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Simulation of Nitrous Oxide Emissions in Zoysia Turfgrass Using DAYCENT and DNDC Ecosystem Models

Mu Hong,^{1,2} Yao Zhang,³ Ross Braun,⁴ and Dale J. Bremer

Summary

Nitrous oxide (N_2O) is an important greenhouse gas (GHG) implicated in global climate change. Process-based ecosystem models, such as DAYCENT and DNDC, have been widely used to predict GHG fluxes in agricultural systems. However, neither model has yet been applied to warm-season turfgrasses such as zoysiagrass. This study parameterized, calibrated, and validated the DAYCENT and DNDC models for N_2O emissions from Meyer zoysiagrass (*Zoysia japonica* Steud.) using Bayes' theorem and field data from Braun and Bremer (2018a, 2019) and Lewis and Bremer (2013). Results indicated DAYCENT, but not DNDC, reasonably simulated the impacts of irrigation and N-fertilization practices on biweekly and annual N_2O emissions in zoysia turfgrass. When assuming no further climate change, the validated DAYCENT model predicted that typical recommendations for N-fertilization and irrigation in zoysiagrass (a low-input turfgrass) would reduce its cumulative global warming potential (GWP) for the first 45 years after establishment by encouraging soil carbon sequestration. Thereafter, soils would become saturated with carbon and hence, reductions of N inputs would be beneficial for mitigating further increases in N_2O emissions and GWP.

¹ All research was conducted at Kansas State University. The following institutions represent the author's affiliation at the time of this publication (August 2022).

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Rationale

Nitrous oxide is an important greenhouse gas that has been implicated in global climate change. Because turfgrass covers large land areas and is typically irrigated and fertilized with nitrogen (N), which may increase its N_2O emissions, it is prudent to accurately estimate N_2O emissions in turfgrass (Braun and Bremer, 2018b). Braun and Bremer (2018a, 2019) extensively measured N_2O emissions in zoysiagrass over two years and C sequestration over three years, which yielded large datasets that created a unique opportunity to calibrate process-based models for zoysia turfgrass, such as DAYCENT (daily time-step version of the CENTURY biogeochemical model) and DNDC (i.e., DeNitrification-DeComposition model). Such model development is important because continuous long-term measurements of N_2O emissions are expensive and time-consuming.

DAYCENT and DNDC have been used widely in agricultural crops to predict crop production, soil carbon and nitrogen cycles, and GHG fluxes in agricultural systems. However, neither model has been calibrated for warm-season turfgrasses such as zoysiagrass (Gu et al., 2015; Zhang et al., 2013a, 2013b). DAYCENT and DNDC need to be calibrated with detailed inputs, and the parameterizations for warm-season turfgrass' characteristics would be different from cool-season turfgrass (Zhang et al., 2013a, 2020). Recently, the Bayes' theorem has been a popular approach to calibrate parameters of process-based models, coupled with certain Monte Carlo techniques to quantify uncertainties in the outputs (Gurung et al., 2020; Zhang et al., 2020).

Objectives

1. Calibrate and validate the DAYCENT and DNDC ecosystem models for N_2O emissions from zoysiagrass mown at fairway height; and
2. Predict long-term N_2O emissions and C sequestration in zoysia and the impacts on its GWP of different irrigation and N-fertilization practices.

Study Description

In Braun and Bremer (2018a), six treatments of N fertilizer (fast and slow-release, each at 0 or 98 $\text{kg ha}^{-1} \text{yr}^{-1}$ [2 lb/1000 ft^2 per year]) and irrigation combinations (at 33 and 66% reference evapotranspiration [ET_0], hereafter ET) were included in Meyer zoysia mown at fairway height (2.54 cm). Treatments included: 1) granular urea irrigated at 66% ET (Urea_66% ET); 2) granular urea irrigated at 33% ET (Urea_33% ET); 3) poly-coated urea irrigated at 66% ET (PCU_66% ET); 4) poly-coated urea irrigated at 33% ET (PCU_33% ET); 5) no N fertilizer irrigated at 66% ET (None_66% ET); and 6) no N fertilization irrigated at 33% ET (None_33% ET).

