surplus nutrients via various pathways (runoff, leaching and gaseous emissions). Estimating farm scale nutrient losses in different pathways and forms, and understanding the contribution of environmental conditions and farm management practices to loss pathways is essential both at small spatial scales (farms) and larger regional scales. At the farm scale, balanced on-farm management practices suited to the environmental conditions may be adopted to reduce losses and maximise production. At the regional or catchment level, this information can be used to inform and evaluate policy options, and help target locations for intervention or intensification to off-set nutrient contributions (Barns et al., 2009). Links between dairy intensification and N concentrations in waterways have been established (Smith et al., 2013) however, there exists limited knowledge about the environmental nitrogen impacts of dairy farms of varying complexity in Australia. A recent review concluded that insufficient research has been

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Nomenclature

Climate zones

FS	Foot slopes
HR	High rainfall zone

Soils

I	Friable earth
II	Red iron-rich structured earth
III	Heavy structured earth
IV	Texture contrast & gradational soils
V	Heavy earthier and texture contrast soils
VI	Sodic texture contrast soils
VII	Cracking clays & wet soils

Periods

Dry	1990 to 1996
Wet	1997-2005

Dairy farm management systems

Sys1	System 1
Sys2	System 2
Sys3	System 3
Sys4	System 4
Sys5	System 5

Model outputs

DN_L	Dissolved nitrogen load
LN_L	Leached nitrogen load
PN_L	Particulate nitrogen load

Q-runoff

DD	Deep drainage
E	Soil erosion

Model parameters

AD	Air dry water content in soil
CNb	Curve number bare
CNr	Curve number reduction at 80% cover
cv	Response curvature
DN_C	Dissolved nitrogen concentration in water
DN_f	Multiplication factor for nitrate content in the surface soil
DN_{Soil}	Nitrate content in the surface soil (0–2 cm)
FC	Water content in soil at field capacity
GC	Green cover
GC_f	Green cover multiplication factor
k	Parameter for soil nitrogen and water nitrogen mixing
LE	Leaching efficiency
LN_C	Leached nitrogen concentration in water
LN_f	Multiplication factor for nitrate content in the soil layer contributing leaching
TN_{Soil}	Total nitrogen content in the surface soil (0–2 cm)
LN_{Soil}	Nitrate content in the soil layer contributing leaching
MD	Maximum drainage rate
NER_{Soil}	Soil nitrogen enrichment ratio
RC	Residual cover
RC_f	Residual cover multiplication factor
RD	Root depth
RD	Root depth multiplication factor
Sat	Water content in soil at saturation
SW	Soil water between air dry and saturated water content in soil
TN_f	Multiplication factor for total nitrogen content in the surface soil
WP	Water content in soil at wilting point

conducted in the area of N leaching and some specific areas of surface N runoff in Australia, and recommended more research to quantify N leaching under different soil and climatic conditions representing Australian dairy production systems (Burkitt, 2014).

Given the difficulties in constructing experiments to cover sufficient environmental heterogeneity, simulation models that integrate complex biological and physical processes are used to predict production benefits and nutrient losses from diverse agricultural systems, to assess best management practice impacts and to evaluate economic-environmental trade-offs (Cameira et al., 2007; Bryant et al., 2011; Vogeler et al., 2012). Nutrient export may vary greatly for combinations of climate, land use, soil type and farm management at the paddock/grid level. Despite the wide variety of available models (RZWQM (Ahuja et al., 2000), SGS (Johnson et al., 2003), APSIM (Keating et al., 2003), EPIC(Gassman et al., 2005), Howleaky (McClymont et al., 2007), DairyMod/EcoMod (Johnson et al., 2008), GLEAMS (Devereux, 2012), and IFSM (Rotz et al., 2012)), no models sufficiently simulate all the aspects of the dairy farming systems and their contribution to nutrient export in all pathways and forms. For example DairyMod and EcoMod can simulate paddock/farm scale complex pasture-animal-nutrient dynamics, predict marketable outputs, and N losses in leaching and gaseous forms (Eckard et al., 2006; Cullen et al., 2008; Snow et al., 2009), but cannot simulate N losses in runoff. In contrast, the Howleaky model (McClymont et al., 2007) simulates the effect of soil and land management on water balance, soil erosion and nutrient exports, but cannot simulate soil-pasture-animal-nutrient interactions.

Understanding parameter sensitivity and its contribution to uncertainty in model estimates is key to making sound, robust environmental decisions and maximising the benefits attained from such decisions (Jakeman and Letcher, 2003; Payraudeau et al., 2007; Refsgaard et al., 2007). Monte Carlo simulations are commonly used to analyse how the distributions of input data and parameter errors are propagated through a simulation model, and how they affect model outputs (Balakrishanan et al., 2005; Miller et al., 2006). To minimise the number of Monte Carlo simulations, a Latin hypercube sampling (LHS) approach can be used which adopts an integrated random and stratified sampling strategy that considers all sections of the parameter space efficiently; thus it is efficient for dealing with many input variables and heterogeneous environmental characteristics (Vachaud and Chen, 2002; van der Keur et al., 2008).

The objective of the study was to estimate N losses in different pathways in dairy systems across the range of climate, soil and farm management using a modelling framework with application to a west Gippsland (Victoria, Australia) catchment as a case study. DairyMod was combined with the Howleaky model to estimate N losses in the dominant pathways and forms. Model parameter sensitivity associated with water and N pathways and fluxes was assessed with a global sensitivity analysis procedure.

2. Materials and methods

2.1. Study area

The Moe River catchment, with an area of 577 km^2 within the Gippsland Lakes basin, south east Australia (Fig. 1) was selected for this study. The Moe River, a tributary of the Latrobe River has been