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Modelling Denitrification and N_2O Emissions from Fertilised Cropping Systems Using Daycent

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Extended Abstract

Nitrogen (N) fertilizer additions are typically necessary to maintain high crop yields but are also largely responsible for agricultural soils being the primary source of anthropogenic nitrous oxide (N_2O) emissions [1]. N_2O is a greenhouse gas with approximately 265-298 times the global warming. potential of CO_2 on a per mole basis [2]. N_2O is also the primary anthropogenic stratospheric ozone-depleting substance after the phaseout of halocarbons [3]. Extensive research shows that different management practices such as N fertilizer type and amount, tillage intensity, and crop rotation have various effects on N_2O emissions, nutrient losses, soil carbon stock changes and crop yields. As interest in mitigating the negative environmental impacts of crop and livestock productions systems increases, it is important to better quantify how environmental factors interact with management decisions to control agronomic and environmental outcomes.

Models of varying complexity have been developed to represent processes such as denitrification that transform N and contribute to N_2O emissions. The DayCent ecosystem model is of intermediate complexity and simulates the complete plant soil system. DayCent represents common management strategies including fertilizer amendments, irrigation, tillage, crop rotation, residue management, etc. and has been widely used to estimate N_2O emissions under conventional and alternative management scenarios. Major model applications include generating N_2O and carbon (C) stock change estimates for agricultural soils reported in the USA national greenhouse gas inventory [4] and investigating how land use and climate change impact agronomic and environmental outcomes [5]. In this paper, we focus on how processes responsible for N_2O emissions are represented in DayCent, compare model outputs with field observations, and describe recent improvements in model algorithms.

The DayCent (daily CENTURY) ecosystem model simulates vegetation growth and soil processes that control changes in carbon stocks and N flows. The model uses a daily time step and the major inputs include weather (daily maximum and minimum air temperature, daily precipitation) soil properties (texture, soil pH, bulk density field capacity, wilting point, and hydrologic properties) and land use/management (vegetation type, site history, fertilizer amounts,

tillage intensity, planting and harvesting schedules, etc.).

Major submodels include: plant production, soil water, soil temperature, and organic matter cycling, nitrification, denitrification, methane oxidation in upland soils, and methanogenesis in flooded systems. Flows of C and nutrients are controlled by the amount of C in the various pools, the nutrient concentrations of the pools, abiotic temperature and soil water factors, and soil physical properties related to texture. Plant production is a function of nutrient availability, soil water and temperature, shading, vegetation type, and plant phenology [6]. Decomposition of soil organic matter (SOM) and external nutrient additions supply the nutrient pool, which is available for plant growth and microbial processes that result in trace gas fluxes. The N gas submodel of DayCent simulates soil N_2O and nitrogen mono/dioxide (NO_x) gas emissions from nitrification and denitrification and N_2 emissions from denitrification. N gas flux from nitrification is assumed to be a function of soil ammonium concentration and mineralization rates, water content, temperature, and pH [7]. Maximum nitrification rates occur at close to 50% water filled pore space (WFPS) and are assumed to decreases as temperature and pH decrease. Denitrification is a function of soil nitrate (electron acceptor) concentration, labile C (electron donor) availability, WFPS, and soil physical properties related to texture that influence gas diffusivity [7].

The DayCent model was tested with soil N_2O emission observations using ground-based chambers from long term winter wheat trials in southern Queensland, Australia. Using default parameters, the model represented the seasonal timing of emission pulses well, but over-estimated compared with observations (Fig. 1). The reason for over-estimating is related to how the model infers soil oxygen (O_2) status based on texture. Specifically, the model assumes that high clay soils have small pores, so air exchange is inhibited, and a substantial portion of the soil volume can become anaerobic even at moderate water contents. The soil at this site is a Vertisol (cracking clay) containing 65% clay and the model simulated substantial denitrification rates. However, the prominent cracking and shrink/swelling of this soil facilitate air exchange but these impacts are not represented in the model. Consequently, the function controlling how soil water content and texture interact to limit dentification rates had to be adjusted so that denitrification was greatly reduced and favorable comparisons with observations were obtained (Figure 1). This suggests that accounting for additional factors beyond texture that influence soil O_2 status (e.g., cracking, aggregation) are necessary to improve general model performance.