Measurements of N_2O emissions from the Urea_66% ET treatment (Braun and Bremer, 2018a), which is a typically recommended management regime for zoysia turfgrass, were used to calibrate two ecosystem models, DAYCENT and DNDC. The remaining five treatments were used for model validation. Data from an earlier

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N₂O emission study (located at the same Kansas State University Rocky Ford Turfgrass Research Center, about 140 m [460 ft] from the Braun and Bremer [2018a] study), was used for model validation, which was also conducted in Meyer zoysia but fertilized with 100 kg N ha⁻¹ yr⁻¹ [~2 lb/1000 ft² per year] and maintained well-watered (irrigated 1× to 3× weekly) (Urea_Regular) (Lewis and Bremer, 2013).

After linear interpolation of measured and simulated data (Braun and Bremer, 2018a; Lewis and Bremer, 2013), biweekly N₂O averages and annual N₂O emissions were calculated. DAYCENT and DNDC models were calibrated using the process described by Gurung et al. (2020). Specifically, nine sensitive DAYCENT parameters and seven DNDC parameters were calibrated by Bayes' theorem with a sampling importance resampling (SIR) method. In brief, after simulations of 1 million parameter sets (each parameter of a parameter set was randomly drawn from a uniform distribution with predefined ranges), each parameter set was ranked by likelihoods using the model outputs and field measurement. The best parameter set was determined by the maximum sum of likelihoods for simulating daily volumetric water content, NH₄, NO₃, and biweekly N₂O emissions.

Net GWP was calculated from the hidden carbon costs of turfgrass management practices (mowing, irrigation, fertilizer, and pesticides) and emissions of N₂O (1 GWP of N₂O = 298 GWP of CO₂) and CH₄ (1 GWP of CH₄ = 25 GWP of CO₂) minus C sequestration (Braun and Bremer, 2019; Gu et al., 2015; Zhang et al., 2013a). Negative net GWP means the turf sward is a sink for atmospheric C via soil carbon sequestration, while positive net GWP means the turf system is a source for atmospheric C. Cumulative net GWP was the aggregation of predicted net annual GWP from years one through 80. Specifically, cumulative net GWP was calculated for different management practices in fairway zoysia from 2021-2100 (80 years) based on a baseline weather scenario (i.e., using 1983–2021 local historical data and assuming no further climate change). *Additional details about this project are available in Hong (2022).*

Results

The calibrated DAYCENT modeled the biweekly N₂O data well, with a strong coefficient of determination (R²), weakly moderate relative root of mean square errors (RRMSE), and minimal relative mean deviation (RMD) (Table 1). Estimated annual N₂O emissions using DAYCENT only averaged 3% higher than the estimates interpolated from field measurements in the Urea_66% ET calibration treatment, which is revealed by (mathematically equal to) the RMD of biweekly N₂O average = 0.032 (Table 1). In contrast, the calibrated DNDC model inadequately described the biweekly N₂O data with weakly moderate R² and very high RRMSE (Table 2). DNDC's annual N₂O simulation of Urea_66% ET underestimated the values interpolated from measurements by 33% on average (biweekly N₂O RMD = 0.3331; Table 2).

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In general, N_2O validation of the calibrated DAYCENT model performed well in the other five treatments with strong R^2 , low to moderate RRMSE, and low RMD, especially in treatments of Urea_66% ET, Urea_33% ET, PCU_66% ET, and None_66% ET (Table 1). The estimated annual N_2O emissions from DAYCENT were within -27 to +16% of emissions interpolated from field measurements (Table 1). Notably, daily N_2O flux simulations of DAYCENT (Figure 1) performed reasonably well ($R^2 = 0.31\text{--}0.71$), similar to the simulations for biweekly N_2O flux ($R^2 = 0.47\text{--}0.89$; Table 1). Although validation of daily and biweekly N_2O emissions was generally poor for the independent study (Lewis and Bremer, 2013), the average annual N_2O simulated values were acceptable (within 10% of the estimates interpolated from field measurements) (Table 1).

For the DNDC model, results from the N_2O validation phase were similar to results from the calibration phase reported previously (i.e., much poorer than DAYCENT), especially under PCU and no N (None) fertilizations (Table 2). The DNDC average annual N_2O simulations underestimated the estimates interpolated from field measurements by 41 to 84%. Notably, in the independent study (Lewis and Bremer, 2013) DNDC underestimated the field measurements by a relatively smaller 22% (Table 2). However, it also yielded a slightly lower R^2 , higher RRMSE, and larger RMD compared to DAYCENT (Tables 1 and 2).

Because of better calibration and validation results from DAYCENT (Table 1; Figure 1) than DNDC, the DAYCENT model was used to predict long-term N_2O emissions and C sequestration for calculating the cumulative net GWP of different irrigation and N-fertilization practices in zoysia turf (Figure 2). In the N fertilized and irrigated treatments ($98 \text{ kg N ha}^{-1} \text{ yr}^{-1}$ [2 lb/1000 ft^2 per year], 66%/33% ET), the cumulative net GWP was predicted to decrease faster than zoysia with no N fertilization through the late 2050s, because of greater sequestration of carbon in soils in the fertilized treatments. However, cumulative net GWP in zoysia with N fertilization would begin to increase faster thereafter and gradually surpass zoysia (by 2080) with no N fertilization. As turfgrass ages and C sequestration slows down after 2060, properly reducing N fertilization rates (or also using slow-release N sources) in zoysia would mitigate the increases in GWP by reducing the slope of the incline in N_2O emissions over the years.

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Table 1. Model evaluation of DAYCENT simulations of biweekly N₂O emissions (coefficient of determination [R²], relative root mean square error [RRMSE], and relative mean difference [RMD])

Study	Dataset	Fertilization_ Irrigation	R ²	RRMSE	RMD
Braun and Bremer, 2018a	Calibration	Urea_66% ET	0.8483	0.4469	0.0320
	Validation	Urea_33% ET	0.7958	0.5482	-0.1919
		PCU_66% ET	0.8906	0.3597	0.1599
		PCU_33% ET	0.5763	0.5547	-0.0391
		None_66% ET	0.8178	0.3677	-0.0625
		None_33% ET	0.4734	0.6606	-0.2714
Lewis and Bremer, 2013		Urea_Regular	0.2248	1.7096	0.0917

Table 2. Model evaluation of DNDC simulations of biweekly N₂O emissions (coefficient of determination [R²], relative root mean square error [RRMSE], and relative mean difference [RMD])

Study	Dataset	Fertilization_ Irrigation	R ²	RRMSE	RMD
Braun and Bremer, 2018a	Calibration	Urea_66% ET	0.4291	1.4197	-0.3331
	Validation	Urea_33% ET	0.3834	1.2995	-0.4061
		PCU_66% ET	0.0237	1.2391	-0.8371
		PCU_33% ET	0.0109	1.1936	-0.8215
		None_66% ET	0.0181	1.2297	-0.8131
		None_33% ET	0.0152	1.2128	-0.8142
Lewis and Bremer, 2013		Urea_Regular	0.1635	1.9284	-0.2173