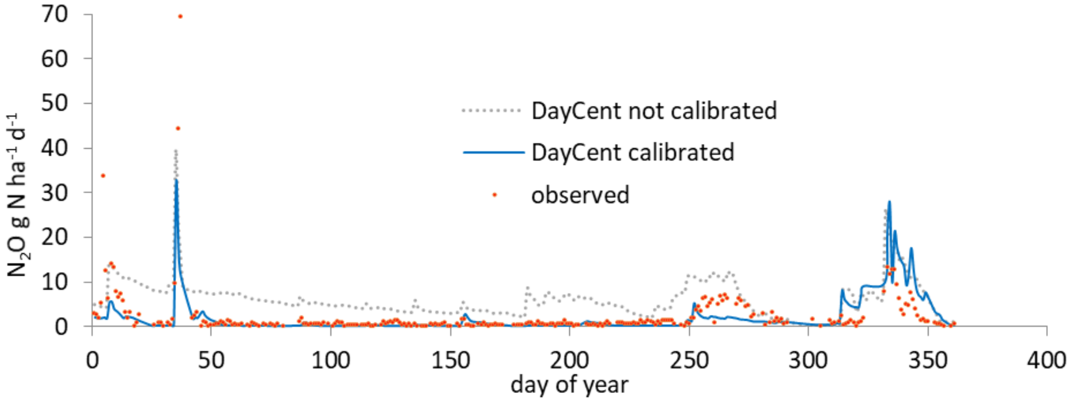

Figure 1. DayCent (calibrated and non-calibrated) simulated and observed nitrous oxide (N_2O) emissions for wheat in Queensland, Australia fertilized with 90 kg N ha^{-1}.

DayCent was also tested with N_2O emission observations using flux towers in Eastern and Western Canada. At these sites, we concentrated on pulses associated with spring season melting of soil water and snow which can make up a large portion of total annual emissions [8]. The standard version of the model greatly under-estimated these pulses which are thought to result mainly from denitrification which is enhanced due to the sudden availability of substrates and freeze thaw impacts on soil O_2 status. To account for this, we relaxed both labile carbon and WFPS constraints on denitrification after the top layer of soil melted for up to 10 days depending on the number of accumulated freezing degree days. The freeze/thaw enhancement was recently evaluated at the regional scale for the US Great Plains and corn/soy belt by comparing DayCent generated emissions with those from a Lagrangian regional inversion [9]. The freeze/thaw enhanced version matched the inversion results more closely than the standard DayCent version and a manuscript is currently in preparation.

Lastly, DayCent was tested on control and basalt-treated plots cropped with corn and miscanthus in Illinois, USA. In addition to mitigating soil acidity, basalt also provides nutrients. Contrary to observations, DayCent showed higher N_2O emissions with basalt addition because of accelerated rates of nitrification associated with increases in pH. However, recent and established literature provide evidence of lower N_2O emissions with increases in pH [1,10,11], due to a direct inhibition of the denitrifier metabolism and to accelerated rates of N_2O reductase that promote complete denitrification. Therefore, we modified the model to include the impact of changes in pH on the denitrification subroutine as well. Specifically, we adapted pH equations from [12] that adjust both gross denitrification rates and the N_2:N_2O ratio which led to improved results (Fig. 2).

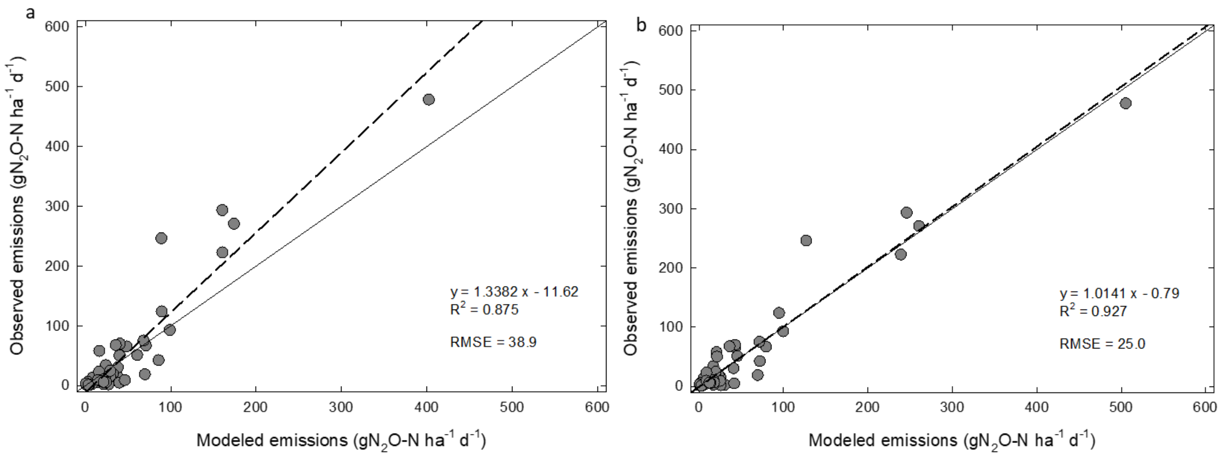

Figure 2. Observed vs. DayCent simulated nitrous oxide (N_2O) emissions for an Illinois, USA soil without (a) and with (b) pH impacts on denitrification rate and the N_2/N_2O ratio.

We conclude that DayCent could be improved by accounting for how soil volume changes in response to wetting and freeze/thaw dynamics which affect soil O_2 status and denitrification rates. Including the impacts of pH on denitrification metabolism also improved model performance. In sum, a more complete implementation of the current understanding of process controls should improve model performance, although increased complexity does not always imply better results and thus it is crucial to compare model outputs with high quality field observations.

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