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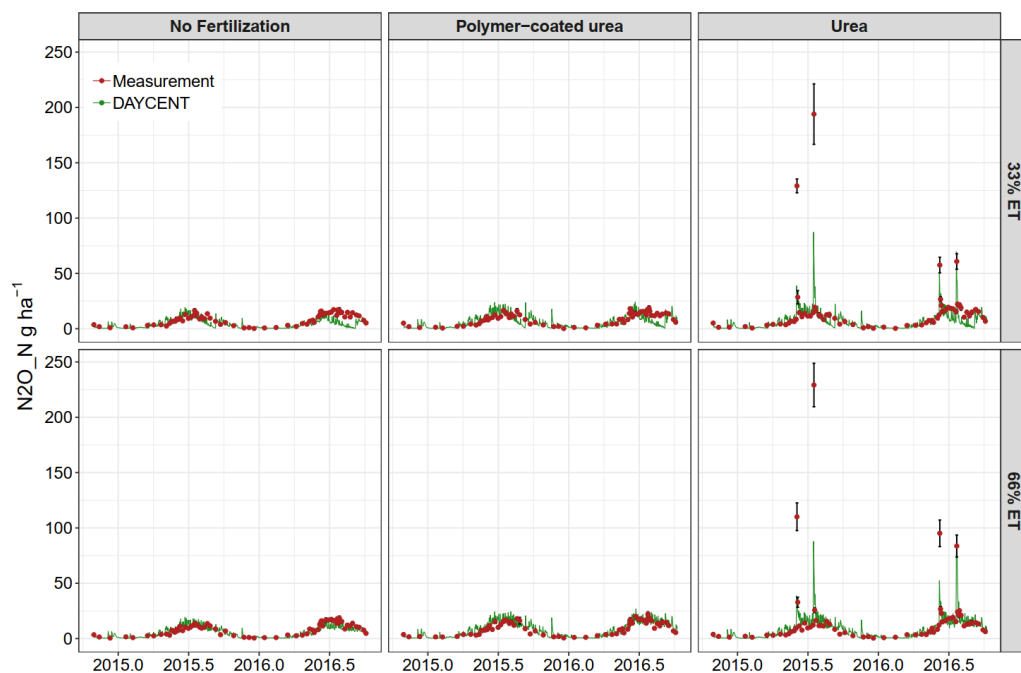


Figure 1. Measured and daily DAYCENT-simulated nitrous oxide (N_2O) under low (33% ET)/medium (66% ET) irrigation and no/polymer-coated urea/urea fertilization.

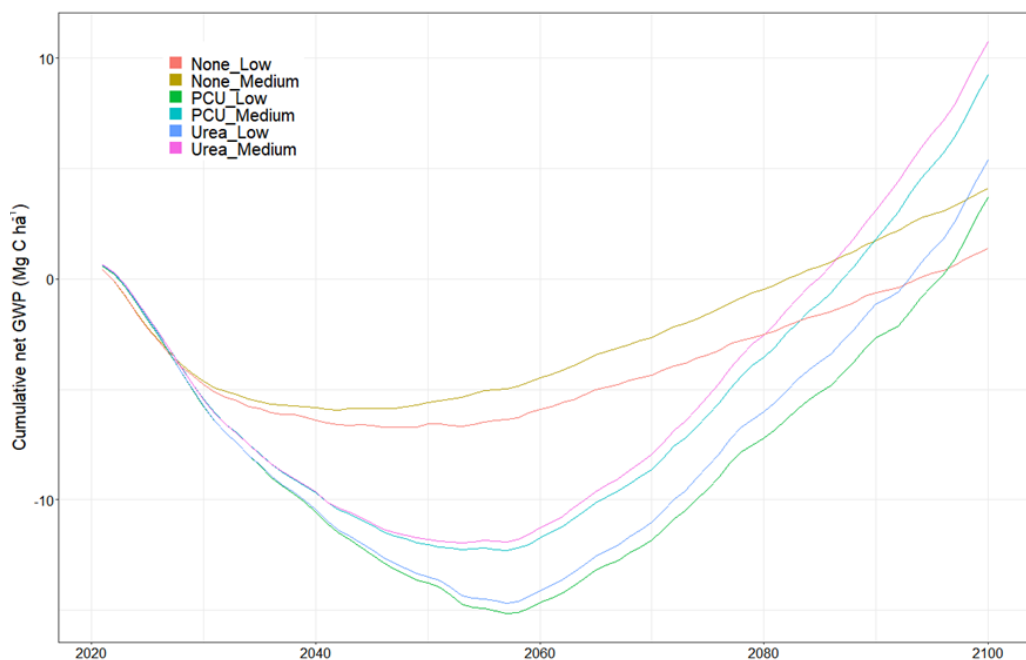


Figure 2. 2021–2100 cumulative net global warming power (GWP) for six management practices in fairway zoysia under baseline weather using the validated DAYCENT model.

